

Article

A MIVES-Based Multi-Criteria Framework for Assessing Courtyard–Biophilic Integration in Sustainable Architecture

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Abstract

Courtyards and biophilic design have each been associated with improved environmental performance, occupant well-being, and architectural quality. However, their integration has received limited scholarly attention, and no comprehensive assessment framework currently exists to evaluate their combined contribution to sustainable architecture. This study addresses this gap by proposing a conceptual assessment framework based on the Integrated Value Model for Sustainability Assessment (MIVES). The framework draws on the literature from courtyard architecture, biophilic design, environmental psychology, and multi-criteria decision analysis. It adopts a hierarchical structure comprising requirements, criteria, and indicators related to environmental sustainability, biophilic quality, human well-being, and functional resilience. The framework also incorporates preliminary weighting strategies and value-function concepts to support the integration of diverse performance dimensions within a unified assessment structure. Rather than providing a validated assessment tool, the proposed framework establishes a conceptual foundation for future empirical calibration and testing while supporting more holistic evaluation of courtyard–biophilic integration across diverse climatic and cultural contexts.

Keywords: MIVES (Integrated Value Model for Sustainability Assessment); courtyard; biophilic design; sustainable architecture; Multi-Criteria Decision Making (MCDM); sustainability assessment; human–nature interaction

1. Introduction

The accelerating impacts of climate change, biodiversity degradation, and urban environmental stress have intensified the search for architectural strategies capable of advancing both ecological sustainability and human well-being. Although sustainable architecture has traditionally concentrated on reducing energy consumption, resource depletion, and environmental impacts throughout the building life cycle, contemporary scholarship increasingly argues that sustainability should also encompass human-centred dimensions, including health, psychological restoration, social cohesion, and quality of experience [1,2]. This broader interpretation reflects a growing recognition that buildings cannot be evaluated solely through technical performance indicators; rather, their long-term sustainability depends equally on their capacity to support human flourishing within environmentally responsible settings.

Within this evolving discourse, biophilic design has emerged as one of the most influential frameworks for reconnecting built environments with natural systems. Rooted in the biophilia hypothesis proposed by Wilson (1984) and subsequently translated into design theory by Kellert and colleagues [3,4], biophilic design is founded on the premise that



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humans possess an inherent tendency to seek connections with nature and living systems. In architectural practice, this perspective extends beyond the incorporation of vegetation or natural materials. Instead, it promotes the creation of environments that facilitate direct, indirect, and symbolic interactions with nature through spatial configurations, sensory experiences, ecological processes, and patterns that foster psychological and physiological well-being [5]. Recent empirical evidence has associated biophilic environments with reduced stress levels, enhanced cognitive performance, improved emotional well-being, and greater occupant satisfaction across residential, educational, healthcare, and workplace settings [6,7]. Despite this growing body of evidence, important questions remain regarding how biophilic principles can be systematically translated into architectural design and how their effectiveness can be evaluated within different environmental, cultural, and climatic contexts.

Courtyards have long been recognized for their ability to moderate microclimatic conditions through shading, natural ventilation, evaporative cooling, and daylight regulation [8,9]. Beyond environmental performance, they can facilitate visual and sensory engagement with nature, social interaction, and place attachment, aligning closely with several principles of biophilic design. Consequently, courtyards may be viewed as environments that support both ecological performance and human–nature relationships.

Despite these complementarities, courtyard architecture and biophilic design have largely evolved as separate research domains. Courtyard studies predominantly emphasize environmental performance, including thermal comfort, daylight availability, and passive cooling [9–11], whereas biophilic design research focuses on psychological restoration, well-being, and human–nature connectedness [6,12]. Consequently, the interactions between courtyard characteristics and biophilic outcomes remain insufficiently understood. This fragmentation is reflected in existing assessment approaches, which often prioritize environmental and technical performance while providing limited capacity to evaluate experiential, socio-cultural, and restorative dimensions within a unified framework [1,13,14].

To address this gap, the present study proposes a conceptual framework based on the Integrated Value Model for Sustainability Assessment (MIVES). Originally developed as a multi-criteria decision-making methodology, MIVES provides a hierarchical structure through which complex sustainability problems can be decomposed into requirements, criteria, and measurable indicators while accounting for stakeholder priorities and value preferences [15]. Rather than employing MIVES solely as a numerical assessment tool, this study adopts its conceptual architecture as a means of organising and modelling the multidimensional relationships that underpin courtyard–biophilic integration. By synthesising environmental, experiential, socio-cultural, and operational dimensions within a unified framework, the proposed model seeks to establish a theoretically grounded foundation for future empirical assessment and comparative evaluation.

The framework should be interpreted as a conceptual and hypothesis-generating model rather than a validated assessment instrument. Its primary purpose is to organize existing knowledge into a coherent evaluative structure that can guide future empirical testing, expert validation, and case-study implementation.

Therefore, this paper addresses the following research question:

How can courtyard architecture and biophilic design principles be systematically integrated within a MIVES-based conceptual framework to support holistic sustainability assessment in architectural design?

Accordingly, the objective of this paper is to develop a MIVES-based conceptual framework for assessing courtyard–biophilic integration in sustainable architecture. Through a critical synthesis of the literature from sustainable architecture, courtyard design, biophilic design, and sustainability assessment, the study identifies the principal dimensions, criteria,

and indicators that shape courtyard–biophilic performance. In doing so, it contributes to the emerging discourse on human-centred sustainability by offering a structured framework that may support future empirical validation, architectural decision-making, and the development of more holistic approaches to sustainability assessment.

2. Literature Review

2.1. Courtyard Architecture and Environmental Performance

Courtyard architecture represents one of the oldest and most resilient spatial responses to environmental challenges in the built environment. Across diverse geographical and climatic contexts, courtyards have historically functioned as passive environmental regulators, providing protection from excessive solar radiation, facilitating natural ventilation, enhancing thermal moderation, and supporting outdoor living conditions. While their origins are deeply rooted in vernacular architecture within hot-arid and Mediterranean regions, contemporary scholarship recognizes courtyards as adaptive architectural systems capable of contributing to broader sustainability objectives beyond climatic performance alone [10,16].

The environmental performance of courtyards has been extensively investigated over the past two decades. Research consistently demonstrates that courtyard geometry, orientation, aspect ratio, enclosure height, and surface characteristics influence microclimatic behaviour and occupant comfort. Variations in these parameters affect solar access, airflow distribution, shading efficiency, daylight penetration, and heat exchange processes, thereby shaping overall building performance [8,17]. Empirical and simulation-based studies further indicate that appropriately designed courtyards can reduce cooling loads, improve thermal comfort conditions, and contribute to energy-efficient building operation in regions characterised by high temperatures and intense solar exposure [10,18]. These findings have reinforced the position of courtyard design as a valuable passive strategy within contemporary sustainable architecture.

However, the significance of courtyards extends beyond their environmental functions. Architectural scholars have long argued that courtyards serve as socially and culturally meaningful spaces that support interaction, privacy, identity formation, and a sense of place [16]. In many cultural contexts, the courtyard operates as an intermediary zone between private and public domains, facilitating social cohesion while simultaneously responding to climatic constraints. Such characteristics suggest that the value of courtyards cannot be fully understood through environmental performance metrics alone. Rather, their contribution to sustainability emerges from the interaction between physical performance, human experience, and socio-cultural practices.

Despite the substantial body of courtyard research, important conceptual limitations remain. The majority of existing studies evaluate courtyards through isolated performance dimensions, most notably thermal comfort, energy consumption, daylight availability, or airflow behaviour. Although these investigations provide valuable technical insights, they frequently overlook the experiential and psychological dimensions of human–environment relationships. Consequently, courtyard performance is often assessed as a collection of discrete environmental variables rather than as an integrated system capable of simultaneously generating environmental, social, cultural, and restorative benefits. This disciplinary fragmentation has become increasingly problematic as sustainability discourse shifts from predominantly technical performance paradigms toward more holistic and human-centred perspectives [19].

From this perspective, courtyards offer a compelling context for examining the convergence of sustainable architecture and biophilic design. Many spatial characteristics traditionally associated with successful courtyard environments—including vegetation,

natural light, airflow variability, seasonal change, sensory richness, prospect-refuge conditions, and opportunities for social interaction—closely correspond to recognised biophilic design patterns [5,12]. Nevertheless, relatively few studies have explicitly investigated these relationships or developed frameworks capable of assessing how courtyard configurations contribute simultaneously to environmental sustainability and biophilic experience. Although courtyards frequently incorporate nature-based attributes and biophilic environments often employ courtyard-like spatial qualities, the two fields have largely developed through separate theoretical and assessment traditions, with limited attempts to integrate their evaluation within a unified sustainability framework [20–22].

This gap highlights the need for integrative assessment approaches that move beyond single-performance evaluations and capture the multidimensional nature of courtyard-based sustainability.

It should be noted that courtyard architecture is not a homogeneous design typology. Courtyard forms, functions, and performance characteristics vary across climatic, cultural, and historical contexts. Consequently, findings reported in courtyard-related research should be interpreted within their specific geographical and socio-cultural settings rather than assumed to be universally applicable.

Accordingly, this study argues that courtyards should be conceptualised not merely as passive climatic devices, but as complex socio-ecological systems through which environmental performance, human well-being, and place-based sustainability interact. Such a perspective provides a necessary foundation for developing comprehensive assessment frameworks capable of evaluating courtyard–biophilic integration within contemporary sustainable architecture.

2.2. *Biophilic Design as a Human-Centred Sustainability Paradigm*

The emergence of biophilic design has expanded sustainability discourse beyond resource efficiency and environmental performance toward the restoration of human–nature relationships within built environments. Rooted in Wilson’s (1984) Biophilia Hypothesis and further developed through environmental psychology and design research, biophilic design seeks to enhance human well-being through meaningful engagement with natural systems, processes, and patterns [23].

Contemporary frameworks conceptualize biophilic design through multiple dimensions, including direct experiences of nature, indirect representations of nature, and spatial configurations that evoke natural environments [4,5]. Empirical studies have associated biophilic interventions with reduced stress, improved cognitive functioning, enhanced emotional well-being, increased productivity, and higher levels of environmental satisfaction. Such findings have reinforced the growing integration of biophilic principles within sustainable architecture, healthcare facilities, educational environments, workplaces, and urban developments.

Nevertheless, the implementation of biophilic design often encounters methodological challenges. Existing frameworks frequently emphasize qualitative interpretation and design guidance rather than measurable performance assessment. Consequently, architects and decision-makers may struggle to evaluate the relative contribution of different biophilic features or compare alternative design solutions using transparent and replicable criteria. This challenge highlights the need for structured evaluation frameworks capable of translating biophilic principles into measurable decision-making tools.

While biophilic design has been associated with numerous environmental and well-being benefits, recent scholarship has emphasized that biophilic preferences and experiences may be shaped by cultural, social, and contextual factors, suggesting that design responses should be adapted to local conditions rather than assumed to be universally applicable [24,25].

2.3. Courtyard–Biophilic Integration in Sustainable Architecture

For the purposes of this study, a courtyard is defined as an open-to-sky or partially enclosed spatial void surrounded wholly or predominantly by built form and functioning as an integral component of the architectural and environmental organization of a building or building complex. The definition encompasses both traditional and contemporary courtyard typologies while excluding fully enclosed glazed atria and winter gardens that operate as conditioned interior spaces.

The integration of courtyard architecture and biophilic design represents a promising convergence between two research traditions that have historically evolved along largely independent trajectories. While studies of courtyard buildings in hot-arid climates have predominantly focused on environmental performance and climatic adaptation, biophilic design research has primarily examined the psychological, physiological, and experiential benefits of human–nature interactions. However, scholars have begun to recognise that these domains share common objectives centred on enhancing both environmental quality and human well-being within the built environment [13,26]. This emerging convergence suggests that courtyards may provide a uniquely suitable spatial platform through which biophilic principles can be operationalised while simultaneously contributing to broader sustainability goals.

Courtyard performance is influenced not only by broader climatic classifications but also by localized microclimatic conditions, including topography, solar exposure, prevailing winds, humidity patterns, and surrounding urban morphology. Consequently, environmental outcomes may vary even within the same regional climate context.

From a design perspective, courtyards inherently possess many of the spatial and environmental characteristics associated with successful biophilic environments. Vegetation, natural daylight, airflow variability, seasonal dynamics, water features, sensory richness, and opportunities for prospect and refuge can all be incorporated within courtyard settings while remaining closely integrated with daily patterns of building occupancy. These characteristics correspond to several established biophilic design patterns identified by Ryan et al. (2020) and Browning et al. (2014), including visual connection with nature, non-visual sensory stimuli, thermal and airflow variability, connection with natural systems, refuge, and prospect [12,27]. Consequently, courtyards may be understood not simply as passive environmental modifiers but as spatial ecosystems capable of fostering meaningful and recurring interactions between occupants and natural processes.

A growing body of empirical research supports this interpretation. Studies conducted across healthcare, educational, residential, and workplace environments indicate that access to courtyard-based green spaces can contribute to psychological restoration, stress reduction, social engagement, and improved user satisfaction [6,7]. Within healthcare settings, exposure to natural courtyard environments has been associated with enhanced recovery experiences and reduced psychological stress [28]. Educational environments have similarly demonstrated positive relationships between nature-integrated outdoor spaces and cognitive performance, attentional restoration, and student well-being. Residential studies further suggest that courtyard greenery and nature-based design elements can strengthen place attachment and support social interaction among occupants. Collectively, these findings indicate that courtyard environments may generate benefits extending well beyond their traditionally recognised environmental functions.

Despite these advances, the current evidence base remains fragmented in both conceptual and methodological terms. Most research on traditional courtyard continue to evaluate environmental indicators such as thermal comfort, daylight performance, ventilation effectiveness, and energy consumption, whereas biophilic investigations frequently focus on psychological outcomes, health indicators, or user perceptions. As a result, environmental

performance and human-experience dimensions are often assessed independently rather than as interconnected components of a unified sustainability system. This separation limits understanding of the synergistic relationships through which environmental quality may influence human well-being and, conversely, how biophilic experiences may contribute to broader sustainability outcomes.

A further limitation concerns assessment methodology. Existing studies typically employ either building-performance simulations, post-occupancy evaluations, user-perception surveys, or qualitative assessments, each capturing only a partial representation of courtyard–biophilic performance. Consequently, there remains limited consensus regarding which design attributes should be prioritised, how competing sustainability objectives should be balanced, and how alternative courtyard configurations can be systematically compared. The absence of an integrative assessment structure hinders the translation of research findings into practical decision-support tools for architects and planners.

These limitations reveal a significant research opportunity. If courtyard environments are understood as socio-ecological systems in which environmental processes, human experiences, and sustainability outcomes interact dynamically, then assessment approaches must be capable of representing this multidimensional complexity. Such a perspective requires frameworks that move beyond isolated performance metrics and instead integrate environmental, experiential, socio-cultural, and operational dimensions within a coherent evaluative structure. It is precisely this need that motivates the adoption of the MIVES methodology in the present study. Through its hierarchical organisation of requirements, criteria, indicators, and value functions, MIVES offers a theoretically robust foundation for conceptualising and assessing courtyard–biophilic integration as a multidimensional sustainability construct. As with other multi-criteria assessment approaches, the practical implementation of MIVES depends on appropriate indicator selection, weighting procedures, and contextual calibration, which may influence assessment outcomes across different applications.

2.4. Multi-Criteria Assessment Approaches and the Potential of MIVES

The increasing complexity of sustainability challenges has encouraged the adoption of multi-criteria decision-making (MCDM) approaches capable of integrating environmental, social, economic, and technical considerations within a unified evaluation framework. Among these approaches, the Integrated Value Model for Sustainability Assessment (MIVES) has attracted growing attention due to its capacity to combine hierarchical decision structures with value functions that transform heterogeneous indicators into comparable sustainability scores [29,30].

MIVES has been successfully applied in diverse domains, including infrastructure assessment, building sustainability evaluation, construction materials selection, and urban development planning. Its principal strength lies in its ability to accommodate both quantitative and qualitative indicators while explicitly incorporating stakeholder priorities through weighting systems. Such characteristics make MIVES particularly suitable for architectural evaluation problems involving multiple interrelated dimensions [30].

Despite its growing adoption in sustainability assessment, the application of MIVES to courtyard–biophilic integration remains largely unexplored. Existing studies on courtyard seldom employ structured multi-criteria models, while biophilic assessment frameworks generally lack rigorous weighting mechanisms and value-based aggregation procedures. This absence reveals a significant opportunity to develop a dedicated MIVES-based framework capable of evaluating courtyard–biophilic integration through a transparent, comprehensive, and decision-oriented methodology.

2.5. Theoretical Positioning

The review of existing literature reveals three interconnected gaps. First, courtyard research remains predominantly performance-oriented, with limited consideration of human–nature interactions and experiential outcomes. Second, biophilic design studies frequently emphasize conceptual and qualitative dimensions while offering limited support for systematic comparative assessment. Third, current sustainability evaluation tools do not adequately capture the integrated contribution of courtyard and biophilic design attributes within a single decision-making framework.

These gaps suggest the need for a conceptual model capable of linking environmental performance, human well-being, spatial quality, and sustainability objectives through a coherent assessment structure. Accordingly, this study positions MIVES as a suitable methodological foundation for developing a multi-criteria framework that evaluates courtyard–biophilic integration in sustainable architecture. By synthesizing knowledge from courtyard studies, biophilic design theory, and sustainability assessment research, the proposed framework seeks to establish a transparent basis for future empirical validation and practical implementation.

The literature demonstrates that courtyards contribute to thermal moderation, daylight optimization, and social interaction, while biophilic design supports psychological restoration and human–nature connections. Existing assessment approaches rarely capture both dimensions simultaneously. Beyond addressing a methodological gap, the proposed framework responds to a broader challenge within contemporary sustainable architecture. Existing assessment systems frequently prioritize quantifiable indicators such as energy performance, resource efficiency, and regulatory compliance, while attributes associated with human experience, restorative quality, sensory engagement, and place attachment remain comparatively underrepresented. Although such metrics are essential for evaluating environmental performance, they may capture only a partial representation of architectural quality. Courtyard–biophilic environments generate value through the interaction of environmental, ecological, social, cultural, and psychological dimensions, many of which are difficult to represent within conventional assessment structures. By integrating these dimensions within a unified evaluative framework, the proposed model seeks to support a more holistic understanding of sustainability that recognizes both measurable performance outcomes and human-centered experiential qualities.

The methodology follows the MIVES approach by defining requirements, criteria, and indicators. A hierarchical decision tree is developed and weighed through literature. The framework is intended for application to architectural projects during design evaluation.

3. Research Gap

3.1. Sustainability Assessment Beyond Single-Performance Metrics

Contemporary sustainability discourse recognizes that architectural performance cannot be adequately evaluated through isolated technical indicators. Traditional assessment approaches have largely focused on measurable environmental outcomes such as energy consumption, carbon emissions, and resource efficiency. While these metrics remain essential, they provide only a partial representation of sustainability, in buildings designed to support human well-being and long-term environmental resilience.

Recent developments in sustainability science advocate for multidimensional evaluation frameworks that simultaneously consider environmental, social, economic, and experiential dimensions [31,32]. Within the built environment, this shift reflects growing awareness that successful architectural solutions must address not only operational performance but also occupant health, psychological restoration, cultural appropriateness, and spatial quality. Consequently, sustainability assessment is viewed as a complex decision-making problem involving multiple criteria that frequently interact and occasionally compete.

The challenge becomes evident when evaluating architectural strategies that generate both environmental and human-centred outcomes. Courtyard spaces enriched through biophilic design interventions represent such a case. Their value cannot be fully captured through conventional performance metrics alone because many of their benefits emerge through experiential, behavioral, and perceptual mechanisms. Therefore, a broader evaluative perspective is required to accommodate the multidimensional nature of courtyard–biophilic integration.

Although rating systems such as LEED, BREEAM, and WELL incorporate indicators related to environmental performance and occupant well-being, they do not explicitly assess the synergistic relationship between courtyard design attributes and biophilic experiences within a single evaluation framework.

An additional limitation of existing sustainability assessment approaches concerns their tendency to prioritize technical and operational performance indicators over experiential and human-centered dimensions. While environmental metrics provide essential evidence of building performance, they often offer limited insight into how architectural environments influence psychological restoration, social interaction, sensory experience, or place attachment. Consequently, aspects of architectural quality that contribute to long-term human well-being may remain insufficiently represented within prevailing evaluation systems.

3.2. Theoretical Foundations of Biophilic Design

Biophilic design is grounded in the proposition that human beings possess an inherent affinity toward natural systems and living organisms. This perspective originates from the Biophilia Hypothesis, which suggests that interactions with nature are not merely aesthetic preferences, but fundamental psychological needs shaped through evolutionary adaptation [33]. Subsequent theoretical developments have expanded this concept into a design paradigm that seeks to strengthen human–nature relationships within contemporary built environments.

Current biophilic design frameworks emphasize three interconnected domains: direct experiences of nature, indirect experiences of nature, and spatial experiences that emulate characteristics commonly found in natural environments [4]. These domains encompass a broad spectrum of design attributes, including vegetation, water features, natural lighting, biodiversity, sensory variability, prospect, refuge, and spatial complexity. Recent scholarship has also noted that responses to biophilic environments may be influenced by cultural, social, and contextual factors, suggesting that biophilic design principles should be interpreted within specific environmental and cultural settings.

Beyond biophilic and environmental psychology perspectives, human engagement with architectural environments has also been explored through eco-phenomenological scholarship, which emphasizes embodied perception, sensory experience, and the lived relationship between people and place. This perspective reinforces the importance of evaluating environmental qualities not only through measurable performance outcomes but also through their contribution to meaningful human experience and connection with the natural world [34,35].

Importantly, the benefits associated with biophilic environments extend beyond visual aesthetics. Empirical research has linked biophilic exposure to improvements in cognitive functioning, emotional well-being, stress recovery, productivity, and overall environmental satisfaction [36,37]. Such outcomes suggest that biophilic design contributes directly to the social and human dimensions of sustainability. However, translating these benefits into measurable architectural performance indicators remains a persistent challenge. This challenge reinforces the need for assessment approaches capable of integrating subjective and objective dimensions within a coherent analytical framework.

Contemporary sustainability discourse recognizes that long-term environmental performance alone cannot define successful architecture. Buildings are also expected to support human flourishing, psychological well-being, social cohesion, and meaningful relationships with place. Consequently, sustainability assessment must evolve beyond purely technical measures toward approaches capable of capturing the broader human consequences of design decisions. This shift is relevant in courtyard–biophilic environments, where many benefits emerge through lived experience rather than through conventional engineering metrics alone [38–40].

3.3. Courtyards as Biophilic Environmental Systems

Traditionally, courtyards have been understood as passive climatic devices that moderate environmental conditions through shading, natural ventilation, evaporative cooling, and daylight regulation [41]. Although these functions remain relevant, contemporary interpretations view courtyards as complex environmental systems that simultaneously influence ecological performance and human experience.

From a biophilic perspective, courtyards possess unique spatial characteristics that facilitate meaningful interactions between occupants and natural elements. Their semi-enclosed configuration creates opportunities for visual connectivity with vegetation, exposure to natural light, sensory engagement with seasonal changes, and direct contact with ecological processes. These characteristics align closely with several established biophilic design patterns and suggest that courtyards may serve as natural platforms for biophilic integration.

Nevertheless, not all courtyards achieve comparable outcomes. Variations in spatial configuration, landscape composition, biodiversity, water features, materiality, and accessibility can influence both environmental and experiential performance. As a result, evaluating courtyard effectiveness requires consideration of multiple dimensions that extend beyond purely climatic performance. This complexity further highlights the importance of structured assessment methodologies capable of examining the interrelationships among diverse performance criteria.

3.4. The MIVES Methodology as a Sustainability Assessment Framework

MIVES (Integrated Value Model for Sustainability Assessment) is a multi-criteria decision-making methodology developed to evaluate complex systems through the integration of environmental, social, economic, and functional criteria within a hierarchical decision structure. The method combines indicator-based assessment, value functions, and weighted aggregation to support transparent and systematic decision-making under conditions involving multiple and potentially competing objectives.

The (MIVES) was developed to support decision-making in complex sustainability contexts where multiple qualitative and quantitative variables must be evaluated simultaneously. Unlike conventional assessment approaches that rely on isolated indicators, MIVES employs a hierarchical structure that organizes evaluation variables into requirements, criteria, and indicators, allowing different dimensions of sustainability to be assessed within a unified framework [30].

A distinctive feature of MIVES is its use of value functions, which transform heterogeneous indicator measurements into standardized value scores ranging from minimum to maximum performance levels. This process enables direct comparison among variables that may differ substantially in scale, units, and measurement methods [29]. Furthermore, weighting procedures allow decision-makers to express the relative importance of different sustainability objectives, thereby improving transparency and supporting more informed evaluations.

Previous studies have demonstrated the applicability of MIVES across diverse sustainability-related fields, including infrastructure projects, building materials selection, urban planning, and environmental assessment. Its flexibility in accommodating both measurable and perceptual indicators make it relevant for architectural applications where human experience and environmental performance must be evaluated concurrently.

3.5. Theoretical Justification for Applying MIVES to Courtyard–Biophilic Integration

The integration of courtyard architecture and biophilic design presents a multidimensional assessment challenge characterized by environmental, spatial, ecological, and human-centred variables. Existing evaluation approaches typically address only selected dimensions of this relationship, resulting in fragmented assessments that fail to capture the holistic value generated by integrated design solutions.

From a theoretical perspective, MIVES provides an appropriate methodological foundation because it accommodates complexity without sacrificing analytical transparency. The hierarchical structure aligns naturally with the layered nature of courtyard–biophilic systems, where broad sustainability objectives can be decomposed into measurable criteria and operational indicators. Simultaneously, value functions enable the incorporation of qualitative aspects such as perceived restorative quality, visual connectivity with nature, and spatial experience alongside quantitative environmental indicators.

Consequently, MIVES offers a mechanism through which environmental performance, biophilic quality, user well-being, and architectural functionality can be integrated within a single decision-support framework. This capability forms the theoretical basis for the framework proposed in the present study.

3.6. Linking Theory to Framework Development

The preceding discussion establishes the conceptual foundations required for constructing a MIVES-based framework for courtyard–biophilic assessment. Sustainability theory highlights the necessity of multidimensional evaluation; biophilic theory identifies human–nature relationships as essential components of environmental quality; courtyard research demonstrates the architectural potential of semi-enclosed nature-integrated spaces; and MIVES provides the methodological mechanism through which these dimensions can be systematically assessed [42].

Building upon these theoretical foundations, the next section develops a hierarchical assessment structure composed of requirements, criteria, and indicators designed specifically to evaluate courtyard–biophilic integration within sustainable architecture. The proposed framework seeks to translate abstract theoretical concepts into a practical assessment model capable of supporting future empirical applications and evidence-based architectural decision-making

4. Proposed MIVES Framework for Courtyard–Biophilic Integration Assessment

4.1. Framework Development Principles

The proposed framework was developed to address the multidimensional nature of courtyard–biophilic integration within sustainable architecture. Building upon the theoretical foundations discussed in the previous sections, the framework adopts the MIVES methodology to organize assessment variables into a hierarchical structure consisting of requirements, criteria, and indicators.

The framework is guided by three fundamental principles. First, assessment variables must capture both environmental performance and human-centred outcomes. Second, the selected indicators should be measurable or assessable using evidence available from archi-

tectural design documentation, simulation studies, post-occupancy evaluations, or empirical research. Third, the framework must remain sufficiently flexible to accommodate different building typologies and climatic contexts while preserving methodological consistency.

The framework is intended to evaluate performance outcomes rather than prescribe specific design configurations. Although the proposed indicators are derived from established research and precedent-based evidence, they remain applicable to emerging courtyard typologies and innovative design approaches that achieve comparable environmental and human-centred objectives.

Rather than evaluating courtyards exclusively as climatic devices or biophilic spaces, the proposed model considers them integrated socio-ecological systems where environmental, spatial, experiential, and functional dimensions interact simultaneously. This perspective provides the basis for the hierarchical structure presented below.

4.2. Hierarchical Structure of the Assessment Framework

Following the MIVES methodology, the proposed framework is organized into four primary requirements representing the principal dimensions of courtyard–biophilic integration:

Environmental Sustainability, Biophilic Quality, Human Well-Being and Experience, Spatial and Functional Performance

Each requirement is further divided into criteria and measurable indicators derived from the literature on sustainable architecture, courtyard design, biophilic design, environmental psychology, and building performance assessment.

The hierarchical organization in Table 1 enables complex relationships between design variables to be represented systematically while maintaining transparency throughout the evaluation process. Although some design attributes may contribute to multiple dimensions of performance, each indicator is assigned to the requirement and criterion that best reflects its primary evaluative function, thereby minimizing overlap and avoiding double counting within the assessment structure.

Table 1. Illustrative Framework Requirements, Criteria, and Representative Indicators.

Requirement	Criterion	Example Indicators
Environmental Sustainability	Microclimatic Performance Ecological Quality	Thermal comfort, daylight availability, natural ventilation Vegetation coverage, Biodiversity support
Biophilic Quality	Nature Presence Nature Experience	Vegetation diversity, water Features Visual connection, Sensory Diversity
Human Well-Being	Psychological Restoration Social Value	Perceived restorative quality, Emotional Satisfaction Social Interaction Quality, Place Attachment
Functional Resilience	Accessibility & Adaptability	Connectivity, Multifunctionality

Table 1 presents representative indicators associated with each criterion and should be interpreted as a conceptual illustration of the proposed assessment structure rather than a finalized indicator set.

4.3. Requirement R1: Environmental Sustainability

Environmental sustainability constitutes the first assessment requirement because courtyards have historically functioned as environmental moderators within the built environment. The literature consistently identifies thermal regulation, daylight optimization, and natural ventilation as key performance outcomes associated with courtyard design.

Within the proposed framework, environmental sustainability is represented through two criteria: microclimatic performance and ecological performance. Microclimatic performance addresses the capacity of the courtyard to improve thermal comfort, enhance

natural ventilation, and regulate daylight conditions. Ecological performance focuses on the contribution of vegetation and landscape elements to biodiversity enhancement, water management, and ecosystem support.

Biodiversity is interpreted broadly to include vegetative and ecological components of living systems that contribute to environmental quality, ecological richness, and human interaction with nature.

These criteria collectively capture the environmental value generated through the interaction between architectural form and natural systems.

4.4. Requirement R2: Biophilic Quality

Biophilic quality reflects the extent to which the courtyard facilitates meaningful engagement between occupants and natural systems. Drawing from established biophilic design frameworks, this requirement encompasses both the physical presence of nature and the experiential qualities associated with human–nature interaction.

The first criterion, nature presence, evaluates tangible biophilic elements such as vegetation diversity, water features, and ecological richness. The second criterion, nature experience, assesses perceptual and sensory dimensions, including visual connectivity, seasonal change, sensory diversity, and opportunities for direct interaction with natural processes.

This requirement acknowledges that the effectiveness of biophilic design depends not only on the existence of natural elements but also on the quality of human engagement with those elements.

4.5. Requirement R3: Human Well-Being and Experience

A growing body of evidence suggests that courtyard environments enriched with biophilic characteristics can contribute positively to psychological well-being, cognitive restoration, and social interaction. In this context, biophilic characteristics refer to environmental qualities that strengthen human connections with nature, including the presence of vegetation, natural light, water elements, sensory richness, and opportunities for direct or indirect interaction with natural systems [3,27]. Consequently, human-centred outcomes represent a core component of the proposed framework.

Two criteria are incorporated within this requirement. Psychological restoration examines the potential of the courtyard environment to reduce stress, support attention recovery, and promote emotional well-being. Social interaction focuses on the capacity of the space to encourage informal encounters, social cohesion, and community engagement.

The inclusion of this requirement reflects the broader transition from performance-based sustainability toward human-centred sustainability paradigms.

4.6. Requirement R4: Functional Resilience (Spatial and Functional Performance)

Although environmental and biophilic dimensions are central to courtyard assessment, successful courtyard spaces must also function effectively within the broader architectural context. Accordingly, the framework incorporates a fourth requirement addressing spatial and functional performance.

Accessibility evaluates the extent to which users can physically and visually access the courtyard space. Adaptability assesses the flexibility of the courtyard to support multiple activities, changing user needs, and evolving functional requirements.

This requirement recognizes that sustainability and biophilic quality may be diminished if courtyard spaces remain inaccessible, underutilized, or disconnected from daily building activities.

4.7. Preliminary Indicator Selection

Indicators were selected according to four criteria: relevance, measurability, applicability across building types, and consistency with established sustainability and biophilic design literature. Preference was given to indicators that can be quantified through environmental simulations, architectural analysis, field observations, or user-based assessment methods.

The preliminary indicator set is intended as a conceptual foundation rather than a finalized evaluation instrument. Future empirical studies may refine, expand, validate, or recalibrate individual indicators through expert consultation methods such as Delphi studies, Analytic Hierarchy Process (AHP), or other multi-stakeholder approaches. Any future weighting process should balance stakeholder perspectives with expert judgment, empirical evidence, and long-term sustainability considerations to ensure relevance across changing user groups and future contexts.

The proposed indicators were derived from a systematic synthesis of findings reported across courtyard architecture, biophilic design, sustainability assessment, and environmental psychology literature. Consequently, the framework does not seek to define new performance attributes; rather, it consolidates and organizes characteristics that have previously been associated with positive environmental, experiential, and well-being outcomes. The novelty of the framework lies in their integration within a unified assessment structure rather than in the creation of entirely new evaluation criteria.

The framework offers a structured decision-support tool for architects and planners. Unlike conventional sustainability assessments, it explicitly evaluates human–nature relationships alongside climatic performance.

5. Indicator Definition and Measurement Framework

5.1. Indicator Selection Strategy

The development of a robust assessment framework requires indicators that are theoretically grounded, measurable, and applicable across different architectural contexts. Accordingly, indicator selection was guided by four principles: relevance to courtyard–biophilic integration, consistency with sustainability objectives, measurability through available assessment methods, and applicability across multiple building typologies.

The indicators proposed were derived from an extensive synthesis of literature on courtyard design, biophilic environments, sustainable architecture, environmental psychology, and building performance assessment. Particular attention was given to indicators that have been repeatedly associated with environmental quality, human well-being, and ecological performance.

Because the present study proposes a conceptual framework rather than an empirical assessment tool, the indicators should be viewed as a preliminary structure requiring future validation through expert consultation and practical case-study applications.

5.2. Environmental Sustainability Indicators

The environmental sustainability requirement focuses on the environmental functions traditionally associated with courtyard spaces. These indicators in Table 2 evaluate the ability of the courtyard environment to improve building performance while reducing resource consumption.

These indicators collectively evaluate the environmental contribution of courtyard–biophilic systems and establish a measurable basis for sustainability assessment.

Table 2. Environmental Sustainability Indicators.

Criterion	Indicator	Unit	Assessment Method	Desired Direction
Microclimatic Performance	Thermal Comfort Improvement	PMV, UTCI, PET	Simulation/Measurement	Higher
	Daylight Availability	Daylight Factor (%)	Simulation	Higher
	Natural Ventilation Potential	ACH (Air Changes per Hour)	CFD Analysis	Higher
Ecological Performance	Vegetation Coverage	% Green Area	Site Analysis	Higher
	Water Efficiency	Water Consumption Reduction (%)	Design Evaluation	Higher
	Biodiversity Support	Species Diversity Index	Ecological Assessment	Higher

5.3. Biophilic Quality Indicators

Biophilic quality indicators in Table 3 assess the extent to which courtyard environments facilitate meaningful interactions between users and natural systems. Unlike environmental indicators, these variables focus primarily on experiential and perceptual dimensions.

Table 3. Biophilic Quality Indicators.

Criterion	Indicator	Unit	Assessment Method	Desired Direction
Nature Presence	Vegetation Diversity	Number of Species	Landscape Assessment	Higher
	Water Features Availability	Presence/Area (%)	Design documentation and site evaluation	Higher
Nature Experience	Visual Connection to Nature	% Visible Greenery	View Analysis	Higher
	Sensory Diversity	Expert/User Evaluation	Expert assessment and/or user surveys	Higher
	Seasonal Variability	Diversity Score	Landscape analysis of seasonal vegetation characteristics and temporal changes	Higher

These indicators recognize that biophilic effectiveness depends not merely on the existence of natural elements but on the quality of human engagement with them. Assessment methods presented in the table are indicative rather than prescriptive and are intended to illustrate potential sources of evaluation data. Detailed measurement procedures and scoring protocols should be established during future empirical implementation and validation of the framework.

5.4. Human Well-Being Indicators

Human well-being represents one of the primary expected outcomes of courtyard–biophilic integration. Consequently, the proposed framework includes indicators shown in Table 4 that capture psychological, emotional, and social dimensions of user experience. Beyond environmental psychology and biophilic theory, human experience of architectural space has also been examined through phenomenological perspectives that emphasize perception, embodiment, place, and lived experience. This body of scholarship highlights how environmental qualities are experienced holistically through sensory engagement and human–environment interaction, providing an additional theoretical foundation for evaluating experiential dimensions within courtyard environments.

Table 4. Human Well-Being Indicators.

Criterion	Indicator	Unit	Assessment Method	Desired Direction
Psychological Restoration	Perceived Restorativeness	PRS Score	User Survey	Higher
	Stress Reduction Potential	Psychological Scale	User Survey	Higher
Social Interaction	Place Attachment	Place Attachment Scale	Survey	Higher

These indicators acknowledge that successful courtyard environments generate value not only through environmental performance but also through their contribution to human health and social sustainability. For indicators related to psychological restoration and place

attachment, survey-based assessments are recommended because they capture subjective experiential outcomes that cannot be directly inferred from physical design characteristics alone. Future applications may consider differences among user groups and supplement survey findings with post-occupancy evaluations where appropriate [43,44].

5.5. Spatial and Functional Performance Indicators

The final requirement addresses the functional integration of courtyard spaces within the architectural system. While environmentally and psychologically beneficial spaces are important, their long-term effectiveness depends on accessibility, usability, and adaptability summarized in Table 5.

Table 5. Spatial and Functional Performance Indicators.

Criterion	Indicator	Unit	Assessment Method	Desired Direction
Accessibility & Adaptability	Connectivity Multi-functionality	Space Syntax Measures Number of Activities Supported	Spatial Analysis Functional Assessment	Higher Higher

These indicators ensure that courtyard–biophilic environments remain integrated components of daily building operations rather than isolated architectural features.

5.6. Indicator Measurement Matrix

To facilitate future implementation, each indicator may be evaluated using one or more complementary assessment techniques, including environmental simulation, site observation, expert assessment, user surveys, and post-occupancy evaluation methods. The integration of objective and subjective measurement approaches reflects the multidimensional nature of courtyard–biophilic performance.

The proposed measurement matrix also provides flexibility for future researchers to adapt indicator selection according to climatic conditions, building typologies, and project objectives. Such adaptability is consistent with the MIVES philosophy of supporting context-sensitive yet methodologically transparent sustainability assessments.

6. Proposed Value Functions and Weighting Strategy

6.1. Rationale for Value Functions in MIVES

One of the fundamental strengths of the Multi-Attribute Integrated Value Model for Sustainability (MIVES) lies in its ability to transform heterogeneous indicators into a common value scale. Unlike conventional assessment methods that treat all performance improvements as equally valuable, MIVES recognizes that the relationship between an indicator and its contribution to sustainability is often non-linear. In many design situations, an increase in performance does not necessarily produce a proportional increase in value. Certain attributes generate substantial benefits during the initial stages of improvement but exhibit diminishing marginal returns beyond a particular threshold, whereas others only become meaningful after reaching a minimum acceptable level.

This distinction is important in the assessment of courtyard–biophilic integration. Architectural environments are characterized by complex interactions among environmental, ecological, spatial, and human-centred variables. For example, increasing vegetation coverage from 5% to 20% may substantially improve occupants’ visual exposure to nature and perceived environmental quality. However, increasing vegetation from 60% to 75% may generate comparatively smaller additional benefits. Conversely, some indicators, such as biodiversity support or access to restorative natural environments, may produce limited value at low levels but become more important once a critical threshold is achieved.

For this reason, MIVES employs value functions that convert raw indicator measurements into standardized value scores ranging from 0 to 1. These functions enable the model to reflect real-world behavioural responses, environmental performance patterns, and human perceptions more accurately than linear scoring approaches [29,45].

6.2. Linear Value Functions

Linear functions assume a proportional relationship between indicator performance and sustainability value. Each incremental improvement generates the same increase in value regardless of the current performance level.

Mathematically, the relationship can be expressed as:

$$\begin{aligned} V(x) &= a + b * x \\ V(x) &= a + b \cdot x \\ V(x) &= a + b \times x \end{aligned} \tag{1}$$

where $V(x)$ represents the normalized value and x represents the measured indicator.

Within courtyard–biophilic assessment, linear functions are appropriate when benefits increase consistently across the entire performance range and no evidence suggests threshold effects or diminishing returns. Indicators such as daylight autonomy, percentage of permeable surfaces, or visual accessibility to courtyard spaces may exhibit approximately linear behaviour within certain design ranges.

The advantage of linear functions is their simplicity and transparency. Nevertheless, they may oversimplify human–environment relationships by assuming that all improvements are equally meaningful. Numerous studies in environmental psychology indicate that human perceptions of environmental quality rarely follow perfectly linear patterns [46,47]. Consequently, linear functions should be applied selectively and only when empirical evidence supports proportional value generation.

6.3. Concave Value Functions and Diminishing Returns

Concave functions represent situations in which initial improvements generate substantial value, but subsequent improvements contribute progressively smaller gains. This phenomenon is commonly described as diminishing marginal returns.

In architectural and environmental systems, diminishing returns frequently occur because basic environmental deficiencies are addressed during early interventions, while additional improvements yield progressively lower perceptual or performance benefits.

For courtyard–biophilic integration, several indicators are expected to exhibit concave behaviour: Vegetation coverage ratio; Number of visible natural elements; Shaded outdoor areas; Daylight penetration; Visual connection to greenery. While indicators such as vegetation coverage ratio provide a useful representation of nature presence, their interpretation should consider that qualitative attributes including vegetation maturity, structural diversity, and spatial configuration may also influence environmental performance and user experience.

For example, increasing visible greenery from 10% to 30% may dramatically improve occupants' perception of naturalness and restorative quality. However, increasing greenery from 70% to 90% may provide only marginal additional benefits. The greatest gains are therefore achieved during the initial stages of improvement.

This behaviour is consistent with research in biophilic design and environmental preference theory, which demonstrates that exposure to natural environments produces substantial psychological benefits at relatively moderate levels of nature contact, after which benefit growth tends to stabilize [46–48].

Accordingly, concave functions are hypothesized as potentially suitable for indicators associated with visual exposure to nature, vegetation abundance, natural ventilation effectiveness, and passive environmental performance.

6.4. *Convex Value Functions and Threshold-Dependent Performance*

Convex functions describe situations in which initial improvements contribute little value, while larger improvements produce increasingly significant benefits. Such relationships are often observed when a minimum performance level must be achieved before meaningful outcomes become apparent.

In courtyard–biophilic environments, several ecological and social indicators may exhibit convex characteristics. Biodiversity enhancement provides a useful example. A courtyard supporting only a few isolated plant species may contribute little ecological value. However, once habitat complexity increases sufficiently to support pollinators, birds, and diverse vegetation communities, ecological performance may improve rapidly.

Similarly, social activation indicators may follow convex trajectories. Small improvements in courtyard usability may not affect user behaviour, whereas achieving adequate comfort, accessibility, and environmental quality simultaneously may trigger substantial increases in space utilization and social interaction.

The use of convex functions therefore reflects the understanding that some sustainability outcomes emerge only after crossing specific performance thresholds. This characteristic aligns with ecological resilience theory, which suggests that ecosystem functionality often depends on minimum levels of diversity and connectivity before significant benefits become observable [49].

6.5. *S-Shaped Functions and Human–Environment Relationships*

Among all value functions employed in MIVES, S-shaped functions are often considered the most realistic representation of human–environment interactions because they combine threshold effects with diminishing returns.

The S-shaped relationship consists of three stages: A slow initial phase characterized by limited value generation. A rapid growth phase in which improvements create substantial value. A stabilization phase where additional gains become progressively smaller.

This pattern closely reflects how occupants experience biophilic environments. Minimal exposure to nature may produce limited perceptual benefits. Once a meaningful level of natural interaction is established, psychological restoration, environmental satisfaction, and place attachment increase rapidly. Beyond this stage, additional improvements continue to generate benefits but at a slower rate.

Several indicators proposed in this framework are expected to exhibit S-shaped behaviour: Overall biophilic experience quality. Perceived restorative potential. Multi-sensory engagement with nature. Thermal comfort satisfaction. User well-being and psychological restoration.

Research in environmental psychology consistently demonstrates that restorative experiences emerge after a minimum threshold of environmental quality is reached, followed by a period of accelerated benefit generation and eventual stabilization [3,48,50].

Consequently, S-shaped functions are provisionally suggested for evaluating experiential dimensions of courtyard–biophilic integration because they reflect both behavioural thresholds and diminishing returns.

The specification of threshold values and inflection points for individual value functions falls beyond the scope of the present conceptual study and will require future calibration through empirical evidence, expert consensus, and application across diverse courtyard contexts.

6.6. Proposed Weighting Strategy

Following MIVES principles, indicator weights should reflect the relative contribution of each component to overall sustainability performance. At the requirement level, environmental performance is proposed as the most influential dimension due to the historical climatic role of courtyards and their contribution to sustainable building performance. Human well-being and biophilic experience are assigned comparable importance because contemporary sustainability frameworks increasingly recognize occupant health and psychological restoration as fundamental performance outcomes. Ecological and socio-cultural dimensions receive complementary weighting reflecting their role in biodiversity enhancement and cultural continuity as indicated in Figure 1.

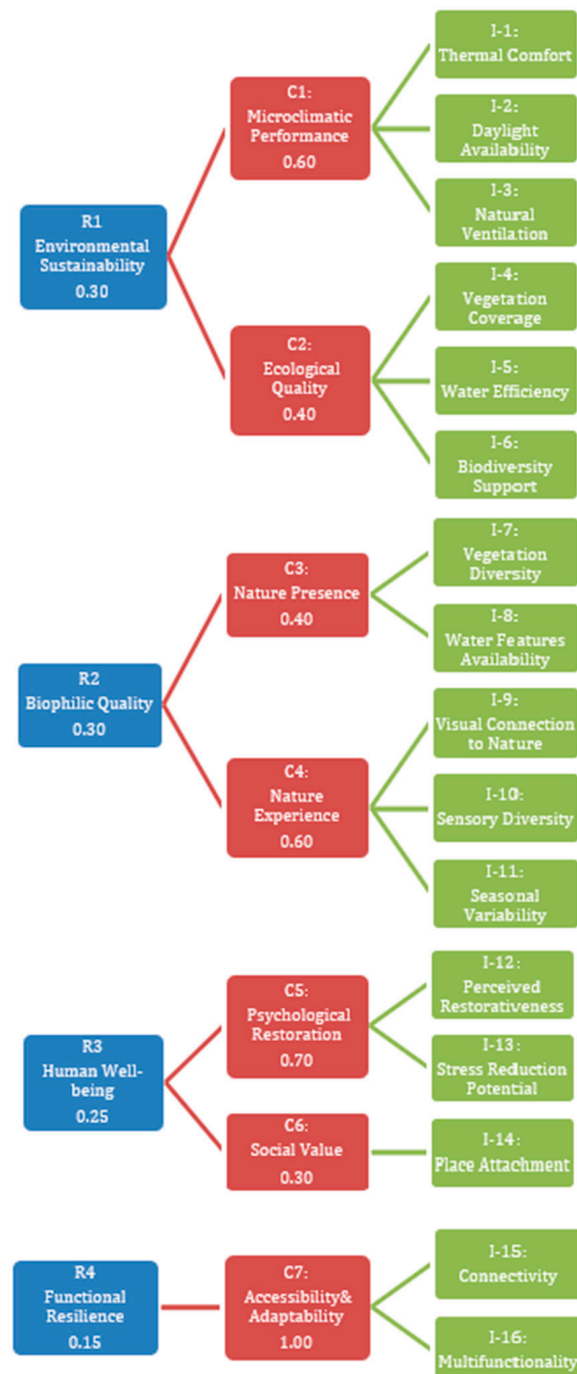


Figure 1. The proposed MIVES framework.

Future empirical studies should refine these weights using structured expert elicitation procedures to ensure contextual relevance across different climatic regions and architectural typologies. The weighting process therefore remains adaptive rather than prescriptive, consistent with the flexible philosophy underlying the MIVES methodology.

Accordingly, the present study should be viewed as a framework-development effort that establishes the conceptual structure of assessment rather than the finalized operational parameters required for implementation. The definition of weighting values, performance thresholds, and calibration procedures constitutes an important next stage of empirical research.

To operationalize the proposed MIVES framework, each indicator must be associated with a measurable unit, a desired performance direction, and an appropriate value function shown in Table 6 that synthesizes the proposed framework by integrating requirements, criteria, indicators, weighting structure, and value-function logic within a unified assessment model.

Table 6. Requirements, Criterion, Indicators Justification.

Requirement	Criterion	Indicator	Unit	Desired Direction	Proposed Function Type	Justification
Environmental Sustainability	Climatic Performance	Thermal Comfort Improvement	PMV / Adaptive Comfort Score	Maximize (↑)	S-shaped	Small improvements around comfort thresholds generate substantial perceived benefits, while benefits plateau beyond acceptable comfort ranges.
Environmental Sustainability	Climatic Performance	Daylight Availability	% Daylight Autonomy	Target Range	S-shaped	Both insufficient and excessive daylight can negatively affect occupants through poor visibility or glare.
Environmental Sustainability	Climatic Performance	Natural Ventilation Efficiency	ACH (Air Changes per Hour)	Maximize (↑)	Concave	Initial improvements enhance indoor comfort, while additional increases yield diminishing returns.
Environmental Sustainability	Ecological Integration	Vegetation Coverage Ratio	% Surface Coverage	Maximize (↑)	Concave	Early increases in vegetation substantially improve environmental quality, while benefits gradually stabilize.
Environmental Sustainability	Ecological Integration	Water Management Efficiency	% Stormwater Retention	Maximize (↑)	Convex	Advanced performance levels contribute more to resilience and resource conservation.
Environmental Sustainability	Ecological Integration	Biodiversity Support Potential	Biodiversity Score	Maximize (↑)	Convex	Higher levels of ecological complexity often generate disproportionately greater ecosystem benefits.
Biophilic Integration Quality	Nature Presence	Vegetation Diversity	Composite Assessment Score	Maximize (↑)	Convex	Higher integration levels often generate synergistic benefits exceeding linear expectations.
Biophilic Integration Quality	Nature Presence	Water Features Availability	Composite Assessment Score	Maximize (↑)	Convex	Not only presence but quality, visibility, accessibility, and ecological contribution should be considered.
Biophilic Integration Quality	Nature Experience	Visual Connection to Nature	Visibility Index (%)	Maximize (↑)	Concave	Initial visual exposure to nature provides substantial restorative benefits.
Biophilic Integration Quality	Nature Experience	Sensory Diversity	Well-being Index	Maximize (↑)	Concave	Early improvements have strong impacts, whereas additional gains become progressively smaller.
Biophilic Integration Quality	Nature Experience	Seasonal Variability	Seasonal Diversity Score	Maximize (↑)	Concave	Captures changing vegetation, flowering cycles, light variation, colour change, ecological succession.
Human Well-Being	Psychological Restoration	Perceived Restorativeness	Survey-Based Index	Maximize (↑)	S-shaped	Psychological restoration often emerges after minimum exposure thresholds are achieved.
Human Well-Being	Psychological Restoration	Stress Reduction Potential	Survey-Based Index	Maximize (↑)	S-shaped	Psychological restoration often emerges after minimum exposure thresholds are achieved.
Human Well-Being	Social Interaction	Place Attachment	User Satisfaction Score	Maximize (↑)	S-shaped	Place attachment tends to emerge only after users develop repeated experiences and emotional connections with a place. Once a threshold of familiarity and engagement is reached, attachment increases rapidly before eventually stabilizing.
Functional Resilience	Accessibility & Adaptability	Courtyard Spatial Connectivity	Connectivity Index	Maximize (↑)	Linear	Improved spatial connectivity generally contributes proportionally to overall performance.
Functional Resilience	Accessibility & Adaptability	Multi-functional Use Capacity	Number of Supported Activities	Maximize (↑)	Concave	The first few additional uses enhance value, while later additions contribute less.

This step is essential because MIVES does not evaluate raw indicator values directly; instead, indicators are transformed into normalized values through predefined value functions that reflect stakeholder preferences and sustainability objectives. The selection of value function types is therefore grounded not only in quantitative performance considerations but also in the behavioral, environmental, and experiential characteristics associated with courtyard–biophilic systems.

The proposed function assignments remain conceptual and are intended to provide a theoretically informed basis for future empirical implementation. During the validation phase, the final form of each value function should be calibrated using expert judgment, simulation outputs, field measurements, or post-occupancy evaluation data. Such calibration would ensure that the transformation of indicator values reflects real-world sustainability performance and stakeholder priorities.

7. Weighting Structure and Aggregation Model

7.1. Rationale for the Weighting Structure

The effectiveness of a MIVES-based assessment framework depends not only on the selection of appropriate indicators but also on the relative importance assigned to each component within the hierarchical value tree. Weighting serves as the mechanism through which stakeholder priorities, sustainability objectives, and contextual considerations are translated into the final evaluation outcome. Since not all dimensions contribute equally to courtyard–biophilic integration, assigning differentiated weights becomes essential for reflecting their relative influence on overall sustainability performance.

Within the proposed framework, weighting is structured across three hierarchical levels: requirements, criteria, and indicators. This hierarchical approach follows the original MIVES methodology and ensures consistency between strategic sustainability objectives and operational assessment variables [30,51,52].

At the highest level, requirement weights represent the relative importance of the major sustainability dimensions. Criteria weights distribute importance among the thematic components within each requirement, while indicator weights determine the contribution of measurable variables to criterion performance. The cumulative effect of these weights enables the aggregation of diverse qualitative and quantitative measures into a single sustainability index.

7.2. Requirement-Level Weighting Strategy

The proposed weighting structure reflects the relative importance of the four principal requirements identified through the synthesis of literature on sustainable architecture, courtyard design, biophilic environments, environmental psychology, and resilience-based design assessment. Consistent with the MIVES methodology, requirement weights are intended to represent the relative contribution of each dimension to the overall performance of courtyard–biophilic integration. The proposed weights should therefore be interpreted as preliminary values derived from the current literature synthesis, recognizing that contextual factors, cultural preferences, and post-occupancy evidence may justify their refinement across different geographical settings and building typologies.

At the conceptual stage, these weights should be regarded as theoretically informed values that require future empirical.

Requirement Level: $(R1 + R2 + R3 + R4) = 0.30 + 0.30 + 0.25 + 0.15 = 1.00$ as shown in Table 7.

Table 7. The proposed requirement-level weighting structure for the conceptual framework.

Requirement	Weight	Theoretical Justification
Environmental Sustainability	0.30	Reflects the fundamental role of courtyards in passive environmental regulation, thermal comfort enhancement, daylight optimization, and natural ventilation.
Biophilic Integration Quality	0.30	Captures the degree of human–nature integration through vegetation, water, sensory experiences, and ecological engagement.
Human Well-Being	0.25	Represents restorative, psychological, emotional, and socio-spatial benefits generated by courtyard–biophilic environments.
Functional Resilience	0.15	Evaluates adaptability, spatial connectivity, and long-term usability supporting sustainable performance over time.
Total	1.00	—

For illustrative purposes, Environmental Sustainability is provisionally assigned a weight of (0.30) because environmental regulation constitutes the historical and functional foundation of courtyard architecture. Across diverse climatic contexts, courtyards have traditionally served as passive environmental systems that improve thermal comfort, facilitate natural ventilation, optimize daylight penetration, and reduce dependence on mechanical conditioning systems. Extensive research has demonstrated the significant contribution of courtyard configurations to energy efficiency and microclimatic regulation in hot-arid and Mediterranean regions [8,10,53]. Consequently, environmental performance remains a primary determinant of courtyard effectiveness within sustainable architectural design.

Biophilic Integration Quality receives an equivalent weight (0.30) due to the growing recognition that sustainability extends beyond environmental efficiency to encompass meaningful human–nature relationships. Contemporary biophilic design theory emphasizes the integration of natural elements, processes, and experiences within the built environment as a means of enhancing both ecological awareness and occupant well-being. Evidence suggests that environments characterized by strong visual, sensory, and ecological connections with nature can generate substantial benefits for health, cognitive performance, and environmental satisfaction [4,47,50]. Given that courtyards frequently function as primary interfaces between occupants and natural systems, biophilic quality represents a core dimension of the proposed framework.

Human Well-Being is assigned a weight of 0.25 to acknowledge the central role of architecture in supporting psychological restoration, emotional comfort, and positive user experiences. Research within environmental psychology has consistently demonstrated that exposure to natural environments contributes to stress reduction, attentional recovery, emotional regulation, and enhanced quality of life [46,48,54]. In courtyard environments, these outcomes are often reinforced through opportunities for social interaction, place attachment, and restorative engagement with nature. Although many of these benefits are mediated by environmental and biophilic conditions, their significance justifies their treatment as a distinct assessment requirement.

Functional Resilience receives a weight of 0.15. While functional attributes such as spatial connectivity, adaptability, and multi-functional capacity may not directly generate environmental or psychological benefits, they strongly influence the long-term usability, flexibility, and operational effectiveness of courtyard spaces. Contemporary resilience literature highlights the importance of adaptable spatial configurations capable of accommodating changing user needs and evolving patterns of occupancy [55–57]. Accordingly, functional resilience serves as an enabling dimension that supports the sustained performance of courtyard–biophilic environments over time.

7.3. Criteria-Level Weighting

Following the allocation of requirement-level weights, individual weights are assigned to the criteria within each requirement. This second hierarchical level reflects the relative contribution of each criterion to achieving the broader sustainability objective represented by its parent requirement. In accordance with the MIVES methodology, criterion weights are normalized within each requirement so that their total equals 1.0. For a requirement containing n criteria: Criterion normalization

$$\sum C_j = 1 \quad (2)$$

represents the weight assigned to criterion j .

Criterion Level

Environmental Sustainability: $(C1 + C2) = 0.60 + 0.40 = 1.00$

Biophilic Integration Quality: $(C3 + C4) = 0.40 + 0.60 = 1.00$

Human Well-Being: $(C5 + C6) = 0.70 + 0.30 = 1.00$

Functional Resilience: $(C7) = 1.00$

The proposed criterion weights were derived through a synthesis of the courtyard sustainability, biophilic design, environmental psychology, and resilience literature. Criteria receiving greater empirical and theoretical support within the literature were assigned relatively higher weights, reflecting their stronger influence on courtyard–biophilic integration performance.

This hierarchical normalization ensures mathematical consistency throughout the assessment structure while maintaining transparency in the aggregation process. As with the requirement-level weights, the proposed criterion weights should be considered preliminary values intended for future validation through other different ways.

7.4. Indicator-Level Weights

At the lowest level of the hierarchy, individual indicators are assigned weights according to their relative contribution to the achievement of each criterion. Indicator weighting represents a critical stage within the MIVES methodology because it determines the influence of measurable variables on the final assessment outcome.

The proposed framework comprises sixteen indicators distributed across seven criteria and four overarching requirements. These indicators were identified through a systematic synthesis of the literature on sustainable courtyard design, biophilic architecture, environmental performance, human well-being, and adaptive architectural systems. Each indicator was selected based on three conditions: (1) theoretical relevance, (2) measurability, and (3) applicability across different architectural contexts.

For each criterion, the sum of indicator weights equals unity: $\sum I_k = 1.00$, where I_k = indicator weight

This normalization ensures that no individual indicator disproportionately influences criterion performance and preserves the hierarchical consistency of the MIVES structure.

7.5. Aggregation Procedure

Following MIVES principles, raw indicator measurements are first transformed into dimensionless values ranging from 0 to 1 through the corresponding value functions. These normalized values are subsequently aggregated using a hierarchical bottom-up procedure.

The aggregation process follows four sequential levels:

After transforming indicator measurements into normalized values through the corresponding MIVES value functions, the overall framework score is calculated through weighted aggregation:

$$ISI = \sum_{i=1}^{16} (W_i \times V_i) \quad (3)$$

where ISI = Integration Sustainability Index, W_i = indicator weight, V_i = normalized indicator value

Finally, the overall performance of courtyard–biophilic integration is obtained by aggregating the requirement scores according to their respective weights.

7.6. Integration Sustainability Index (ISI)

The final output of the proposed framework is the Integration Sustainability Index (ISI), which expresses the overall degree of courtyard–biophilic integration achieved by a design alternative.

Higher values indicate stronger integration between courtyard design strategies, biophilic attributes, environmental performance, human well-being outcomes, and functional resilience characteristics.

For interpretative purposes, the following performance classification is proposed as shown in Table 8:

Table 8. Performance classification levels.

ISI Range	Performance Level	Interpretation
0.00–0.20	Very Low	Severe biophilic detachment; critical failure in microclimatic modification; space functions as a sterile thermal void.
0.21–0.40	Low	Superficial or decorative landscaping; negligible contribution to building thermodynamics or human psychological restoration.
0.41–0.60	Moderate	Baseline compliance; localized passive cooling or active vegetation present but lacks topological connectivity or holistic sensory integration.
0.61–0.80	High	Robust socio-ecological integration; demonstrable microclimatic optimization aligned with strong biophilic pattern density and space syntax connectivity.
0.81–1.00	Very High	Regenerative paradigm performance; complete systemic synergy between passive thermodynamic physics, ecosystem support, and cognitive restorative mechanics.

This classification is intended as an initial interpretative guide and should be calibrated through future empirical validation involving expert assessment, case-study applications, and sensitivity analyses.

7.7. Sensitivity Analysis and Future Validation

As with all multi-criteria assessment models, the weighting structure proposed in this framework shown in Table 9 involves a degree of expert judgment. Consequently, future empirical applications should incorporate sensitivity analyses to evaluate the stability of the results under alternative weighting scenarios and to identify indicators exerting the greatest influence on overall performance.

Table 9. Proposed Criterion Weights within the MIVES Framework.

Requirement	Criterion	Local Weight
Environmental Integration	Climatic Performance	0.60
Environmental Integration	Ecological Integration	0.40
Biophilic Quality	Nature Presence	0.40
Biophilic Quality	Nature Experience	0.60
Human Well-Being	Psychological Restoration	0.70
Human Well-Being	Social Interaction	0.30
Functional Resilience	Accessibility and Adaptability	1.00

The weighting structure presented in this study should therefore be regarded as a theoretically informed starting point rather than a definitive representation of stakeholder

priorities. In addition, empirical validation using real-world case studies is required to assess the robustness, transferability, and practical applicability of the proposed framework across different climatic conditions, building typologies, and socio-cultural contexts. Given the diversity of courtyard typologies worldwide, future empirical validation should examine the framework across different climatic and cultural contexts to evaluate its transferability and contextual sensitivity.

To ensure mathematical consistency, weights are normalized at each hierarchical level such that the sum of weights within every branch equal unity: $W = 1$

This normalization guarantees proportional contribution of all requirements, criteria, and indicators throughout the aggregation process.

7.8. ISI Calculation and Formulation

Following MIVES principles, each indicator is transformed into a normalized value through its corresponding value function. The overall level of courtyard–biophilic integration is then calculated using weighted aggregation: $0 \leq ISI \leq 1$ where (ISI) = Integration Sustainability Index, (W_i) = global weight assigned to indicator (i), (V_i) = normalized indicator value, (16) = total number of indicators

The resulting score ranges from 0 to 1

Higher values indicate stronger integration between courtyard design strategies, biophilic qualities, environmental performance, human well-being outcomes, and functional resilience.

These thresholds are proposed for conceptual interpretation and should be calibrated through future empirical testing and expert validation.

7.9. Limitations of the Proposed Framework

The proposed framework represents a conceptual synthesis of knowledge derived from sustainable architecture, courtyard design, biophilic design, and MIVES-based sustainability assessment. Although the framework provides a structured basis for evaluating courtyard–biophilic integration, it has not yet undergone empirical validation through expert consensus procedures, case-study implementation, or statistical testing. Consequently, the proposed indicators, value functions, weighting structure, and aggregation procedures should be interpreted as preliminary and illustrative rather than definitive. Future studies are required to verify indicator relevance, evaluate weighting reliability, assess indicator interdependencies, and test framework robustness across different climatic, cultural, and building contexts.

8. Future Empirical Application

The framework developed in this study establishes a conceptual foundation for assessing courtyard–biophilic integration within sustainable architecture. Future research should focus on empirical validation through real-world case studies encompassing different building typologies, climatic conditions, and cultural contexts.

A first stage of validation may involve expert assessment of the proposed hierarchy, indicators, and weighting structure using Delphi or AHP-based procedures. A second stage may evaluate the relationship between framework scores and actual building performance outcomes through environmental simulations, post-occupancy evaluations, and user-based well-being assessments.

Further investigations may also explore regional calibration of indicator thresholds and value functions to accommodate climatic and socio-cultural variations while preserving methodological consistency. Through such iterative refinement, the proposed framework can evolve from a conceptual model into a robust decision-support tool for sustainable and biophilic architectural design.

For Indicator Level each criterion distributes its weight among its indicators so that: $\sum w_i = 1$ within each criterion.

At this conceptual stage, the proposed weights are intended as illustrative values derived from theoretical priorities identified in the literature on sustainable architecture, courtyard performance, and biophilic design. The selection of a weighting method is not trivial. While AHP remains the most widely adopted approach in MIVES-related studies due to its transparency and ease of implementation, several researchers have argued that Delphi-based consensus procedures may better capture interdisciplinary judgments when environmental, social, and architectural dimensions interact simultaneously. Consequently, the final weighting structure should be viewed as a hypothesis requiring validation rather than a definitive representation of stakeholder priorities.

Following MIVES principles, each indicator is transformed into a normalized value through its corresponding value function. The framework is intended as a decision-support model rather than a prescriptive design tool. The overall performance score is then obtained through weighted aggregation:

$$ISI = \sum_{i=1}^n (W_i \times V_i) \quad (4)$$

where ISI = Integration Sustainability Index, (W_i) Weight assigned to indicator (i), (V_i) Normalized value obtained from the indicator value function, (n) Total number of indicators. The resulting index ranges from: $0 \leq ISI \leq 1$.

The framework is intended to provide a foundation for future empirical implementation in courtyard-based architectural projects. Subsequent studies may apply the proposed assessment structure to residential, educational, healthcare, or mixed-use courtyard environments to evaluate indicator performance, calibrate weighting schemes, and examine contextual variations across climatic and cultural settings. Such applications will contribute to refining the framework and establishing its practical utility for design evaluation and decision-making.

9. Conclusions

This study has proposed a novel MIVES-based multi-criteria framework for assessing the integration of courtyard design and biophilic principles within sustainable architecture. Although both courtyards and biophilic design have independently attracted considerable scholarly attention, existing research has rarely examined their interaction through a unified assessment methodology. Designers and researchers currently lack a systematic mechanism for evaluating the extent to which courtyard environments simultaneously support environmental performance, human well-being, ecological value, and socio-cultural sustainability.

Through a critical synthesis of the literature, the study identified key theoretical relationships linking traditional courtyard architecture with contemporary biophilic design principles. The review demonstrated that courtyards possess inherent characteristics that align closely with biophilic objectives, including visual and physical access to nature, environmental moderation, sensory engagement, and opportunities for social interaction. Nevertheless, the absence of an integrated assessment framework has limited the ability to quantify and compare the performance of courtyard–biophilic environments in a consistent manner.

To address this gap, the study developed a hierarchical MIVES value tree comprising sustainability requirements, criteria, and measurable indicators. The framework further incorporated value functions capable of representing different performance behaviours, including linear, concave, convex, and S-shaped relationships. This approach acknowledges that sustainability value is rarely generated through simple proportional relationships and instead reflects the complexity of environmental and human responses within architectural settings.

In addition, a weighting and aggregation structure was proposed to facilitate the calculation of a comprehensive Integration Sustainability Index (ISI). By transforming heterogeneous performance indicators into a unified value scale, the framework provides a transparent and adaptable mechanism for evaluating courtyard–biophilic integration across diverse building typologies and geographical contexts. Importantly, the proposed model accommodates both quantitative and qualitative indicators, thereby recognizing the multidimensional nature of sustainable architectural performance.

The contribution extends beyond the development of a multi-criteria assessment structure. The proposed framework seeks to bridge the longstanding divide between performance-oriented sustainability assessment and human-centered architectural evaluation. By integrating environmental performance, biophilic quality, psychological restoration, social value, and functional resilience within a unified framework, the study advances a more comprehensive interpretation of sustainable architectural quality.

From a practical perspective, the proposed framework offers architects, planners, researchers, and policymakers a structured methodology for guiding future design decisions. It provides a foundation for identifying strengths and weaknesses within courtyard environments and supports the development of design strategies that balance environmental efficiency with human and ecological well-being.

Nevertheless, the study remains conceptual in nature. The proposed value functions, indicator weights, and performance thresholds have not yet been empirically validated. Future research should therefore focus on expert evaluation, case-study applications, and post-occupancy investigations to refine the framework and verify its applicability under real-world conditions.

In conclusion, the integration of courtyard design and biophilic principles represents a promising pathway toward more regenerative, human-centred, and sustainable built environments. By introducing a structured MIVES-based assessment methodology, this study contributes a theoretical and methodological foundation that may support future research, facilitate evidence-based design practice, and advance the broader discourse on sustainability in architecture. The proposed framework provides a systematic basis for assessing courtyard–biophilic integration in sustainable architecture. Future research should validate the model through case studies and expert calibration.

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Abbreviations

The following abbreviations are used in this manuscript:

MIVES	Integrated Value Model for Sustainability Assessment
ISI	Integration Sustainability Index
MCDM	Multi-Criteria Decision Making

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