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Integrating parametric modeling (iLEED) with the LEED framework for sustainable site planning at the conceptual design stage

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Abstract

Although numerous building information modeling-based and computational approaches have been proposed to support sustainable building certification, most focus on isolated credits, require semi-manual workflows, or lack integration with real-time parametric design. These limitations reduce their usefulness for iterative, early-stage decision-making. By streamlining workflows for evaluating Leadership in Energy and Environmental Design (LEED) v4 sustainable sites credits, this study introduces intelligent LEED (iLEED), the first unified, Grasshopper-based parametric dashboard that automates the assessment of Open Space, Heat Island, Rainwater Management, and Site Development within a single interactive platform. By directly linking geometric and environmental data to LEED compliance metrics, iLEED delivers instant feedback, comprehensive performance visualizations, and rapid testing of site strategies during the conceptual design stage. The tool's accuracy was validated against the United States Green Building Council's official calculators, demonstrating strong agreement and confirming its reliability. A case study further illustrated how embedding site-related assessments into a real-time parametric dashboard streamlines compliance evaluation, improves calculation accuracy, and expands opportunities for biodiversity-oriented, sustainable site development strategies. This work highlights the potential of integrated parametric frameworks to transform LEED compliance from a static, documentation-driven process into a dynamic, performance-driven design workflow.

Keywords: Automation; Grasshopper; Leadership in Energy and Environmental Design v4; Site compliance; Parametric design; Sustainable architecture

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1. Introduction

The urgency of mitigating climate change, coping with rapid urbanization, and preserving ecosystems has intensified the need for sustainable building practices and resilient urban planning (Altomonte, 2009; Al-Zubaidy, 2015; Sijakovic & Peric, 2021). Among the frameworks that guide these efforts, the Leadership in Energy and Environmental Design (LEED) rating system (https://www.usgbc.org/leed), developed by the United States (US) Green Building Council (USGBC), and remains one of the most widely recognized international standards. Within LEED v4, the Sustainable Sites (SS) category plays a pivotal role in promoting biodiversity, improving hydrological performance, and enhancing outdoor environmental quality at both the building and community scales (Allam, 2012; Çelebi, 2003; Cidell, 2009).

Despite the importance of SS credits, their evaluation has largely relied on manual calculations, static documentation, and consultant-driven assessments (Alothaimeen *et al.*, 2023; Boake & Prochazka, 2004). These conventional approaches are time-intensive, prone to human error, and disconnected from early design exploration—when design decisions are most flexible and cost-effective (Madson *et al.*, 2022). In response, research on building information modeling (BIM)-based and computational methods has grown in recent years; however, most of these efforts focus on isolated credits—such as energy performance, daylighting, and hydrological modeling (Hegger *et al.*, 2012; USGBC, 2001)—or rely on semi-manual workflows that require exporting data to external calculators (Alwan *et al.*, 2015). Only a few studies have embedded LEED credit evaluation directly within parametric design environments (Brophy & Lewis, 2012), and these have typically addressed individual site-related credits rather than offering an integrated, multi-credit, real-time framework.

Parametric modeling platforms, such as Rhinoceros 3D with Grasshopper have demonstrated strong potential for linking geometric design parameters with performance-based metrics. By enabling rule-based calculations and real-time feedback, these tools support rapid exploration of design alternatives and facilitate evidence-driven decision-making. However, the integration of multiple SS credits—such as Open Space, Heat Island, Rainwater Management, and Site Development—into a single parametric environment remains underexplored, creating a critical gap in current BIM–LEED automation research.

To address this gap, this study introduces intelligent LEED (iLEED), the first unified, Grasshopper-based parametric dashboard for real-time assessment of multiple LEED v4 SS credits. Implemented using GhPython, iLEED links geometric inputs and environmental data to LEED performance metrics through four integrated modules—Open Space, Heat Island, Rainwater Management, and Site Development—and consolidates their results into an Integrated Site Compliance Dashboard. By delivering instant performance feedback, LEED point estimates, and interactive visualizations, iLEED enables designers to rapidly test alternative site strategies during conceptual and schematic design stages.

The objectives of this research are threefold: (i) To situate iLEED within the evolving field of BIM–LEED automation, emphasizing its novelty as the first multi-credit, unified SS assessment tool; (ii) to validate its outputs against official USGBC calculators to ensure accuracy and reliability; and (iii) to demonstrate how embedding real-time, performance-driven compliance tools into early-stage workflows can accelerate sustainable decision-making and promote biodiversity-oriented site development.

2. Literature review

2.1. Sustainable site planning and LEED framework

Sustainable site planning is central to mitigating the impacts of urban development by conserving biodiversity, maintaining hydrological balance, and improving outdoor environmental quality (Cidell, 2009; Mahdavinejad *et al.*, 2014). The LEED v4 SS category advances these goals through credits for Open Space, Heat Island Reduction, Rainwater Management, and Site Development (Ismaeel, 2022).

However, the prevailing workflow for assessing these credits relies on manual calculations, static documentation, and consultant-driven processes, often using spreadsheets or external calculators. These methods are time-consuming, prone to error, and poorly suited for conceptual design—when early interventions are most effective in shaping sustainable outcomes (Çelebi, 2003; Madson *et al.*, 2022).

2.2. From manual workflows to automation

Traditional LEED assessment delays sustainability integration because it provides feedback only after major design decisions have been made, limiting opportunities for proactive site strategies (Boake & Prochazka, 2004; USGBC, 2001). For example, estimating impervious-to-pervious surface ratios or calculating stormwater runoff typically requires switching between design software and hydrological calculators (Cascone, 2023; Celadyn, 2014). Automating these assessments reduces manual effort and human error while enabling iterative testing of alternatives in real time (Cascone, 2023; Di Gaetano *et al.*, 2023). Although automation is now common in building-scale performance simulations—such as daylighting and energy—its application to site-related LEED credits remains limited and fragmented.

2.3. Computational design and existing BIM–LEED tools

Recent advances in parametric design environments, particularly Rhino/Grasshopper, have made it possible to link geometric models directly with environmental metrics to support rapid option testing (Fandino *et al.*, 2015; USGBC, 2001). Early studies, such as Azhar *et al.* (2011), demonstrated the advantages of BIM-assisted LEED compliance over manual methods. Nocerino &Leone (2024) applied parametric modeling to support sustainability decisions at the conceptual stage, while Sanhudo & Martins (2018) focused on automated hydrological modeling for SS Rainwater Management.

More recent efforts, such as the work of Shafique & Mollaoglu (2022), who developed GIS-linked parametric tools for Open Space and Site Development, and by Xu *et al.* (2025), who implemented Grasshopper–Python workflows providing real-time feedback for Heat Island and Open Space credits, show a gradual shift toward interactive, early-stage tools. Yet, these frameworks are credit-specific or semi-manual, often requiring data exchange with external applications. No existing study provides a single, unified parametric dashboard that integrates multiple SS credits for real-time, early-stage decision support.

2.4. Contribution and novelty of iLEED

To address this gap, this study introduces iLEED—the first unified, Grasshopper-based parametric framework that automates the assessment of multiple LEED v4 SS credits. Implemented in GhPython, iLEED embeds LEED compliance logic directly into the design workflow, linking geometric and environmental data to metrics for Open Space, Heat Island, Rainwater Management, and Site Development.

By providing instant feedback, LEED point estimates, and visualizations through a single dashboard, iLEED supports early, iterative, and performance-driven decision-making when design flexibility is highest and impact on sustainability is greatest. This integration advances BIM–LEED automation by shifting compliance from a post-design, documentation-heavy process to an interactive design support system.

The comparative scope, focus, and technical approaches of previous studies and iLEED are summarized in Table 1, highlighting the research gap that this framework addresses.

2.5. Research framework

This study proposes iLEED, a computational framework that embeds sustainability assessment directly into the early stages of architectural design. Unlike traditional certification workflows, where sustainability criteria are checked only after design development, iLEED redefines the process by treating sustainability as a real-time driver of decision-making. Implemented as a parametric system within Rhino–Grasshopper, iLEED employs algorithmic logic, quantitative models, and automated compliance reporting to evaluate site-related credits under LEED v4. By doing so, it enables iterative exploration, allowing design alternatives to be tested, compared, and optimized dynamically for their environmental performance.

The SS credits that iLEED aims to automate include: Construction activity pollution prevention (CAPP), site assessment, protect or restore habitat, Open Space, Rainwater Management, Heat Island Reduction, and Light Pollution Reduction (Table 2).

The framework is structured around four specialized modules that reflect core sustainability priorities. The Open Space module calculates the ratio of open to total site area and evaluates vegetation distribution, ensuring alignment with outdoor space quality credits while enhancing user well-being and ecological value. The Heat Island module assesses the thermal performance of site surfaces through solar reflectance index (SRI), surface albedo, and shaded area estimations, thereby providing designers with quantitative insights into strategies for mitigating Urban Heat Island effects. The Rainwater Management module computes pervious and impervious surface ratios, models stormwater infiltration, and estimates retention capacity, directly supporting compliance with rainwater management requirements while promoting resilient site hydrology. Finally, the Site Development module evaluates land disturbance, habitat conservation areas, and protection zones, thereby ensuring that ecological preservation and site integrity are considered primary drivers in early design stages.

To consolidate the computational logic and streamline early-stage decision-making, these modules were organized according to their primary objectives, key analytical parameters, and the corresponding LEED SS credits they support (Table 3).

In addition to these core analytical functions, iLEED incorporates supporting capabilities that streamline the certification workflow. Automated routines distinguish between hardscape, softscape, and water bodies, providing accurate baselines for subsequent credit calculations. Integrated algorithms calculate parking footprints and related surface coverage, facilitating compliance with non-roof Heat Island credits. Furthermore, the framework embeds reporting and visualization features: Automated documentation tools reduce the potential for human error during credit submission, while color-coded site plans provide instant visual feedback that guides designers in aligning spatial decisions with sustainability objectives.

By consolidating these functions into a single computational ecosystem, iLEED shifts sustainability assessment from a manual, linear, and often tedious process into an automated, iterative, and quantitative methodology. This transformation empowers designers to proactively integrate sustainability metrics into site planning, form development, and material selection, advancing architectural practice from reactive compliance

Table 1. Comparative studies on automation and parametric approaches for LEED-based site planning

Author (s)	Year/LEED version	Project type	Main objective	SS credits	Digital/parametric approach
Azhar *et al.* (2011)	2011/LEED v3	Office building	Compare manual versus BIM-assisted LEED compliance workflows	SS, EA, MR (All credits)	BIM-assisted sustainability assessment using external simulation tools
Nocerino & Leone (2024)	2016/LEED v4	Conceptual building design	Support early-stage sustainability decisions	SS, WE (All credits)	Parametric modeling in Grasshopper integrated with computational rules
Sanhudo & Martins (2018)	2018/LEED v4	Urban drainage and stormwater	Automate hydrological assessment for rainwater-related credits	SS (Rainwater)	BIM-based plugin for Revit linked with hydrological simulation
Shafique & Mollaoglu (2022)	2022/LEED v4 BD+C	Mixed-use development	Improve the efficiency of site analysis for green/open space and site development	SS (Open Space, Site Development)	GIS-linked parametric tools with visual programming
Xu *et al.* (2025)	2025/LEED v4	Educational campus	Provide real-time performance feedback for site-related credits in conceptual design	SS (Heat Island, Open Space)	Grasshopper+Python-based parametric optimization
This study – iLEED	2025/LEED v4	Pilot project in Duhok	Integrates and automates multi-credit assessment with performance-driven guidance	SS (Open Space, Heat Island, Rainwater, Site Development)	Unified Grasshopper-based parametric framework with iLEED Dashboard for real-time feedback and point estimation

Abbreviations: BIM: Building information modeling; EA: Energy and atmosphere; GIS: Geographic information system; LEED: Leadership in energy and environmental design; MR: Material and resources; SS: Sustainable sites; WE: Water efficiency; iLEED: Intelligent leadership in energy and environmental design.

Table 2. Sustainable sites credits automated by intelligent leadership in energy and environmental design in this study

Credits	Point	Automated
Construction Activity Pollution Prevention (prerequisite)	1	Yes
Site Assessment	2	No
Protect or Restore Habitat	1	Yes
Open Space	3	Yes
Rainwater Management	2	Yes
Heat Island Reduction	1	Yes
Light Pollution Reduction	1	No

toward performance-driven, sustainability-oriented design, as depicted in Figure 1.

3. Methodology

The proposed methodology establishes a parametric computational workflow to automate the evaluation of site-related LEED v4 SS credits. The workflow integrates Rhinoceros 7 (https://www.rhino3d.com/), Grasshopper 3D, and GhPython scripting into a seamless platform for geometric data acquisition, quantitative analysis, visualization, and automated reporting. The process consists of four core phases: (i) Data acquisition, (ii) automated calculation, (iii) visualization, and (iv) reporting, all designed to improve efficiency, accuracy, and reproducibility. This research did not involve human participants, animals, or personal data. Therefore, approval from an institutional ethics committee was not required.

3.1. Phase 1: Data acquisition

Project geometries are imported from pre-defined Rhino layers representing critical components, such as site boundary, building footprints, hardscape, vegetated/pervious zones, parking, bicycle racks, transit stops, and points of interest. Optional datasets include luminaire locations with backlight–uplight–glare ratings and material tables with SRI values.

Before analysis, geometries undergo validation: For example, boundary curves are checked for closure to ensure correct area computation. Surfaces and boundary representation (Breps) are standardized through RhinoCommon coercion methods to maintain parametric compatibility.

In addition to geometric data, design parameters (e.g., curve numbers [CNs], transit walk radii, shading dates, and SRI thresholds) are defined using Grasshopper sliders and panels. These flexible inputs allow the simulation of alternative scenarios and the evaluation of compliance under varying conditions.

3.2. Phase 2: Automated calculation

GhPython scripts link the acquired data to LEED evaluation logic, automating tasks, such as calculating surface areas, pervious/impervious ratios, and weighted SRI values; assessing shading and Heat Island performance; estimating stormwater retention capacity and runoff reduction; and computing walking distances to transit, parking reductions, and open-space ratios. This phase

Table 3. iLEED framework modules and their relation to LEED v4 sustainable sites credits

Module	Purpose	Key parameters/algorithms	Relevant LEED SS credits
Construction activity pollution prevention	Identify the total construction disturbance area	- Import site boundary polyline/mesh - Compute area (gh Area or Brep.GetArea) - Zoning of disturbed versus protected surfaces	SS pre-requisite: Construction Activity Pollution Prevention (disturbed area threshold)
OpenSpace	Assess the quality and extent of open space to promote biodiversity and user well-being	Open-to-total site area ratio, vegetation type and distribution, pedestrian-accessible green areas	SS credit: Open Space
HeatIsland	Quantify the potential reduction of Urban Heat Island effects	Solar Reflectance Index, surface albedo, shaded area calculations, parking coverage estimation	SS credit: Heat Island Reduction (Non-Roof and Roof)
RainManagement	Support resilient hydrological performance through effective stormwater handling	Pervious versus impervious surface ratios, infiltration modeling, retention capacity estimation	SS credit: Rainwater Management
SiteDevelopment	Promote habitat protection and minimize ecological disturbance	Baseline land cover assessment, conserved/restored habitat areas, and land disturbance footprints	SS credit: Site Development—Protect or Restore Habitat
Reporting & visualization (supporting feature)	Provide real-time design guidance and streamline certification submissions	Automated area classification (hardscape, softscape, waterbody), color-coded site plans, automated compliance reports	Supports all the above SS credits

Abbreviations: LEED: Leadership in energy and environmental design; SS: Sustainable sites; iLEED: Intelligent leadership in energy and environmental design.

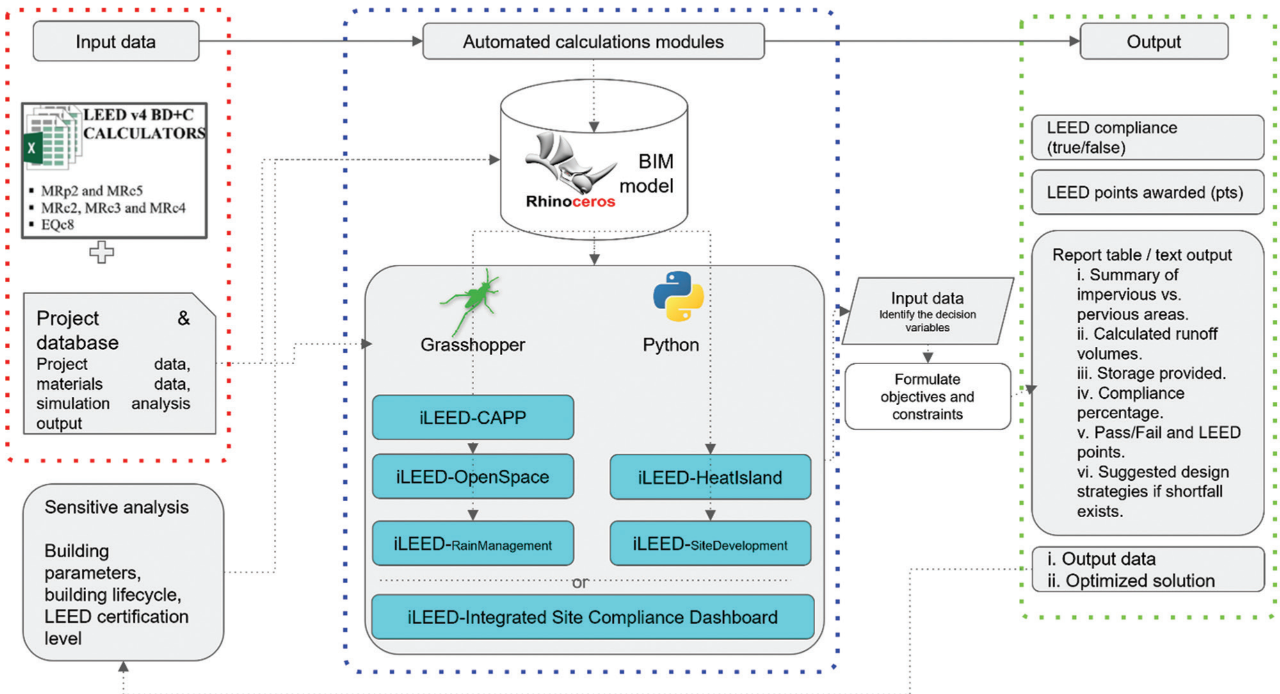

Figure 1. iLEED sustainable sites system architecture
Source: Diagram by the author.
Abbreviations: BIM: Building information modeling; LEED: Leadership in energy and environmental design.

replaces manual tabulation with algorithmic computation, reducing time and human error.

3.3. Phase 3: Visualization

Color-coded diagrams generated in Grasshopper provide real-time feedback. For example, hardscape, vegetated, and water bodies are visually distinguished, and shading analyses across seasonal intervals indicate compliance with Heat Island Reduction strategies. This immediate visual feedback supports rapid design iteration at conceptual and schematic stages.

3.4. Phase 4: Reporting

The framework automatically generates LEED-aligned reports, including tabulated areas, compliance percentages, and estimated points; color-coded overlays in the Rhino viewport for intuitive spatial communication; and design guidance for improving performance (e.g., increasing vegetated areas and using high-SRI surfaces). By embedding reporting within the parametric workflow, iLEED reduces external documentation needs and accelerates compliance verification.

3.4.1. Automated modules

Each module addresses a specific LEED pre-requisite or credit:

3.4.1.1. iLEED-CAPP module

The iLEED-CAPP module automates the LEED SS pre-requisite CAPP by integrating site geometry and environmental parameters into a computational workflow within Grasshopper. The inputs include the site boundary, disturbed areas, stabilized areas, terrain mesh, water bodies, soil type, rainfall intensity (mm), and a set of thresholds defining erosion risk, buffer distance, stabilization percentage, and critical slope angle. The script processes these inputs using Rhino and Python functions to calculate total site, disturbed, and stabilized areas; determine average terrain slope from mesh normals; estimate erosion potential based on rainfall and slope; and evaluate compliance with LEED erosion and sediment control criteria. The outputs include a compliance status (pass/fail), a textual report summarizing site conditions and recommended actions, and numerical values for erosion index, average slope, and percentage of stabilized area. Compared to conventional manual methods, this automated approach significantly reduces calculation time, improves accuracy, and provides real-time visual and quantitative feedback during early site design (Figure 2).

The user must obtain an OpenStreetMap file (https://www.openstreetmap.org/) and import it into the Elk plugin (https://www.grasshopper3d.com/groups/group/show?groupUrl=elk&overrideMobileRedirect=1&page=3) to extract site features. Using the Elk plugin, CAPP extracts site amenities, 3D buildings, highways, landscapes, water bodies, and natural features. This visualization assists in determining the CAPP parameters. Slope-based erosion risk is assessed by computing mesh face normals and slope angles:

$$\Theta = arccos(\frac{\underline{n}\,\underline{z}}{|\underline{n}||\underline{z}|}) \quad (1)$$

Where n is the face normal and $\underline{z}$ is the vertical axis. Faces with $\theta \leq \theta_{crit}$ (environmental protection agency construction general permit or local standards) are considered stable.

$$Stable\ area\ \% = \frac{A_{stable}}{A_{total}} \times 100 \quad (2)$$

3.4.1.2. iLEED-OpenSpace module

Open space is evaluated as:

$$Open\ space\ ratio = \left(\frac{Qualifying\ open\ space\ area}{Total\ site\ area}\right) \quad (3)$$

To assess the vegetation requirement, the system cross-references the designated vegetated polygons with the qualifying open space, calculating the share of green

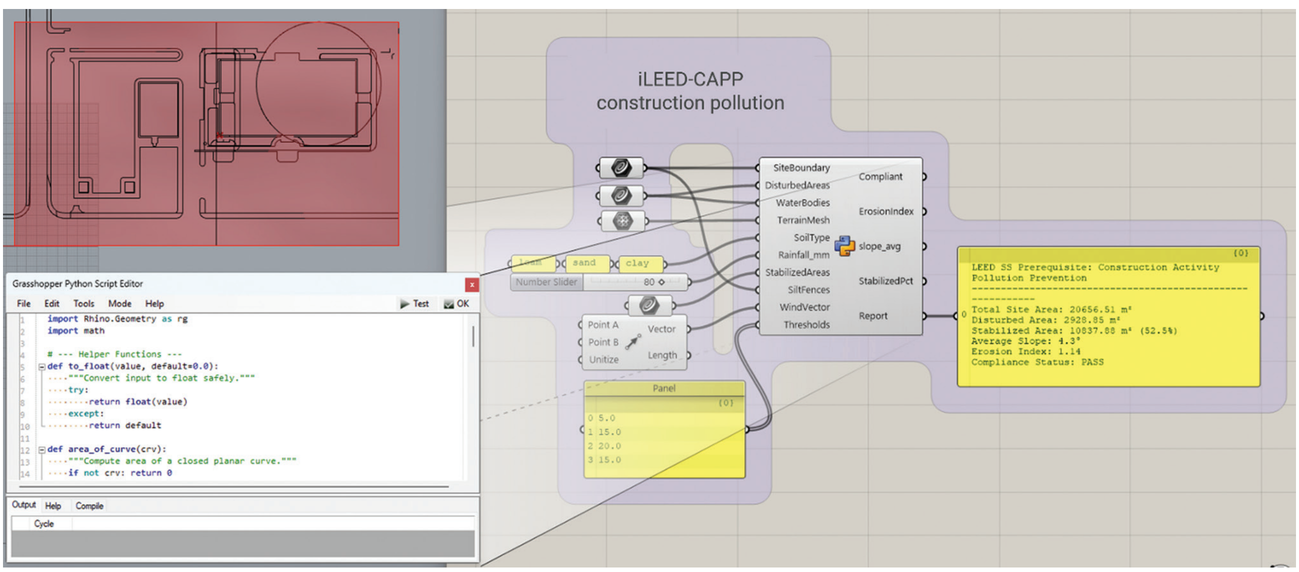

Figure 2. Construction pollution prevention
Source: Diagram by the author.
Abbreviations: CAPP: Construction activity pollution prevention; iLEED: Intelligent leadership in energy and environmental design.

infrastructure relative to the site area. This relationship is expressed in Equation (4):

$$Vegetated\ open\ space\ ratio = \left(\frac{Vegetated\ portion\ of\ open\ space}{Total\ site\ area}\right) \tag{4}$$

Compliance requires ≥30% of the site to be designated as open space, with ≥25% of that open space vegetated. The module automatically identifies eligible open-space areas, computes ratios, flags compliance status, and generates dashboards with color-coded overlays (Figure 3).

3.4.1.3. iLEED-HeatIsland module

Heat Island reduction is assessed under two LEED v4.1 options:

(i) Option 1 (non-roof):

$$Compliance = \left(\frac{Vegetation + Tree\ canopy}{Total\ hardscape}\right) 100\% \tag{5}$$

(ii) Option 2 (roof + site):

$$Compliance = \left(\frac{Vegetation + Tree\ canopy + High\ SRI\ roof + Covered\ parking}{Hardscape + Roof}\right) 100\% \tag{6}$$

The denominator excludes non-measurable roof surfaces, as specified by LEED rules. Combining the options:

$$R_{combined} = \frac{A_{shaded} + A_{highSRI} + A_{openGrid} + A_{vegRoof} + A_{highSRIroof}}{A_{total\ nonroof} + A_{total\ roof}} where\ R_{combined} \tag{7}$$

Where A_{shaded} is the area of hardscape shaded (by trees at 10 years, canopies, photovoltaic panels, etc.); $A_{highSRI}$ is the area of paving with SRI ≥ 0.33 (initial) or ≥0.28 (3-year aged); $A_{openGrid}$ is the area of open-grid paving (≥50% pervious); $A_{vegRoof}$ is the vegetated roof area; $A_{highSRIroof}$ is the roof area with SRI ≥ 82 (low-slope ≤ 2:12) or SRI ≥ 39 (steep-slope > 2:12); $A_{tota\ nonroof}$ is the total non-roof hardscape area (roads, parking, plazas, etc.); and $A_{total\ roof}$ is the total eligible roof area. The credit award is calculated as follows: One point if the threshold is met (non-roof + roof or combined), or 0 points otherwise.

The compliance percentage is then evaluated against LEED thresholds. If compliance equals or exceeds 50%, the project earns one point, while compliance ≥75% results in two points. Otherwise, no points are awarded. The results are automatically summarized in a structured report that includes total areas, compliance percentages, pass/fail status, and estimated LEED credit points. Beyond assessment, the module also generates practical design

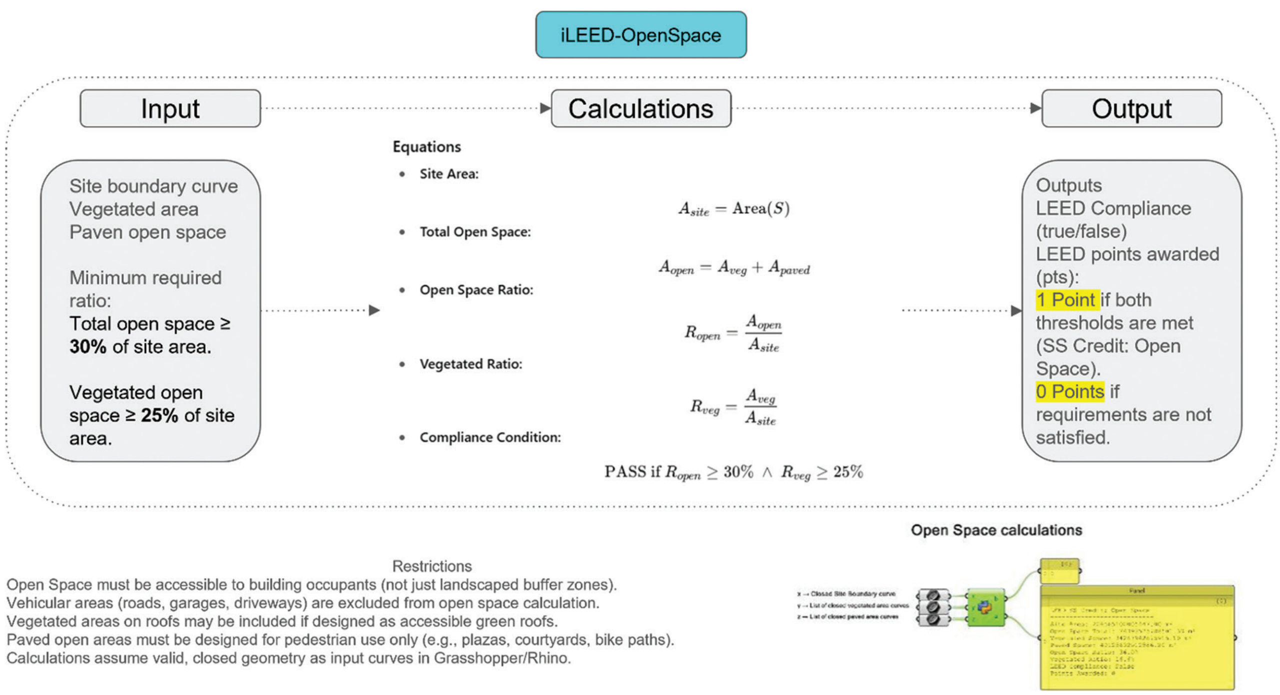

Figure 3. System architecture of the iLEED-OpenSpace module
Source: Diagram by the author.
Abbreviations: iLEED: Intelligent leadership in energy and environmental design; SS: Sustainable sites.

recommendations to improve compliance. These include strategies, such as increasing vegetated cover, applying high-SRI materials to roofs and pavements, shading hardscapes with trees, and integrating covered parking.

This structured approach provides transparency and reproducibility in evaluating Heat Island Reduction strategies. By combining automated geometry processing, compliance equations, and point allocation within a unified workflow, the iLEED HeatIsland module streamlines credit documentation and facilitates sustainable design decision-making, as illustrated in Figure 4.

3.4.1.4. iLEED-RainManage module

The iLEED-RainManage module automates compliance with the LEED v4 Rainwater Management credit by applying the Natural Resources Conservation Service CN method. The potential maximum retention capacity (S [mm]) is calculated as:

$$S_{(mm)} = \frac{1000\ 25.4}{CN} - 10\ 25.4 \qquad (8)$$

where S is the potential maximum soil water retention after runoff begins (in mm). It represents how much water the soil and land cover can store before generating surface runoff. CN is dimensionless, ranging from 30 to 100. It is assigned based on land use, hydrologic soil group, cover type, and imperviousness. A low CN (30–60) indicates permeable soils, forests, or grasslands, suggesting a higher infiltration, hence a larger S. In contrast, a high CN (80–98) indicates impervious or compacted areas, suggesting a lower infiltration, hence a smaller S.

The initial abstraction, which represents interception and infiltration losses, is then defined as:

$$I_a = 0.2\ S \qquad (9)$$

Runoff depth (Q) is calculated per subcatchment according to:

$$Q = \begin{cases} 0, & \text{if } P \le I_a \\ \dfrac{(P - I_a)^2}{P - Ia + S} & \text{if } P \succ I_a \end{cases} \qquad (10)$$

The runoff volume for each subcatchment is obtained by converting Q into volume:

$$Runoff\ Volume_{m^3} = \frac{Q}{1000} \times Area_{m^2} \qquad (11)$$

Total site runoff is determined by summing the runoff volumes of all subcatchments. The effect of low-impact development (LID) strategies is incorporated by subtracting the total storage capacity of all installed systems (e.g., bioretention cells, permeable paving storage, and rainwater harvesting tanks):

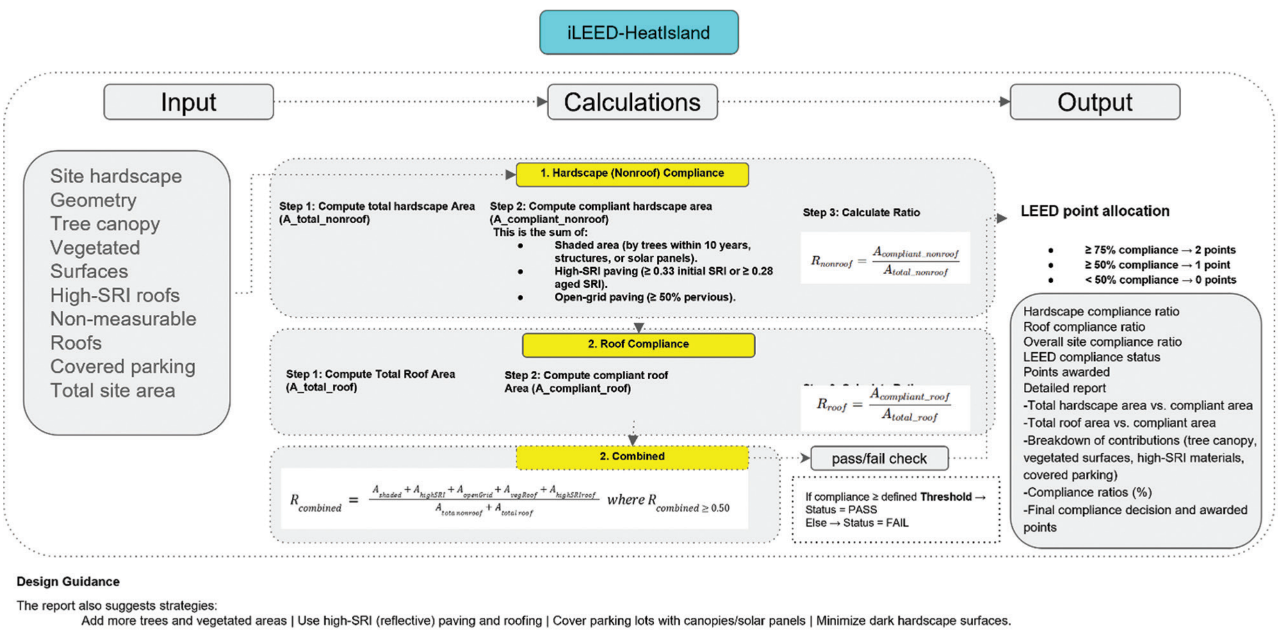

Figure 4. System architecture of the iLEED-HeatIsland module
Source: Diagram by the author.
Abbreviations: iLEED: Intelligent leadership in energy and environmental design; SRI: Solar reflectance index.

$$Remaining\ Runoff = \sum Runoff\ Volume - LID_{storage} \quad (12)$$

The compliance criterion is met if RemainingRunoff ≤ 0 (full management), or if the managed percentage meets LEED's partial credit thresholds. A secondary calculation is performed for compliance based on the pervious surface ratio:

$$Remaining\ management(\%) = \frac{A_{Pervious}}{A_{site}} \times 100 \quad (13)$$

Outputs of the module include tabulated results per subcatchment (CN, impervious ratio, Q, and volume), the total site runoff versus provided storage, compliance percentage, and final pass/fail status. LEED points are assigned based on compliance: One point for managing 50 percent of runoff, and two points for managing 75 percent or more. The module further suggests design strategies, such as increasing landscaped areas, introducing permeable pavements, or expanding LID capacity to improve compliance. Finally, the iLEED system automates reporting by generating both numerical outputs and descriptive text summaries, ensuring transparency of assumptions, equations, and compliance decisions, as depicted in Figure 5.

The workflow is implemented in GhPython, where site geometries are extracted, areas computed, and hydrologic parameters evaluated. Core logic is:

if P ≤ Ia: Q = 0
else: Q = ((P - - Ia)²)/(P – Ia + S)
runoff = (Q/1000) × area
remaining = runoff – LID_storage
compliance = (pervious_area/total_area) × 100

Outputs include runoff volumes, compliance percentages, LEED points, and design recommendations (e.g., green roofs and permeable paving). This approach delivers rapid, transparent, and reproducible stormwater performance assessment in the pre-design stage.

3.4.1.5. iLEED-SiteDevelopment module

The module calculates the share of undisturbed habitat. The primary metric is defined as:

$$Site\ development(\%) = \frac{A_{undist}}{A_{site}} \times 100 \quad (14)$$

where A_{undist} is the undisturbed site area and A_{site} is the total project site area. The resulting percentage is dynamically compared against LEED v4 thresholds, and LEED points are allocated accordingly.

Then, LEED compliance is assessed by comparing the calculated percentage against credit thresholds. Projects with ≥75 percent undisturbed area are awarded 2 points, while those with ≥50 percent but <75 percent receive 1 point. Sites with <50 percent undisturbed area do not earn

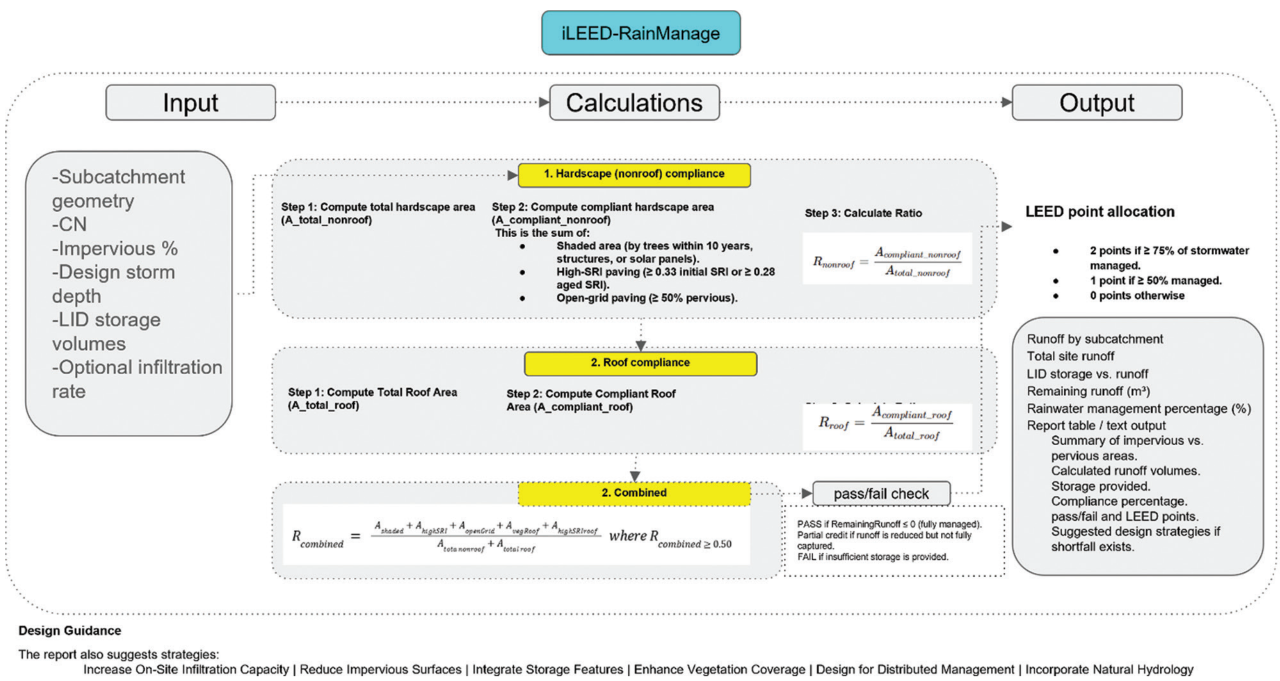

Figure 5. System architecture of the iLEED-RainManage module
Source: Diagram by the author.
Abbreviations: CN: Curve number; iLEED: Intelligent leadership in energy and environmental design; LID: Low-impact development.

the credit. The GhPython script is designed to dynamically update these calculations whenever project geometry is modified, ensuring real-time feedback during design iterations.

The outputs of the module are organized in a structured report containing: (i) Total site area, (ii) disturbed area, (iii) undisturbed area, (iv) compliance percentage, (v) compliance status (pass/fail), (vi) estimated LEED points, and (vii) recommended design strategies. These outputs provide designers and project managers with both quantitative performance metrics and qualitative guidance to inform sustainable site planning decisions, as depicted in Figure 6.

3.4.1.6. iLEED-Integrated site compliance dashboard

To operationalize the automation of site-related LEED v4 SS credits, this research develops the iLEED Integrated Site Compliance Dashboard, a parametric decision-support system embedded within Rhino/Grasshopper. Unlike the traditional manual and linear LEED calculation workflow, the dashboard enables real-time, multi-criteria evaluation of Open Space, Heat Island Reduction, Rainwater Management, and Site Development credits. This integration facilitates iterative design exploration, where architects and planners can immediately visualize the certification implications of design choices, thereby reducing human error and accelerating compliance verification.

The dashboard operates in several computational stages. First, site geometry is ingested either directly from user inputs or automatically extracted from pre-defined Rhino layers, including SiteBoundary, Disturbed, Impervious, and Pervious. A set of helper functions was implemented to compute geometric properties, such as areas of curves, surfaces, and Breps, and to retrieve categorized geometry from the model environment.

Next, the area calculations establish the core quantitative metrics. The total site area is computed from the SiteBoundary. The disturbed and undisturbed areas are derived by subtracting disturbed extents from the total site boundary, while impervious and pervious areas are directly measured from their respective layers. The pervious surface area is further associated with Open Space and Rainwater Management, enabling credit-specific compliance checks.

The compliance assessment is then carried out by comparing calculated percentages against LEED v4 thresholds. Specifically, the dashboard evaluates based on Equations (3), (6), and (14), as well as Equation (15):

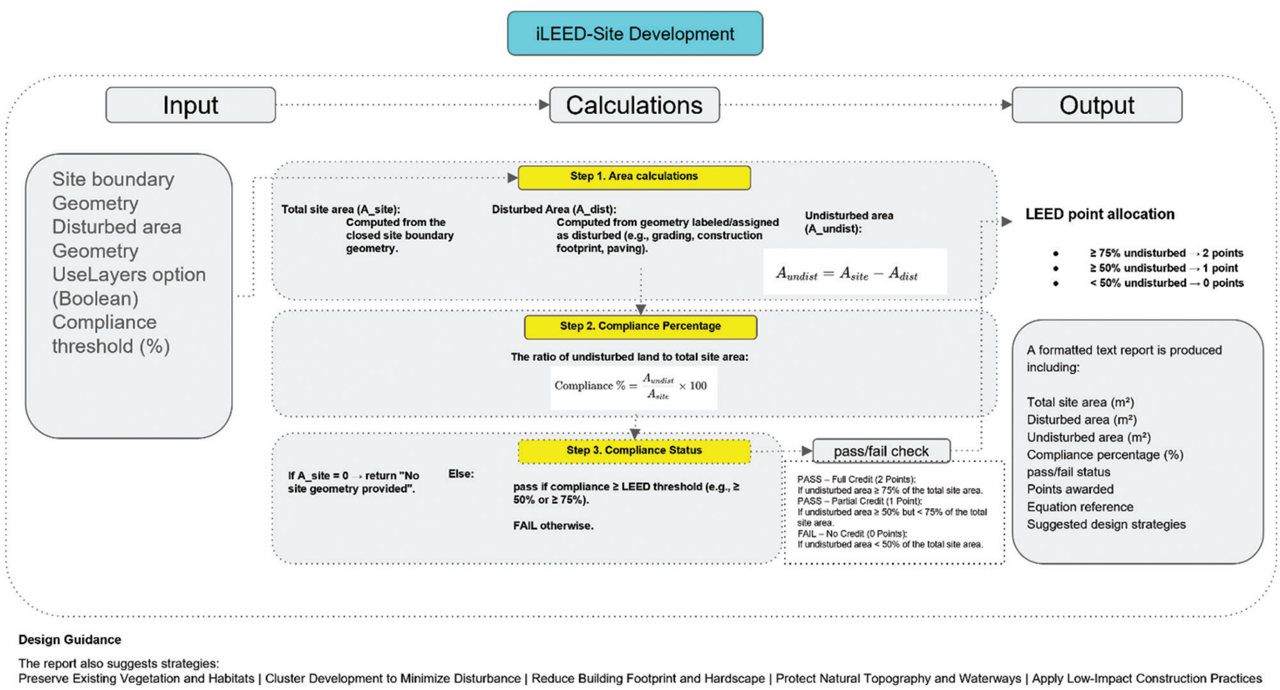

Figure 6. System architecture of the iLEED-SiteDevelopment module
Source: Diagram by the author.
Abbreviation: iLEED: Intelligent leadership in energy and environmental design.

$$Rainwater\ management = \frac{}{Total\, runoff\ volume} \tag{15}$$

For each metric, the system determines a pass/fail status and estimates LEED point allocation based on credit-specific thresholds. Points are aggregated to provide a holistic view of site-level sustainability performance.

The outputs of the dashboard include a detailed text-based report summarizing areas, percentages, compliance status, and estimated LEED points. In addition, a visual overlay is generated within Rhino, where geometries are color-coded (e.g., green for Open Space, blue for Rainwater Management, and yellow for Site Development) and annotated with compliance labels. This dual reporting format supports both technical assessment and intuitive design communication, as depicted in Figure 7.

4. Case study: Application of iLEED in Duhok, Iraq

This case study demonstrates the practical application of the iLEED computational tool in assessing and optimizing sustainable site performance in a mixed-use development in Duhok, Iraq. The city's rapid urbanization and intensifying Urban Heat Island effects provided a relevant context for evaluating how parametric workflows can enhance LEED credit attainment.

4.1. Site context

The selected project, the residence facility for men (RFM), is a large-scale student housing development at the American University of Kurdistan, situated along Zakho road in Duhok. The site spans approximately 22,000 sqm and exemplifies the university's commitment to sustainable campus growth. The project is pursuing LEED v4 Silver certification, positioning it as a regional benchmark for sustainable building practices. The development comprises two main buildings: (i) A 6-story main residential building with a gross floor area of 2,466 sqm, designed for student housing with integrated sustainable building systems; and (ii) a 1-story technical support building of 460 sqm, housing mechanical and utility services.

The master plan also includes garages, pedestrian walkways, landscaped green spaces, and hardscape outdoor areas (Figure 8), all of which are central to the project's SS performance—particularly Open Space, Heat Island Reduction, and Rainwater Management credits. The RFM project provided a robust testbed for implementing the iLEED framework, enabling automated evaluation of site decisions against LEED criteria and demonstrating the potential of computational tools, such as Grasshopper, for real-time sustainability assessment.

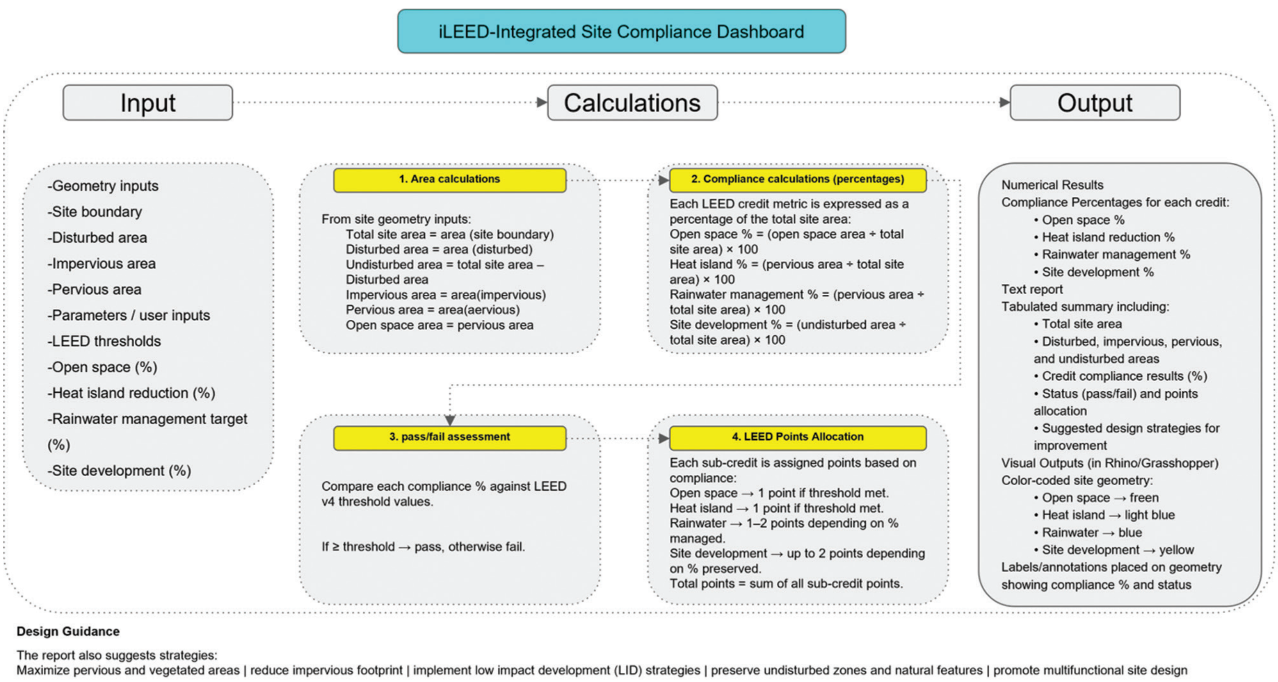

Figure 7. System architecture of the iLEED-integrated site compliance dashboard
Source: Diagram by the author.
Abbreviation: iLEED: Intelligent leadership in energy and environmental design.

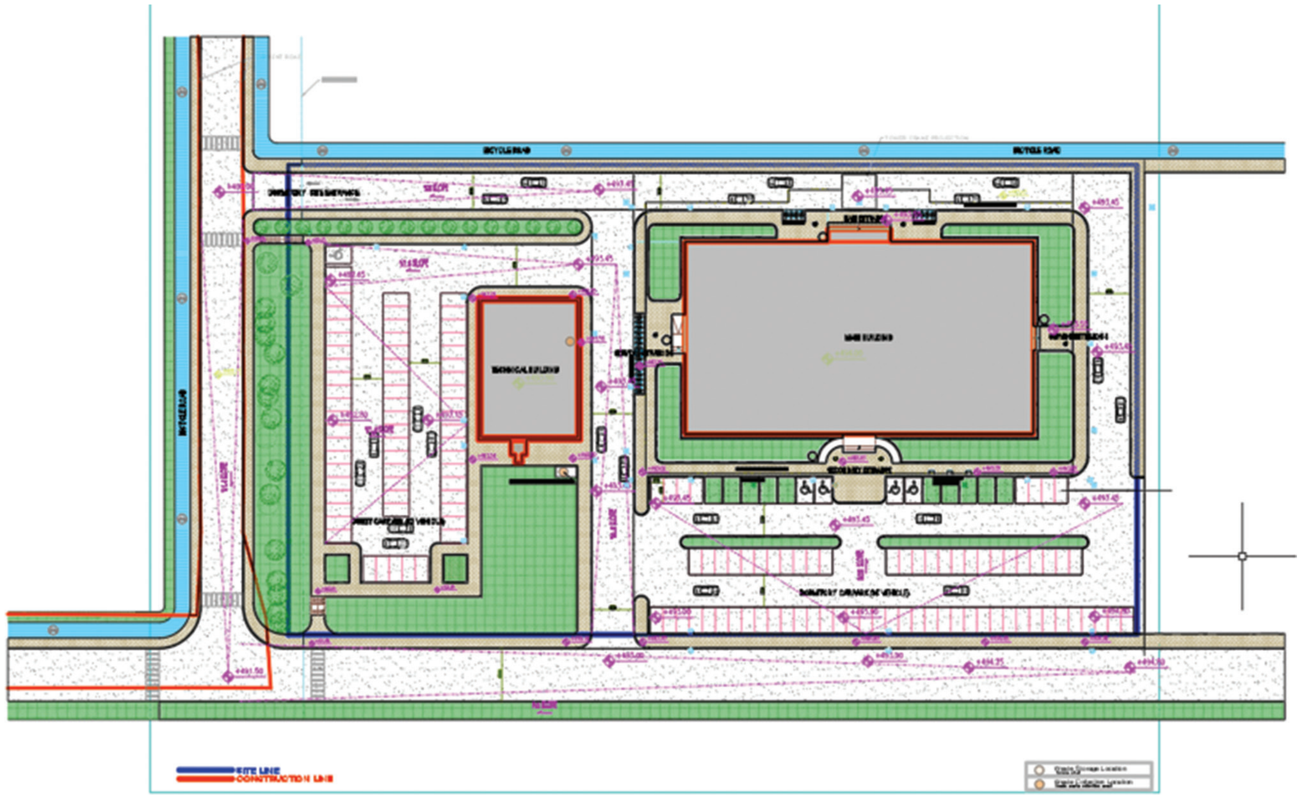

Figure 8. Residence facility for men at the American University of Kurdistan, Duhok, Iraq
Source: Diagram by the author.

4.2. iLEED integration workflow

The case study applied the four core iLEED modules to streamline LEED compliance:

(i) iLEED-hardscape: Computed weighted SRI for pavements and other non-roof hardscapes;
(ii) iLEED-roof: Analyzed roof materials for compliance with LEED SRI thresholds (≥82 for low-sloped; ≥39 for steep-sloped roofs);
(iii) iLEED-OpenSpace: Quantified accessible, vegetated, and non-vehicular open spaces contributing to habitat conservation and public use; and
(iv) iLEED-shading: Evaluated shading potential from trees, structural overhangs, and renewable energy installations.

The workflow was implemented entirely within Grasshopper, leveraging RhinoGeometry, RhinoScriptSyntax, and GhPython scripts to automate geometric data processing, compliance calculations, and performance visualization.

4.3. Surface material strategy

Surface materials were selected to balance functionality, durability, and compliance with LEED criteria for Heat Island Reduction and sustainable site design:

(i) Building pavement: 140.8 sqm of stamped concrete, chosen for aesthetic quality and slip resistance;
(ii) Pedestrian walkways: 3,200.5 sqm surfaced with paving stone for high SRI and permeability;
(iii) Garage areas: 2,450.3 sqm of paving stone, supporting circulation and thermal performance;
(iv) Open-grid grass stone: 1,875.2 sqm beneath garage surfaces to enhance stormwater infiltration and reduce heat gain;
(v) Dedicated bike lane: 875.4 sqm of durable, high-SRI paving stone promoting sustainable mobility;
(vi) Vehicular circulation: 4,261.1 sqm of asphalt roadway, selected for load resistance and integration with site traffic patterns.

This material palette was strategically assembled to support thermal comfort, hydrological performance, and user experience, contributing to the project's targeted LEED v4 Silver certification (Figure 9).

5. Results

The application of the iLEED Grasshopper-based plugin demonstrated substantial capability in automating LEED v4 compliance analysis for urban and architectural projects. The system processed geometric data from the

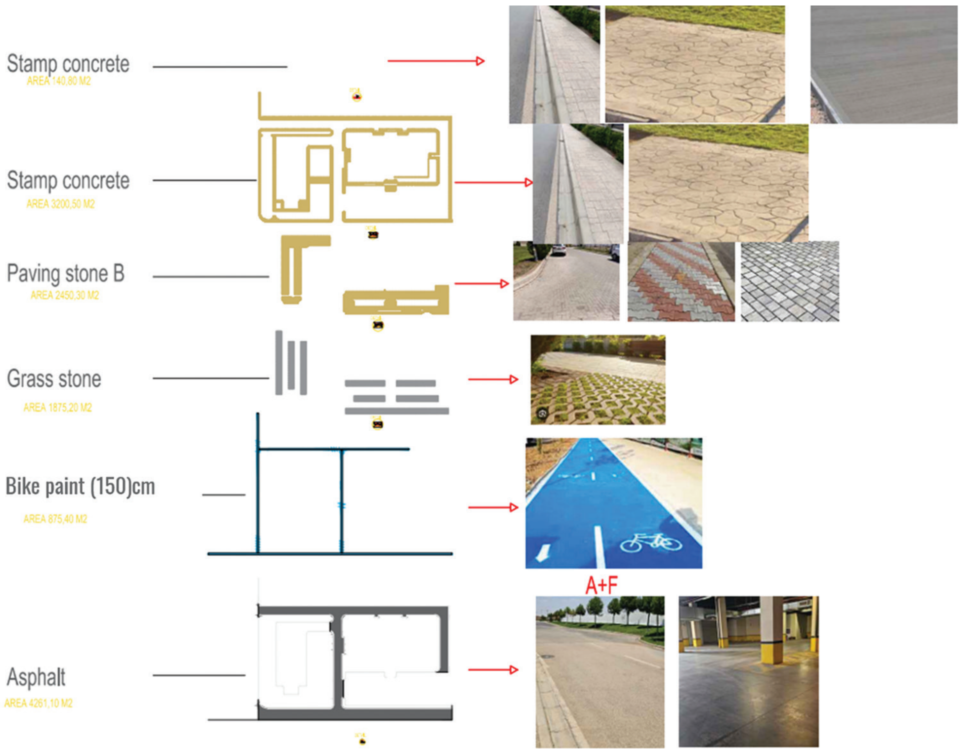

Figure 9. Surface material palette for the residence facility for men site
Source: Diagram by the author.

Shahan and Lalav Towers in Duhok, Iraq, and produced both visual and numerical outputs for key SS credits: Heat Island Reduction, Open Space, Rainwater Management, and Site Disturbance/Protect or Restore Habitat.

5.1. Hardscape heat island reduction

The iLEED-Hardscape module evaluated the total hardscape area, identifying compliant reflective materials and shading contributions. Results showed that 42 percent of the hardscape surfaces met LEED's SRI thresholds, achieving 1.8 out of 2 points in this category.

5.2. Open space evaluation

The iLEED-OpenSpace module assessed the LEED v4 SS credit Open Space, with a total site area of 20,656.51 sqm, a qualifying open space of 6,693.22 sqm (32.4%), a vegetated area of 3,426.79 sqm (16.6%), and a paved open area of 3,266.42 sqm.

Although the project exceeded the required 30 percent total open space, it fell short of the 25 percent vegetated open-space threshold. As a result, the project received a fail status (0 points) for this credit (Figure 10).

To comply, the design would need an additional 1,760–1,800 sqm of vegetated space, which could be achieved by converting paved plazas into vegetated areas, introducing green roofs, or creating landscaped courtyards. This highlights a frequent challenge: Projects emphasizing hardscape gathering areas often meet the general open-space requirement yet fail the vegetated-coverage criterion. The real-time feedback provided by iLEED enables early-stage design adjustments, preventing late redesign and ensuring alignment with LEED requirements.

5.3. Rainwater management

The iLEED-Rainwater module identified a total site area of 17,851.17 sqm, an impervious area of 7,100.02 sqm, and a pervious area of 10,751.15 sqm.

The compliance ratio was 60.23 percent, exceeding the LEED minimum of 25 percent pervious area and earning one point for this credit (Figure 11). The strong performance demonstrates effective stormwater infiltration and reduced runoff impacts, with potential for further improvement through permeable pavements, green roofs, bioswales, or rain gardens.

5.4. Site disturbance assessment

The iLEED-SiteDisturbance module quantified land alteration, with a total site area of 20,656.51 sqm, a

Figure 10. iLEED-OpenSpace application on the case study
Source: Diagram by the author.
Abbreviations: iLEED: Intelligent leadership in energy and environmental design; SS: Sustainable sites.

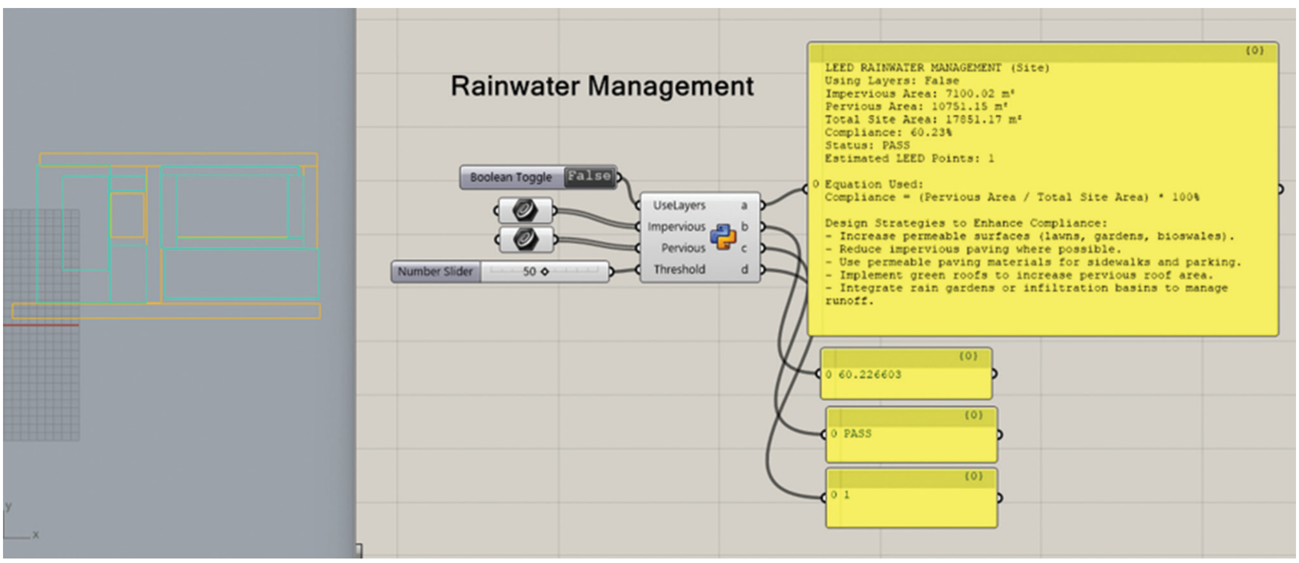

Figure 11. iLEED-RainManage application on the case study
Source: Image by the author.

disturbed area of 9,150.71 sqm, and an undisturbed area of 11,505.80 sqm.

$$Compliance(\%) = \left(\frac{Total\,site\,area - Disturbed\,area}{Total\,site\,area}\right) \times 100 \quad (15)$$

$$= \left(\frac{20{,}656.51 - 9{,}150.71}{20{,}656.51}\right) \times 100$$

This surpassed the LEED requirement of ≥50 percent preserved habitat, earning one point (Figure 12). The

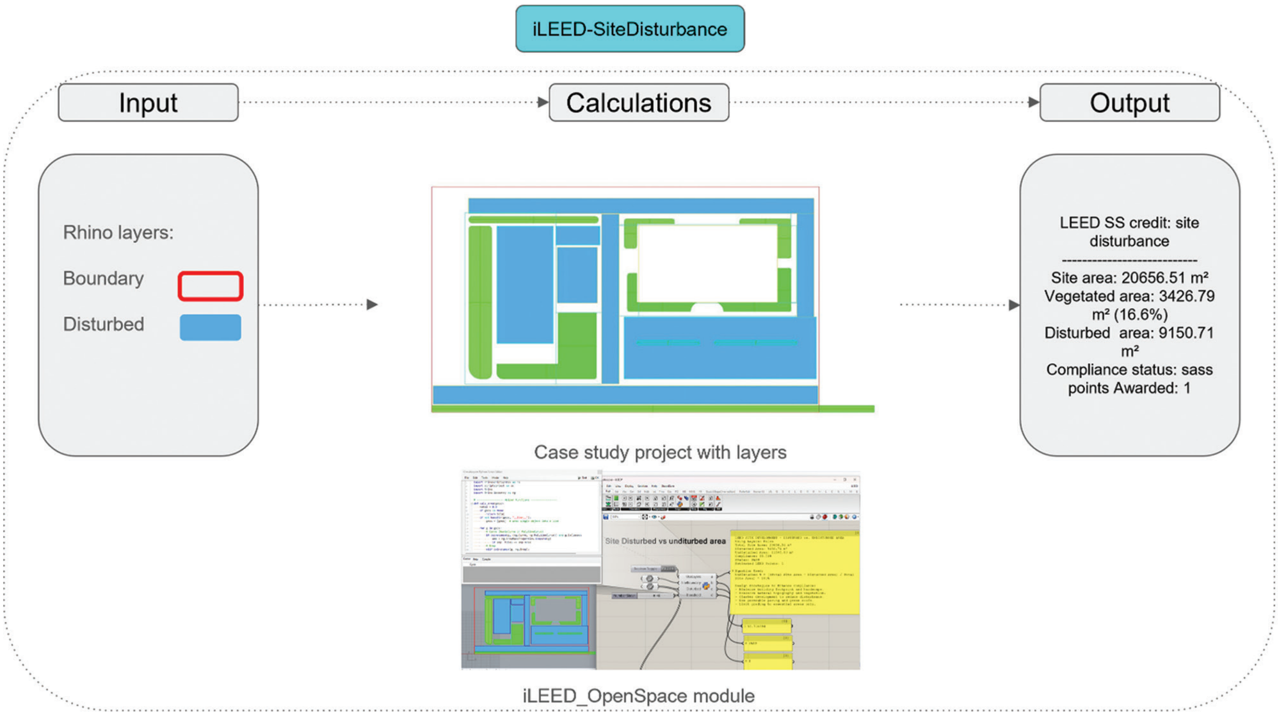

Figure 12. iLEED-Disturbed application on the case study
Source: Diagram by the author.
Abbreviations: iLEED: Intelligent leadership in energy and environmental design; SS: Sustainable sites.

results emphasize that even modest reductions in grading or hardscape—e.g., 2–3 percent—can further enhance compliance and biodiversity outcomes.

5.5. Computational efficiency

For models with 5,000–7,000 surfaces, the average computational time per LEED category was 2–4 s, a reduction in assessment time by approximately 75 percent compared to manual methods. This enables faster iteration and more informed decision-making during early design stages.

5.6. Visualization and reporting

The plugin generated interactive, color-coded diagrams and automatically compiled data into structured reports suitable for LEED documentation. Dynamic labeling in Rhino provided immediate visual understanding of compliance levels.

5.7. Implementation and optimization

The baseline performance was as follows: Hardscape compliance: Hardscape impact compliance (HIC) = 0.21, roof compliance = 28 percent of high-SRI/vegetated roofing, shading = 18 percent of pedestrian coverage, and open space = 32 percent of site area. Post-optimization using iLEED increased HIC to 0.46 through the use of reflective pavements and permeable surfaces, converted 40 percent of roofs to vegetated/high-SRI roofing, improved shading coverage to 35 percent with photovoltaic canopies and native trees, and enhanced open space to 46 percent by increasing biodiversity and public accessibility. The LEED outcomes were: +2 points for High-priority site and equitable development (Location and Transportation credit); +2 points for Open Space (SS credit); +2 points for Rainwater Management (SS credit); and +2 points for Heat Island Reduction (SS credit) (Table 4 for the LEED v4 scorecard).

5.8. Validation of iLEED against USGBC calculators

To ensure the accuracy and reliability of the proposed iLEED framework, the Grasshopper-generated outputs were validated against official USGBC LEED calculators and conventional manual evaluation methods. The comparison focused on the four SS credits automated within iLEED: Open Space, Heat Island Reduction, Rainwater Management, and Site Development. Each module's results were cross-checked using standardized USGBC tools and manual calculations based on LEED v4 guidelines, as shown in Table 5.

Error margins for all credits were within 2–5 percent, demonstrating high consistency with official evaluation

Table 4. Leadership in energy and environmental design v4 scorecard showing the total points gained

Credit	Credit points	Points earned (yes)	Points earned (maybe)	Points earned (no)
Location and Transportation	16	0	0	0
High Priority Site and Equitable Development	2	2	-	-
Sustainable Sites	10	0	0	0
Open Space	1	1	-	-
Rainwater Management	3	2	-	-
Heat Island Reduction	2	2	-	-

Table 5. Validation of iLEED outputs against USGBC LEED calculators

Credit (SS v4)	iLEED output	USGBC/ manual result	Error (%)	Interpretation
Open Space	32% qualifying area ratio	31%	3.2	Minor variation due to perimeter discretization; acceptable
Heat Island Reduction	67% compliant surface area	66%	1.5	Strong alignment; minor difference from surface categorization
Rainwater Management	23 mm retained runoff	22.5 mm	2.2	Slight overestimation from mesh-based runoff modeling
Site Development (Habitat)	61% habitat preserved/restored	60%	1.7	Excellent match; minor variation from land-cover classification

Abbreviations: iLEED: Intelligent leadership in energy and environmental design; SS: Sustainable sites; USGBC: United states green building council.

tools and confirming the reliability of iLEED as a real-time, design-integrated decision-support system for sustainable site planning.

6. Discussion

The findings of this research highlight the effectiveness of iLEED as the first unified Grasshopper-based dashboard that automates multiple SS credits within a single parametric workflow. Unlike prior BIM–LEED automation efforts that typically addressed isolated credits or relied on external simulation platforms, iLEED consolidates Open Space, Heat Island, Rainwater Management, and Site Development into an integrated system. This unification transforms LEED credits from static compliance criteria into dynamic design parameters, directly embedded in the iterative decision-making process.

A key contribution lies in the ability of iLEED to quantify environmental performance metrics—such as habitat preservation, hardscape-to-landscape ratios, and stormwater infiltration—through computational algorithms rather than manual approximation. By embedding these calculations directly within Rhino/Grasshopper, the tool enables real-time evaluation and visualization, reducing both time delays and the risk of human error. The case study demonstrated how color-coded overlays, numerical dashboards, and parametric equations facilitated clearer communication with stakeholders, supporting evidence-based decisions during early design stages.

Another important insight is the framework's scalability. Because each module is modular and computationally discrete (e.g., iLEED-OpenSpace and iLEED-RainManage modules), the system can be extended to other LEED categories or adapted to regional sustainability standards, such as Building Research Establishment Environmental Assessment Method (BREEAM) or Estidama. This adaptability positions iLEED not only as a compliance tool but also as a broader platform for performance-driven urban and architectural planning.

Nevertheless, certain limitations should be acknowledged. The accuracy of iLEED outputs is contingent upon the quality of input data, including geometric precision, material definitions, and climate datasets. Moreover, the reliance on Grasshopper scripting requires a level of technical expertise that may limit accessibility for non-specialists. Future refinements could focus on creating simplified interfaces, integrating automated data import functions, and validating outputs across multiple project types and climatic conditions.

Overall, the discussion underscores how iLEED shifts LEED assessment from a retrospective documentation exercise to a proactive, design-integrated process. By offering real-time metrics and interactive feedback, the system supports a more iterative, collaborative, and performance-oriented approach to sustainable site planning (Table 5).

7. Conclusion

This study presents iLEED, a unified parametric framework within Rhino–Grasshopper that automates the evaluation of multiple LEED v4 SS credits in real time. Unlike conventional workflows, which depend on manual calculations and retrospective documentation, iLEED embeds computational equations, Python scripts, and dynamic visualizations directly into the design process. This integration transforms LEED from a static compliance checklist into an interactive design driver. The case study demonstrated that iLEED reduces calculation time, improves accuracy, and enhances interdisciplinary communication by providing instant feedback on site-related performance metrics. Compared with conventional assessment methods, the framework supports earlier integration of sustainability criteria, reducing redesign costs and enabling more iterative, performance-driven design decisions.

While the system requires proficiency in parametric modeling, the efficiency gains and modular scalability outweigh this limitation. Beyond LEED, the framework can be extended to other certification systems and regional green codes, strengthening its adaptability to diverse contexts. Future research could expand iLEED by covering additional LEED categories, integrating predictive machine learning for design optimization, and linking with sensor data for post-occupancy validation.

In summary, iLEED represents a shift from compliance-based sustainability toward performance-driven innovation, offering architects and planners a replicable digital methodology to accelerate sustainable site design and strengthen resilience in the built environment.

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Conflict of interest

The author declares no conflict of interest.

Author contributions

This is a single-authored article.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data

The data and scripts that support the findings of this study are available from the corresponding author upon reasonable request.

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