

# A Bio-Cultural Biomimetic Framework for Climate-Responsive Building Envelopes in Hot and Arid Environments: Integrating Biological Mechanisms and Saoura Vernacular Knowledge

**Mohammed Mourni<sup>1\*</sup>**

**Widad Ratiba Biara<sup>2</sup>**

<sup>1</sup>Department of Architecture, Faculty of Science and Technology, Laboratory of Architecture and Environmental Heritage (ARCHIPEL), Tahri Mohamed University of Béchar, Béchar, Algeria

\*Corresponding author: [mourni.mohammed@univ-bechar.dz](mailto:mourni.mohammed@univ-bechar.dz) | ORCID: 0000-0001-6915-396X

<sup>2</sup>Department of Architecture, Faculty of Science and Technology, Tahri Mohamed University of Béchar, Béchar, Algeria. [biara.wided@univ-bechar.dz](mailto:biara.wided@univ-bechar.dz) | ORCID: 0000-0001-6682-2021

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## ABSTRACT

Building envelopes in hot-arid climates are often labelled biomimetic on the basis of formal analogy, while source mechanisms, operating limits, and evaluation routes remain underreported. This conceptual study develops and illustratively applies a framework for combining biological evidence with situated knowledge from the Saoura region of Algeria. An illustrative purposive evidence sample connects biomimetic design methods, climate-responsive envelopes, four biological source systems, and Saoura vernacular architecture. The Desert Biomimicry Model (DBM) stores linked source records, while the Desert Biomimetic Design Logic (DBDL) guides Observation, Abstraction, context-gate decision, Application, and feedback. An author-developed Function–Form–Process–Environment/context (FFPE) schema separates documented claims from interpretation. Persistent identifiers link source records (SR), abstracted rules (AR), propositions (P), and prospective evaluation specifications (ES); the matrices also record an accept, modify, defer, or reject decision for each transfer. The analysis corrects common simplifications: beetle fog collection is treated as a taxon-bounded behavioural and fluid-mechanical process; cactus self-shading remains an architectural hypothesis; and termite ventilation is species- and context-dependent. Retrospective mapping of Eastgate Centre and Saoura ksour illustrates descriptive fit only. The distinctive combination, within the methods examined, is a bio-cultural translation and reporting structure that exposes provenance type, assumptions, boundary conditions, and tests still required. No numerical performance benefit is claimed; studies with independent users, simulation, prototyping, and field monitoring remain necessary.

## 1 Introduction

Buildings in hot-arid regions must moderate intense solar exposure, high daytime temperatures, large diurnal temperature ranges, low and irregular rainfall, and dust-laden winds. The envelope is the principal boundary across which heat, air, and moisture are exchanged and through which solar radiation and daylight are transmitted. Mechanical cooling can reduce heat stress, but sole dependence on active systems increases operational energy demand and exposes occupants to service interruption and rising cooling loads. Climate-responsive envelopes therefore need passive and controllable strategies whose operation can be explained, parameterised, and tested under local conditions (Andreeva et al., 2022; Cuce & Cuce, 2025; Kuru et al., 2019).

Biomimicry offers one route to such strategies by transferring knowledge from biological systems to design. The field has moved beyond the literal imitation of natural appearance toward the study of functions, processes, materials, and relationships between organisms and their environments (Benyus, 1997; Ilieva et al., 2022; Verbrugghe et al., 2023). ISO 18458:2015 also distinguishes broad biological inspiration from a biomimetic development process and cautions that biomimetics is not inherently equivalent to sustainability. In architecture, this distinction matters because a facade can resemble an organism without reproducing the relation that makes a biological feature effective, and it can reproduce one relation while creating new energy, material, maintenance, or social burdens at building scale (International Organization for Standardization [ISO], 2015; Wagermaier et al., 2025).

The principal methodological difficulty is translation. A biological feature operates at a particular scale, in a particular material system, and under particular boundary conditions. Removing it from that system can change or eliminate the causal relation of interest. Function-centred abstraction helps different disciplines communicate, yet function alone is insufficient unless the relevant form, operating process, and environmental context are retained (Ng et al., 2021; Snell-Rood & Smirnoff, 2023). Recent guidance also calls for transparent reporting of the biological source, level of mimicry, and evidential basis so that inspiration is not mistaken for biological information (Harvey, 2026). These concerns are especially important in architectural publications, where iconic analogies may circulate more widely than the primary biological evidence on which they are presumed to rest.

A second difficulty is contextual translation. General biomimetic methods typically begin with either a technical challenge or a biological solution and then move through search, abstraction, and application (Fayemi et al., 2017; Helms et al., 2009; Linder & Huang, 2025). Digital repositories and structured team tools improve documentation and interdisciplinary exchange (Graeff et al., 2021). Sustainability-oriented frameworks add ecological criteria, while methods for multifunctional design coordinate several biological functions or domains (Ilieva et al., 2022; Velivela & Zhao, 2022). These contributions provide a strong foundation, but their cited presentations do not explicitly combine claim-level provenance, a vernacular accept–modify–defer–reject decision, and a prospective envelope evaluation specification in one linked record.

The Saoura Valley in south-western Algeria provides an appropriate context for examining this combination. Its ksour embody accumulated responses to heat, solar exposure, scarce resources, and social practice through compact settlement morphology, shaded circulation, courtyards, controlled openings, and massive earthen construction. These relations occur across settlement, building, envelope, and occupation scales; they are not reducible to a single facade motif. Evidence from studies in Béchar and from monitored adobe buildings elsewhere in southern Algeria supports treating such architecture as situated environmental evidence, without transferring numerical results between sites (Bassoud et al., 2021; Benslimane et al., 2020; Khoukhi & Fezzioui, 2012; Ouahchi et al., 2025). Vernacular architecture is not biological evidence and should not be retrospectively described as biomimetic. It is instead a distinct knowledge domain produced through culturally transmitted construction, use, repair, and adaptation. In this article, bio-cultural denotes coordination between biological abstraction and this independent cultural evidence; it does not imply that vernacular knowledge is biological. The Saoura record supplies local criteria that can accept, modify, defer, or reject a biologically derived idea.

This article asks: how can mechanism-level biological evidence and situated knowledge from Saoura ksour be combined without conflating their origins and translated into testable building-envelope propositions? To answer this question, the article refines a two-part Desert Biomimicry Framework. The

Desert Biomimicry Model (DBM) is a knowledge structure for source records. The Desert Biomimetic Design Logic (DBDL) is the linked decision sequence through which a project moves through Observation, Abstraction, context decision, and Application, with feedback from evaluation. Within that sequence, Function–Form–Process–Environment/context (FFPE) is introduced explicitly as an author-developed coding schema rather than an established external standard.

The article makes three bounded contributions. First, it positions DBM–DBDL against selected established biomimetic methods and identifies a distinctive combination within those methods: claim-level provenance plus a formal bio-cultural context decision. Second, persistent SR–AR–P–ES identifiers connect source evidence, abstraction, proposition, and prospective evaluation so that interpretive steps are visible. Third, the framework is illustrated through four biological systems, a Saoura vernacular record, a worked envelope assembly, and a retrospective comparison of Eastgate Centre and Saoura ksour. The article does not report simulation, experimental, survey, or field-monitoring results. The term “climate-responsive” therefore denotes a design intent to respond to climatic conditions through passive, manual, or future automated operation; it is not evidence that the proposition performs effectively.

## **2 Research Design and Evidence Synthesis**

### **2.1 Study design and scope**

The study follows a conceptual framework-development design informed by theory synthesis: concepts from biomimetic design, biological mechanism research, adaptive-envelope studies, and vernacular environmental knowledge are integrated to solve a clearly specified translation problem (Jaakkola, 2020). General design-science guidance on transparency also informed the separation of problem framing, knowledge inputs, construction decisions, evaluation requirements, and claimed contribution (Hevner et al., 2024). The intended output is a method and reporting structure, not a causal estimate of building performance. The object of analysis is therefore a source-to-design relation: a documented environmental function, the configuration and process associated with it, the conditions under which it operates, an abstracted rule, a candidate architectural mapping, and the test needed to evaluate that mapping.

The framework is scoped to building envelopes in hot-arid environments and to five illustrative knowledge records: dromedary heat tolerance, fog collection studied in selected Namib darkling beetles, ribbed cactus morphology, exchange in selected termite-mound systems, and Saoura ksour. The taxa do not all occupy identical climates, and the term desert in the framework name describes the architectural problem context rather than a universal ecological classification of every biological source. The set exposes different translation problems—physiological integration, behaviour and fluid mechanics, form and heat transfer, taxon-dependent network processes, and culturally embedded multiscale practice. It is not a comprehensive taxonomy of desert adaptation. Transfer to another climate would require rebuilding the source records and redefining boundary conditions and performance objectives.

### **2.2 Evidence identification, selection, and status**

An illustrative purposive evidence sample was assembled across five domains: biomimetic terminology and design processes; reporting and interdisciplinary translation; adaptive and ventilated envelopes; biological studies and recent syntheses for the selected systems; and peer-reviewed studies of Algerian hot-arid vernacular architecture. In September 2026, sources were identified and checked through targeted scholarly-web searches, DOI/Crossref metadata, publisher pages, and backward citation checking. Representative search concepts combined biomimetic design method/reporting, adaptive or ventilated facade, dromedary thermoregulation, Namib beetle fog-basking/aerosol capture, Cactaceae ribs thermal radiation, termite mound ventilation, and Algeria vernacular thermal comfort. Searches used English terms; no date cutoff was applied because recent syntheses were paired with foundational primary studies.

The final bibliography contains 41 retained sources: 38 DOI-linked journal articles, one standard webpage, and two books or book chapters. No candidate-source count, duplicate-removal log, formal exclusion flow, or independent second screener/coder was retained. The sample therefore cannot be reproduced or appraised as a systematic review, and it is used only to illustrate the record structure and

translation logic. Bibliographic verification is not a substitute for a formal risk-of-bias or evidence-quality appraisal.

A source was retained when it met at least one of three criteria: it documented a biological or vernacular relation relevant to heat, solar exposure, airflow, moisture, or resource use; it provided an explicit biomimetic design or reporting method; or it described an existing envelope or settlement precedent used in the illustration. Primary peer-reviewed evidence was preferred for biological mechanisms. Reviews were used to establish current interpretation and uncertainty, while books and standards were used for canonical concepts or process definitions. Popular descriptions were not used to support mechanistic or numerical claims. When later primary research qualified an influential earlier explanation, both the historical account and the qualification were recorded.

Claim-level provenance tags separate unlike forms of knowledge. B1 denotes primary biological empirical or mechanistic evidence; B2 denotes a peer-reviewed biological synthesis or measurement guideline; V1 denotes an empirical or analytical vernacular-building study; V2 denotes a peer-reviewed synthesis of vernacular studies; C denotes a published contemporary built-precedent account; and P denotes an author-generated abstraction or architectural proposition. These tags identify origin and evidence type, not methodological quality or strength. A P statement cannot inherit a B1, B2, V1, V2, or C tag. This separation is consistent with calls for explicit provenance and biological-evidence reporting (Harvey, 2026; Ng et al., 2021), and prevents evidence about a source or existing building from being treated as proof that a new facade will behave similarly.

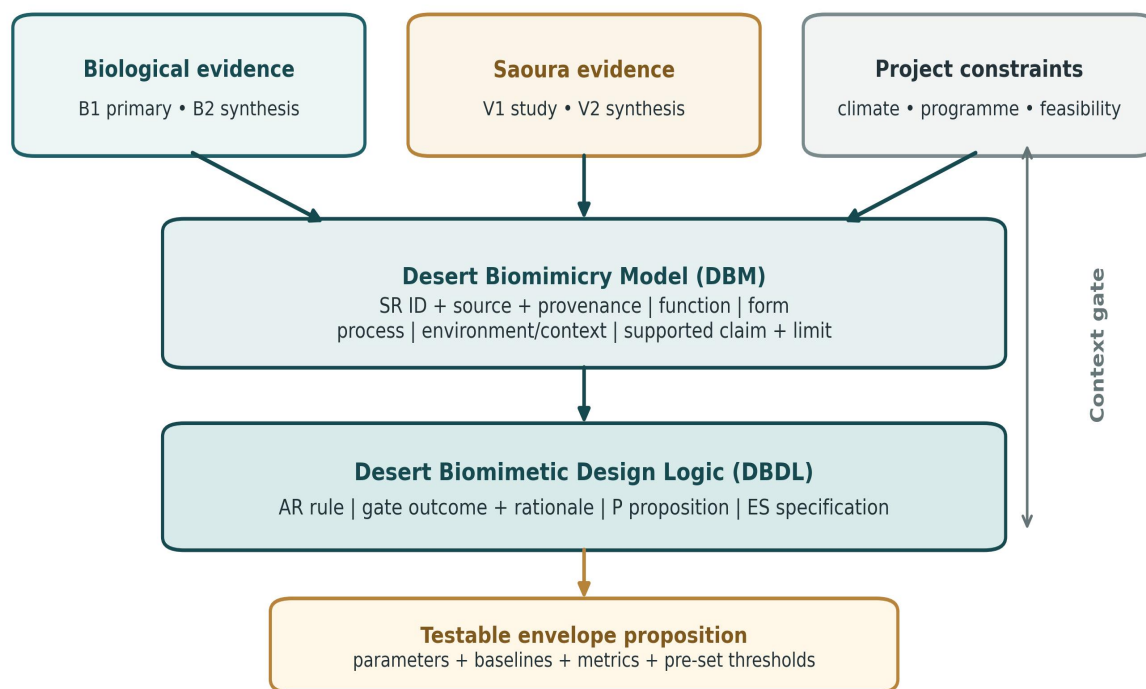
### 2.3 Framework construction and analytical protocol

Framework construction proceeded in seven operations. (1) Define a project-level environmental challenge at the envelope boundary. (2) Identify a potentially relevant biological or vernacular source. (3) Create a source record (SR) with six canonical fields: source identity and claim-level provenance; function; relevant form; operating process; environment/context and scale; and supported claim plus uncertainty. (4) Create a linked source-independent abstracted rule (AR) only after enabling conditions are recorded. (5) Apply a Saoura context gate and record one outcome—accept, modify, defer, or reject—with a rationale grounded in local climate, materials, construction capacity, occupation, maintenance, and cultural practice. (6) Map an accepted or modified AR to a proposition (P) with specifiable variables. (7) Link P to a prospective evaluation specification (ES) containing inputs, boundaries, comparators, metrics, and project-specific thresholds to be set before testing.

The FFPE schema structures four of the SR fields. Function states the environmental role. Form records the material, geometry, or spatial organisation relevant to that role. Process describes how the effect is produced over time, including flows, state changes, and interactions. Environment/context records the climatic, ecological, behavioural, or cultural conditions that enable or limit the process; the term replaces the broader and potentially ambiguous field label Ecosystem. FFPE is an author-developed coding schema assembled from function-centred, mechanism-sensitive, and contextual principles in the biomimetic literature; it is not a previously standardised framework (Gerola et al., 2023; Graeff et al., 2021; Snell-Rood & Smirnov, 2023). Its explicit definition makes the coding rule available for future inter-coder testing.

The DBM stores the six-field SR records in Table 2. The DBDL creates and links the AR, context-decision, P, and ES records in Tables 3 and 4. The two structures are connected but not interchangeable: a knowledge record does not decide whether a transfer is locally appropriate, and a decision sequence cannot operate without a documented source. Figure 1 reproduces these canonical fields and identifiers.

Figure 1. Knowledge architecture of the Desert Biomimicry Framework



Source: Authors' elaboration, 2026.

## 2.4 Illustration logic and evaluation boundary

The framework is illustrated at three levels. First, five knowledge sources are coded as SR1–SR5. Second, each SR is linked to an AR, a recorded Saoura-gate outcome, a P, and an ES. Third, the provisionally accepted or modified propositions are assembled as a worked multilayer envelope concept. The identifier chain exposes where assumptions enter; it does not establish coding reliability, usability, or environmental effectiveness. The atmospheric-water proposition is rejected from the core assembly and retained only as a deferred option until local fog liquid water content, droplet size, wind, seasonality, water quality, and maintenance feasibility are established.

A separate retrospective comparison applied the same fields to Eastgate Centre in Harare and Saoura ksour. These cases were not designed using DBDL. Eastgate was included because it is widely narrated as a termite-related precedent, while the ksour represent culturally accumulated environmental knowledge. The comparison asks whether the protocol can describe unlike knowledge trajectories without erasing their differences. It is not a reconstruction of either design history, an experiment, or a numerical comparison. Any performance value reported for a precedent remains attached to that case and cannot be transferred to the worked envelope.

## 3 Framework and Illustrative Application

### 3.1 Positioning and bounded contribution

Comparison with selected existing methods shows that the contribution does not reside in using biology, moving through problem- and solution-driven pathways, or combining biomimicry with contextual knowledge in a broad sense. Those ideas are established. Within the methods examined, the distinctive combination is an operational chain for hot-arid envelope research: DBM separates the source record from the DBDL decision record; FFPE retains mechanism and environment/context; claim-level tags identify provenance without implying quality; the Saoura gate records an accept–modify–defer–reject outcome; and the prospective ES prevents an untested proposition from being labelled validated. Table 1 states this bounded comparison without claiming field-wide novelty or universal priority.

**Table 1. Positioning of DBM–DBDL relative to established biomimetic approaches**

| Approach                                            | Core design logic                                                   | Principal strength                                                                  | Distinctive addition examined here                                                            |
|-----------------------------------------------------|---------------------------------------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| ISO 18458:2015                                      | General biomimetic terminology and development process              | Common vocabulary; distinguishes biomimetics from generic inspiration               | Adds a hot-arid architectural record and a vernacular context decision                        |
| Biologically Inspired Design (Helms et al., 2009)   | Problem-driven and solution-driven iterative pathways               | Makes problem formulation, biological search, abstraction, and application explicit | Adds claim-level provenance and a locally recorded gate outcome                               |
| Process-and-tools synthesis (Fayemi et al., 2017)   | Comparison of recurring biomimetic stages and tools                 | Clarifies process families and support needs                                        | Adds an envelope-specific prospective evaluation specification                                |
| Linkage (Graeff et al., 2021)                       | Digital interdisciplinary source, analysis, and abstraction records | Strong traceability and team communication                                          | The present framework adds a Saoura gate, architectural evidence tags, and test specification |
| Biomimicry for Sustainability (Ilieva et al., 2022) | Biomimetic ideation integrated with sustainability considerations   | Connects biomimicry to explicit sustainability intent                               | Narrows the record to mechanism, local context, and propositions linked to future tests       |
| Design process framework (Linder & Huang, 2025)     | Explicit Challenge-to-Biology and Biology-to-Design moves           | Makes abstraction and design moves teachable and reviewable                         | Adds provenance tags and bio-cultural accept–modify–defer–reject decisions                    |
| DBM–DBDL (this study)                               | SR knowledge records + linked AR–P–ES decision records              | Inspectable source-to-test chain for hot-arid envelopes                             | Requires validation by independent users and performance testing; it is not predictive        |

*Source: Authors' comparison based on ISO (2015), Helms et al. (2009), Fayemi et al. (2017), Graeff et al. (2021), Ilieva et al. (2022), Verbrugghe et al. (2023), and Linder and Huang (2025).*

The comparison also identifies proximity to recent multifunctional and domain-integrated methods (Velivela & Zhao, 2022). DBM–DBDL does not replace those approaches. Its narrower purpose is to control provenance, environmental boundary conditions, and local architectural translation. It can therefore be used upstream of computational optimisation or alongside a multifunctional method, provided that each objective and trade-off is separately defined.

### 3.2 Desert Biomimicry Model: knowledge structure

Each DBM source record uses the six fields defined in Section 2.3 and reproduced in Table 2: (1) SR identifier, source identity, citation, and claim-level provenance; (2) function; (3) relevant form; (4) operating process; (5) environment/context and scale; and (6) supported claim plus uncertainty. Rules, design decisions, and tests are not DBM fields; they belong to the linked DBDL decision record. This separation allows contradictory source claims to remain visible. For example, an influential account proposed patterned wettability for beetle water capture, whereas later behavioural evidence did not establish that feature as universal. The present abstraction therefore privileges exposure, stance, impaction, coalescence, and drainage while retaining the earlier claim as historical context (Nørgaard & Dacke, 2010; Parker & Lawrence, 2001; Shahrokhian et al., 2024).

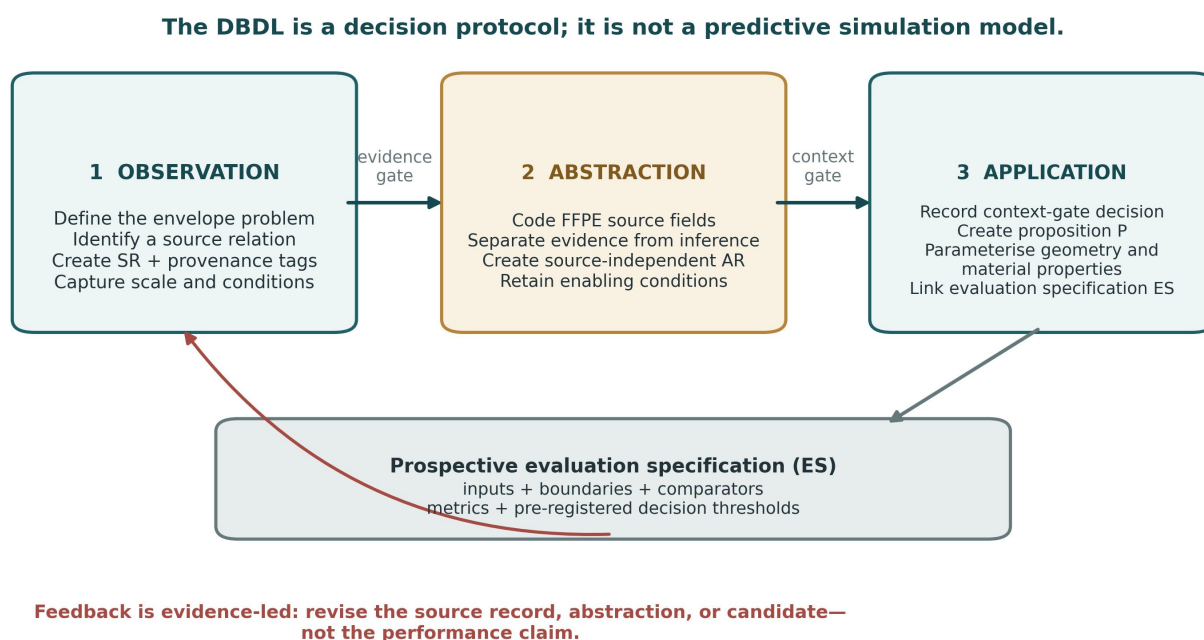
The biological and vernacular pathways remain distinct. SR1–SR4 pass through the biological evidence gate before abstraction. SR5 records Saoura relations with V1/V2 provenance and populates the local criteria used at the context gate; it is not treated as an organism or as proof of a biological mechanism. Each AR is checked against compactness and mutual shading at settlement scale; courtyards and circulation at building scale; mass, openings, and exposure at envelope scale; and operation, repair, water use, and seasonal practice at social scale. The decision record in Table 3 states accept, modify, defer, or reject and gives a rationale. Strong source evidence cannot override an incompatible local condition.

### 3.3 Desert Biomimetic Design Logic: operational workflow

The DBDL begins with an envelope problem rather than with a preferred organism. Observation specifies the climatic variable, building boundary, spatial and temporal scale, user requirement, and baseline condition. A source is recorded only when a relevant relation can be supported. The biological evidence gate asks whether an SR contains enough mechanistic and contextual information for abstraction. A striking form without a defensible process remains inspiration and does not progress as a bio-informed mechanism.

Abstraction converts the source relation into an AR that no longer depends on the source's appearance but retains variables and enabling conditions. The Saoura gate then records an explicit outcome and rationale. Application maps an accepted or modified AR to a P and assigns variables, materials, control states, and interfaces. The linked ES is a template rather than a completed test contract: it identifies comparators and metrics, but numerical or categorical acceptance thresholds must be selected and pre-registered for a defined site and brief before testing. Feedback may return to any earlier record when testing reveals a false assumption, unsuitable source, or functional conflict. Figure 2 presents this workflow; DBDL denotes Desert Biomimetic Design Logic.

*Figure 2. Operational workflow of the Desert Biomimetic Design Logic*



*Source: Authors' elaboration, 2026.*

### 3.4 Source mechanisms and FFPE evidence matrix

Table 2 applies the six-field SR schema and limits each inference to the taxa and conditions studied. Dromedary heat tolerance in *Camelus dromedarius* combines coat, physiology, hydration state, behaviour, and temporal heat storage. Nørgaard and Dacke (2010) compared *Onymacris unguicularis*, *O. laeviceps*, *Stenocara gracilipes*, and *Physasteria cribripes*; their taxon-specific results caution against a generic 'Namib beetle' mechanism. Cactus evidence concerns *Ferocactus acanthodes* and selected Cactaceae, not every ribbed succulent. The termite studies address *Odontotermes obesus*, *Macrotermes michaelseni*, and *Trinervitermes geminatus* in different climates and nest types; they do not establish one universal stack (Karibi-Botoye et al., 2025; King et al., 2015; Ocko et al., 2017; Singh et al., 2019).

Table 2. Source evidence and author-developed FFPE coding matrix

| ID, source, and claim provenance                                                                                                                                                                           | Function                                                                                            | Relevant form                                                                             | Operating process                                                                                                                              | Environment / context and scale                                                                     | Supported claim / limit                                                                                   |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| SR1 — <i>Camelus dromedarius</i> . B1: Bouâouda et al. (2014); Schmidt-Nielsen et al. (1957). B2: Tibary and El Allali (2020)                                                                              | Limit external heat gain and conserve water while maintaining body temperature within viable limits | Coat above skin; large body mass; integrated physiological and behavioural system         | Coat resists external heat gain; with heat and dehydration, state-dependent heterothermy can store sensible heat and delay evaporative cooling | Strong radiation; scarce water; hydration-dependent response; organism scale; day-night cycle       | Coupled animal response documented; no single envelope layer reproduces camel physiology                  |
| SR2 — Selected Namib Tenebrionidae. B1: Nørgaard and Dacke (2010); Shahrokhian et al. (2024)                                                                                                               | Collect liquid water from fog                                                                       | Wind-exposed curved dorsal geometry; surface; drainage path; head-down stance             | Droplet impaction, coalescence, and gravity transport; geometry affects low-inertia aerosol capture                                            | Fog liquid water content and droplet size; wind; orientation; contamination; organism/test geometry | Behaviour and capture physics documented in specified taxa/models; patterned wettability is not universal |
| SR3 — <i>Ferocactus acanthodes</i> and selected Cactaceae. B1: Lewis and Nobel (1977); Mauseth (2000); Nobel (1980). B2: Mauseth (2006); Paredes Cubas et al. (2025)                                       | Accommodate hydration-related stem-volume change; influence heat and radiation exchange             | Longitudinal ribs and furrows on succulent stems                                          | Folded geometry changes exposed area and facet orientation with hydration state and solar angle                                                | Pulse rainfall; drought; irradiance; wind; taxon-specific geometry; organism scale                  | Hydration and organism-scale exchange relations documented; facade self-shading remains untested          |
| SR4 — <i>Odontotermes obesus</i> , <i>Macrotermes michaelseni</i> , and <i>Trinervitermes geminatus</i> . B1: King et al. (2015); Ocko et al. (2017); Singh et al. (2019). B2: Karibi-Botoye et al. (2025) | Exchange respiratory gases, heat, and moisture                                                      | Taxon-specific flutes/channels, porous walls, and multiscale conduits                     | Buoyancy, wind pressure, diffusion, reversible thermal circulation, and drainage vary by nest                                                  | Taxon and colony load; porosity; geometry; solar forcing; wind; soil; humidity; nest scale          | Several mechanisms documented; neither one geometry nor a one-way stack is universal                      |
| SR5 — Saoura ksour. V1: Benslimane et al. (2020); Khoukhi and Fezzioui (2012). V2: Ouahchi et al. (2025)                                                                                                   | Moderate heat and solar exposure within local living practices and resource limits                  | Compact fabric; shaded routes; courtyards; controlled openings; massive earthen envelopes | Mutual shading, thermal lag, controlled exchange, occupation, repair, and seasonal adaptation interact                                         | Algerian hot-arid climate; settlement-to-social scales; craft; use; maintenance; resources          | Situated relations documented; not biological evidence and not a universal quantitative baseline          |

Source: Authors' illustrative synthesis from the cited studies. Tags identify provenance/type, not evidence quality: B1 = primary biological study; B2 = biological synthesis or guideline; V1 = vernacular empirical/analytical study; V2 = vernacular synthesis.

The matrix corrects two recurring simplifications. First, the four-taxon comparison found hydrophobic elytra and did not support bumpy topography as a general predictor of collection efficiency; *O. unguicularis* was the species observed adopting the characteristic fog-basking stance. Recent fluid-mechanical work further separates interception geometry from drainage (Nørgaard & Dacke, 2010;

Shahrokhian et al., 2024). Second, cactus ribbing is not reduced to self-shading. Energy-budget work associated ribbing in *F. acanthodes* with greater area for convective loss; rib-depth modelling showed an altered spatial distribution of intercepted radiation; and anatomical work relates ribs to hydration-driven volume change and surface-area-to-volume ratios (Lewis & Nobel, 1977; Mauseth, 2000, 2006; Nobel, 1980; Paredes Cubas et al., 2025). A folded shading screen is therefore an architectural abstraction requiring its own solar, daylight, airflow, and maintenance tests.

### 3.5 From source record to evaluation specification

Table 3 makes the decision chain explicit. Each biological SR links to a source-independent AR, a documented Saoura-gate outcome and rationale, an author-generated P, and a prospective ES. SR5 follows the vernacular pathway and supplies both a local proposition and gate criteria; it is never relabelled biological. Accept means that the rule may proceed unchanged to specification; modify means that only a bounded part proceeds; defer means that required local evidence is missing; and reject means that the candidate does not proceed in the stated project. These are design decisions, not measures of source quality or performance.

**Table 3. Linked source-to-rule-to-proposition decision matrix**

| Linked records | Abstracted rule                                                                                                    | Saoura gate: outcome and rationale                                                                                                        | Proposition                                                                                      | Evaluation link / current status                                                               |
|----------------|--------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| SR1 → AR1      | Coordinate a resistive external boundary with time-dependent heat storage; do not copy camel anatomy or physiology | MODIFY — retain resistance and time-lag aims; require separately specified, locally repairable layers; exclude physiological heterothermy | P1 — multilayer solar/thermal buffer with independently defined properties                       | ES1; analogy and mapping only; thermal benefit untested                                        |
| SR2 → AR2      | Coordinate wind exposure, interception geometry, coalescence, and gravity drainage                                 | REJECT FROM CORE / DEFER — no local fog-resource, water-quality, or maintenance record supports integration                               | P2 — optional directional fog-interception panel with separate drainage                          | ES2; outside the core assembly unless local feasibility thresholds are met                     |
| SR3 → AR3      | Use corrugation to vary exposed area, facet orientation, and exchange; do not assume facade self-shading           | MODIFY — retain folded geometry; take shade as a local objective; treat solar benefit as an architectural hypothesis                      | P3 — parameterised folded external screen                                                        | ES3; geometry defined conceptually; solar, daylight, airflow, structure, and cleaning untested |
| SR4 → AR4      | Organise exchange as a coupled, time-dependent network rather than a universal stack                               | MODIFY — test a controlled cavity network; reject literal mound geometry and universal flow direction; include dust and maintenance       | P4 — ventilated cavity with controlled inlets/outlets and differentiated thermal response        | ES4; network analogy only; airflow and comfort untested                                        |
| SR5 → AR5      | Coordinate shade, thermal mass, controlled openings, use, and maintenance across scales                            | ACCEPT AS LOCAL BASELINE/CONSTRAINT — evidence is cultural/architectural, not biomimetic, and remains site-bounded                        | P5 — local massive wall, shaded interface, operable inner layer, and compatible spatial relation | ES5; precedent relations documented; contemporary transfer untested                            |

*Source: Authors' illustrative decision record, 2026. AR = abstracted rule; P = author-generated proposition; ES = prospective evaluation specification.*

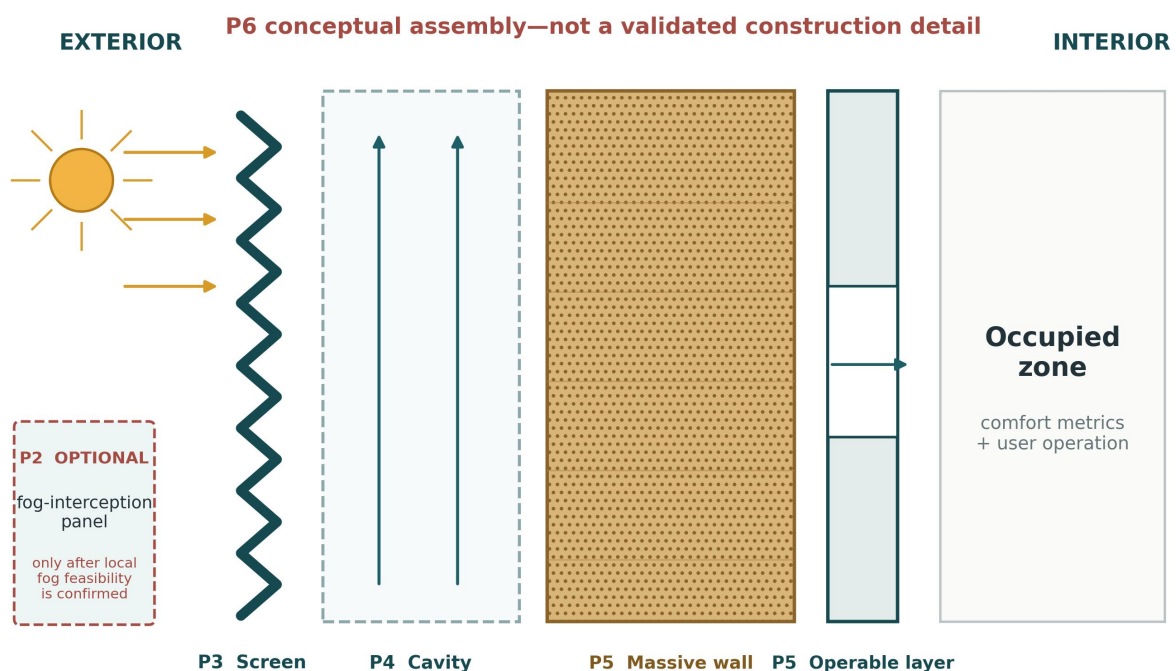
One chain shows how the identifiers constrain interpretation. SR3 records hydration and organism-scale heat/radiation relations in specified cacti. AR3 removes cactus appearance but retains corrugation, exposed area, facet orientation, and operating conditions. The Saoura gate modifies AR3 because local shading is relevant, while the facade effect remains untested and dust, view, and maintenance must be considered. P3 is therefore a folded screen, not a claim that a facade duplicates a cactus. ES3 links that

proposition to two baselines, declared metrics, and project-specific thresholds in Table 4. The chain is inspectable, but neither its coding reliability nor P3 performance has been established.

### 3.6 Worked conceptual envelope proposition

P6 combines the provisionally modified or accepted propositions P1, P3, P4, and P5 into a four-part concept (Figure 3); P2 remains outside the core. P3 is a parameterised folded outer screen. P4 is a ventilated cavity with defined inlet and outlet paths. P5 contributes a massive local wall, a shaded interface, and an operable inner layer. P1 is the overall requirement that the resulting solar/thermal buffer use separately specified physical properties rather than claim a literal camel analogue. The assembly is bio-cultural because the biological abstractions are filtered through Saoura priorities of shade, mass, restrained openings, available materials, repair, and use. It may include passive and manually operated responses, but it is not described as automated or intelligent: no sensor, actuator, controller, optimisation routine, or fault response has been designed or tested.

**Figure 3. Worked conceptual climate-responsive envelope proposition**



*Source: Authors' elaboration, 2026. P6 incorporates P1 and P3–P5; P2 is conditional. The diagram is not a construction detail or performance result.*

The component interfaces are as important as the individual layers. The folded screen changes the radiation and wind conditions at the cavity; cavity flow changes the convective boundary at the massive wall; thermal storage changes the appropriate opening schedule; and user operation changes actual airflow and comfort. These couplings mean that performance cannot be inferred by adding benefits reported for separate precedents. A whole-building model must represent the combined geometry, materials, weather, internal loads, schedules, and controls, while targeted physical tests should investigate pressure loss, dust deposition, cleaning access, material deterioration, and failure states.

The atmospheric-water proposal remains a conditional module rather than a core layer. Fog interception is distinct from dew condensation and requires suspended liquid droplets, sufficient wind exposure, and a reliable drainage and storage path. Annual relative humidity alone is not evidence of a usable fog resource. Before integration, a local campaign should measure or obtain data on fog frequency, liquid water content, droplet size distribution, wind direction and speed, dust load, water quality, and seasonal alignment with demand. If these conditions are not met, the module should be rejected rather than retained for symbolic biomimetic value.

Table 4 summarises the minimum model definitions, comparators, metrics, and decision rules for evaluating the assembly. It is an evaluation-specification template, not a report of completed tests. For a

defined site and brief, investigators must pre-register two relevant comparators—BL0, a code-compliant conventional envelope, and BLV, a locally documented vernacularly informed baseline—together with numerical or categorical thresholds for every listed benefit and penalty. The table deliberately does not invent those values for an unspecified project.

**Table 4. Prospective evaluation-specification template for the worked proposition**

| ES / proposition                   | Intended role                                                      | Minimum model or test definition                                                                                                                                     | Comparators and primary metrics                                                                                            | Pre-registered decision criterion                                                                                                                |
|------------------------------------|--------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| ES1 / P1 — multilayer buffer       | Limit external heat gain and coordinate time lag                   | Layer absorptance, emissivity, resistance, heat capacity, vapour transfer, interfaces, weather, and operating state                                                  | BL0 and BLV; heat flux, surface/operative temperature, cooling demand, moisture risk, durability                           | Retain P1 only if the pre-set thermal target is met against both baselines and moisture/durability penalties remain within limits                |
| ES2 / P2 — optional fog panel      | Intercept liquid fog and drain collected water                     | Local fog climatology; wind-tunnel or field panel; orientation, geometry, wettability, dust, drainage, storage, and cleaning                                         | No panel and conventional mesh; annual yield per area, water quality, pressure loss, cleaning time, cost                   | Integrate only if pre-set yield, quality, maintenance, and pressure-loss thresholds are all met; otherwise reject                                |
| ES3 / P3 — folded screen           | Redistribute exposure and provide time-dependent shade             | Azimuth, fold depth/pitch, porosity, optical/thermal properties, wind, dust, view, structure, and cleaning access                                                    | BL0 and flat-screen comparator; solar heat gain, surface temperature, daylight, view, pressure loss                        | Retain only if solar/thermal targets are met and every pre-set daylight, view, airflow, structural, and maintenance limit is respected           |
| ES4 / P4 — ventilated cavity       | Provide pressure- and buoyancy-driven exchange                     | Annual multizone simulation plus computational fluid dynamics (CFD) or physical tests for critical periods; openings, coefficients, wind, thermal mass, and schedule | Sealed and conventional cavity cases; mass flow rate, pressure, air change rate, cavity temperature, comfort, energy, dust | Accept only if target flow/comfort is maintained across specified weather cases without exceeding reverse-flow, dust, acoustic, or energy limits |
| ES5 / P5 — mass, openings, and use | Shift peak heat transfer and preserve controlled user exchange     | Verified local material properties, thickness, openings, schedules, occupancy, security, noise, dust, repair, and manual/automatic mode                              | BL0 and BLV; heat flux, time lag, comfort, indoor air quality, user acceptance, embodied impact                            | Retain if pre-set comfort/IAQ targets and local feasibility limits are met; describe passive, manual, or automatic operation accurately          |
| ES6 / P6 — coupled assembly        | Coordinate solar, thermal, airflow, use, and maintenance functions | Whole-building geometry, weather file, occupancy, loads, material data, interfaces, control logic, and uncertainty ranges                                            | BL0 and BLV; annual energy, peak temperature, comfort, daylight, embodied impact, cost, maintainability                    | Advance to a prototype only if all priority targets are met and the result remains acceptable across pre-registered sensitivity ranges           |

*Source: Authors' elaboration informed by literature on performance-based design and adaptive and ventilated envelopes (Andreeva et al., 2022; Cuce & Cuce, 2025; Faragalla & Asadi, 2022; Kuru et al., 2019; Soudian & Berardi, 2021).*

### 3.7 Retrospective comparison of precedent types

Eastgate Centre and Saoura ksour were mapped retrospectively through comparable DBDL fields while retaining different origins and evidential limits. Eastgate is an existing contemporary building associated with a termite-inspired narrative and a hybrid environmental strategy; the comparison does not imply that it literally reproduces a mound or that one universal mound mechanism exists. The ksour are existing vernacular systems in which spatial form, mass, openings, shade, occupation, and maintenance operate together. Neither case was developed using DBDL, so neither can establish the framework's prospective usability.

**Table 5. Retrospective DBDL mapping of Eastgate Centre and Saoura ksour**

| Analytical field              | Eastgate Centre                                                                                     | Saoura ksour                                                                                       | Interpretive boundary                                                                                    |
|-------------------------------|-----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| Knowledge origin / provenance | Contemporary built precedent and published termite-related design narrative (C)                     | Culturally accumulated practice documented in empirical/analytical studies (V1) and synthesis (V2) | Built-precedent and vernacular evidence are not biological evidence and are not equivalent to each other |
| Observation                   | Building descriptions; thermal mass, ventilation, controlled exchange, and hybrid operation         | Compact fabric, shade, courtyards, controlled openings, earthen mass, use, and repair              | The present study does not reconstruct complete design histories or collect new field data               |
| Abstraction                   | Coordinate thermal storage and controlled air exchange; avoid claiming a universal termite stack    | Coordinate solar protection, mass, spatial hierarchy, opening control, occupation, and maintenance | Rules remain interpretations tied to documented conditions                                               |
| Application status            | Existing building not designed using DBDL                                                           | Existing settlement/building systems not designed using DBDL                                       | Retrospective fit illustrates descriptive use, not prospective usability                                 |
| Claim illustrated             | DBDL is intended to report a biology-associated precedent without inheriting its narrative as proof | DBDL is intended to report situated vernacular knowledge without relabelling it as biological      | No new claim about envelope performance, energy savings, or comfort is established                       |

*Source: Authors' synthesis based on Benslimane et al. (2020), Khoukhi and Fezzioui (2012), King et al. (2015), Ocko et al. (2017), Ouahchi et al. (2025), and Pearce (2005).*

The comparison illustrates that the same reporting fields can be applied to two unlike trajectories while preserving their provenance and interpretive limits. It does not establish inter-rater reliability, designer usability, causal validity, or environmental performance. Those outcomes require prospective studies in which independent users receive the same brief and evidence set, apply the framework, and produce records that can be compared for completeness, agreement, and design consequences.

## 4 Discussion

### 4.1 Theoretical contribution

The proposed theoretical contribution is the separation and coordination of three domains: biological evidence, vernacular environmental knowledge, and building-performance evaluation. Conventional analogy can compress these domains into a single story in which an organism provides a solution and a building inherits its success. DBM-DBDL instead proposes two explicit boundaries. The evidence boundary distinguishes what is documented about the source from what the designer infers. The context boundary tests whether the inference remains meaningful in the Saoura. Only after both records are completed does an architectural proposition receive variables and a prospective evaluation route.

This structure responds to concerns about biological provenance and the gap between inspiration and information (Harvey, 2026; Ng et al., 2021). Observation, abstraction, application, iteration, and function-centred reasoning are not new individually (Fayemi et al., 2017; Helms et al., 2009; Linder & Huang, 2025). The distinctive combination within the methods examined is the architecture-specific coupling of these moves to a bio-cultural context decision, claim-level provenance tags, persistent SR-AR-P-ES links, and a

prospective evaluation specification. That is a bounded conceptual contribution, not a claim to replace general biomimetic design theory.

Giving vernacular knowledge a gatekeeping role changes its position in the design process. It is neither a decorative source of identity nor a biological analogue. It introduces situated constraints—local earth, construction skill, spatial custom, maintenance capacity, resource scarcity, and user operation—that can alter the biological abstraction before geometry is fixed. This relation is asymmetrical in a productive way: biological evidence expands the search space, while Saoura knowledge tests whether the proposed transfer belongs in the local project. The result is bio-cultural coordination without conceptual conflation.

## **4.2 Practical implications**

For practice, the framework is intended to support a reviewable handover among an architect, a biologist, an environmental engineer, a materials specialist, and a local stakeholder. The biological specialist can challenge the source mechanism and provenance; the local expert can challenge cultural and material assumptions; the engineer can translate a proposition into boundary conditions and metrics; and the architect can manage spatial, regulatory, and constructability trade-offs. Studies with independent users are still needed to determine whether the record actually improves such collaboration.

The record structure could also support computation. DBM fields could become structured data attributes, while DBDL records could guide parameter generation, simulation, sensitivity analysis, and decision review. The folded screen, for example, can be varied by depth, pitch, orientation, and porosity, but optimisation should not begin until daylight, view, pressure loss, dust, structure, and maintenance are constraints. Likewise, a channelled cavity cannot be labelled termite-informed solely by resemblance; its pressure network, thermal forcing, and local-weather performance must be tested. Computational efficiency does not compensate for an incorrect biological premise or incomplete boundary condition.

The strongest near-term application is therefore an evaluation-specification template, not a finished facade. A project team can use the SR-AR-P-ES chain to select a mechanism, state the expected relation, define BL0 and BLV, and pre-register variables and decision thresholds for simulation or prototype testing. Negative results can remain informative because the record identifies whether revision is needed in the source interpretation, abstraction, local decision, architectural mapping, or control strategy.

## **4.3 Limitations and validation roadmap**

The study has six principal limitations. First, the purposive evidence sample lacks a reproducible candidate/exclusion log, independent screening, and formal quality appraisal; additional or contradictory studies may change individual records. Second, FFPE and the SR-AR-P-ES linkage are author-developed and have not undergone inter-coder or independent-user testing. Third, the biological records concern specified taxa, scales, and environments and are not commensurable merely because they appear in one table. Fourth, the Saoura gate is illustrated from published literature without new ethnographic, participatory, or field validation. Fifth, Eastgate and the ksour are mapped retrospectively and cannot establish prospective usability. Sixth, P6 has no assigned site, dimensions, final materials, control algorithm, simulation, prototype, cost analysis, or measured performance. No numerical claim about energy, temperature, airflow, daylight, water yield, or comfort is therefore supported.

Validation should proceed in four stages. Stage 1 is methodological: publish a protocol and codebook, have independent designer-biologist-local-expert teams code the same evidence set, and report agreement, disagreements, task time, missing fields, and gate decisions. Stage 2 is computational: specify a Saoura site and brief, pre-register BL0, BLV, metrics, and thresholds, and test individual layers before P6 using transparent weather, geometry, material, occupancy, and operation inputs. Stage 3 is physical: build component and room-scale prototypes to test heat transfer, pressure loss, airflow, dust deposition, weathering, cleaning, acoustics, and manual or automatic operation as applicable. Stage 4 is in-use: monitor a demonstrator across seasons and compare predicted with measured performance, maintenance demand, and occupant experience. Automated or intelligent operation should be claimed only after its sensors, controls, and fail-safe behaviour are validated; passive or manual climate response should be described on its own terms.

Future evidence synthesis should use a registered systematic protocol, explicit database strings, screening records, critical appraisal, and a publicly shareable evidence repository where licensing permits. Biological and vernacular experts should review contested mechanisms and cultural interpretations. The

evidence-status scheme should be tested against the 2026 transparent-reporting framework for bio-inspired design, and future articles should state whether a proposal is analogy-led, biomimetic, or bio-informed rather than using those terms interchangeably (Harvey, 2026).

## 5 Conclusions

This study proposes a bio-cultural biomimetic framework for climate-responsive building envelopes in hot and arid environments. The DBM stores six-field source records; the DBDL links each SR to an AR, context decision, P, and prospective ES. The structure is intended to keep biological evidence, vernacular knowledge, and design inference distinct while exposing the path from source claim to future test.

The illustrative records show why taxonomic and mechanistic precision matters. Dromedary heat tolerance is a coupled, hydration-dependent response rather than a single insulating layer. Fog collection evidence is bounded to specified beetles, behaviours, and capture models; patterned wettability is not assumed universal. Cactus ribs support hydration-related shape change and modify exchange geometry, while facade self-shading remains a hypothesis. Termite ventilation varies with taxon, nest geometry, porosity, wind, thermal forcing, diffusion, and colony load; it is not a one-way stack. Saoura ksour contribute culturally situated relations among shade, mass, space, openings, use, and maintenance rather than a catalogue of forms.

The contribution is conceptual and procedural, not numerical. Persistent identifiers, explicit gate outcomes, provenance tags, and prospective evaluation specifications make the reasoning inspectable and expose tests still required. P6 and the retrospective cases illustrate use of the record structure only. Claims of environmental effectiveness require testing by independent users, climate-specific simulation, physical prototypes, and field monitoring; claims of automation or intelligence require tested controls. Within those limits, DBM-DBDL offers a defensible basis for locally grounded envelope research without mistaking inspiration for validated performance.

## Data Availability

No numerical dataset was generated or analysed. Tables 2–4 contain the illustrative source and decision records used in this article, but no separate claim-level extraction database, screening log, or quality-appraisal dataset exists. Table 1 is a bounded method comparison, Table 5 is a retrospective illustration, and the diagrams are authors' elaborations. Future systematic-review, simulation, prototype, and monitoring datasets should be deposited with versioned documentation when those studies are undertaken.

## Competing Interests

The authors declare no competing interests.

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## References

- Andreeva, D., Nemova, D., & Kotov, E. (2022). Multi-skin adaptive ventilated facade: A review. *Energies*, 15(9), Article 3447. <https://doi.org/10.3390/en15093447>
- Bassoud, A., Khelafi, H., Mokhtari, A. M., & Bada, A. (2021). Evaluation of summer thermal comfort in arid desert areas. Case study: Old adobe building in Adrar (South of Algeria). *Building and Environment*, 205, Article 108140. <https://doi.org/10.1016/j.buildenv.2021.108140>

- Benslimane, N., Biara, W. R., & Bougdah, H. (2020). Traditional versus contemporary dwellings in a desert environment: The case of Bechar, Algeria. *Environmental Research, Engineering and Management*, 76(4), 118–130. <https://doi.org/10.5755/j01.erem.76.4.21595>
- Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature*. William Morrow.
- Bouâouda, H., Achâaban, M. R., Ouassat, M., Oukassou, M., Piro, M., Challet, E., El Allali, K., & Pévet, P. (2014). Daily regulation of body temperature rhythm in the camel (*Camelus dromedarius*) exposed to experimental desert conditions. *Physiological Reports*, 2(9), Article e12151. <https://doi.org/10.14814/phy2.12151>
- Cuce, P. M., & Cuce, E. (2025). Ventilated facades for low-carbon buildings: A review. *Processes*, 13(7), Article 2275. <https://doi.org/10.3390/pr13072275>
- Faragalla, A. M. A., & Asadi, S. (2022). Biomimetic design for adaptive building façades: A paradigm shift towards environmentally conscious architecture. *Energies*, 15(15), Article 5390. <https://doi.org/10.3390/en15155390>
- Fayemi, P.-E., Wanieck, K., Zollfrank, C., Maranzana, N., & Aoussat, A. (2017). Biomimetics: Process, tools and practice. *Bioinspiration & Biomimetics*, 12(1), Article 011002. <https://doi.org/10.1088/1748-3190/12/1/011002>
- Gerola, A., Robaey, Z., & Blok, V. (2023). What does it mean to mimic nature? A typology for biomimetic design. *Philosophy & Technology*, 36(4), Article 65. <https://doi.org/10.1007/s13347-023-00665-0>
- Graeff, E., Maranzana, N., & Aoussat, A. (2021). Linkage, an online tool to support interdisciplinary biomimetic design teams. *Journal of Mechanical Design*, 143(10), Article 101401. <https://doi.org/10.1115/1.4049969>
- Harvey, C. (2026). How bio-inspired is your design? A transparent reporting framework. *Communications Engineering*, 5, Article 70. <https://doi.org/10.1038/s44172-026-00641-4>
- Helms, M., Vattam, S. S., & Goel, A. K. (2009). Biologically inspired design: Process and products. *Design Studies*, 30(5), 606–622. <https://doi.org/10.1016/j.destud.2009.04.003>
- Hevner, A. R., Parsons, J., Brendel, A. B., Lukyanenko, R., Tiefenbeck, V., Tremblay, M. C., & vom Brocke, J. (2024). Transparency in design science research. *Decision Support Systems*, 182, Article 114236. <https://doi.org/10.1016/j.dss.2024.114236>
- Ilieva, L., Ursano, I., Traista, L., Hoffmann, B., & Dahy, H. (2022). Biomimicry as a sustainable design methodology—Introducing the ‘Biomimicry for Sustainability’ framework. *Biomimetics*, 7(2), Article 37. <https://doi.org/10.3390/biomimetics7020037>
- International Organization for Standardization. (2015). *ISO 18458:2015 Biomimetics—Terminology, concepts and methodology*. <https://www.iso.org/standard/62500.html>
- Jaakkola, E. (2020). Designing conceptual articles: Four approaches. *AMS Review*, 10(1–2), 18–26. <https://doi.org/10.1007/s13162-020-00161-0>
- Karibi-Botoye, N. F., Theraulaz, G., Muljadi, B., Demyanov, V., & Singh, K. (2025). Termite mound architecture and climate control: A review of X-ray tomography and flow field simulation approaches. *Journal of the Royal Society Interface*, 22(231), Article 20250263. <https://doi.org/10.1098/rsif.2025.0263>
- Khoukhi, M., & Fezzioui, N. (2012). Thermal comfort design of traditional houses in hot dry region of Algeria. *International Journal of Energy and Environmental Engineering*, 3, Article 5. <https://doi.org/10.1186/2251-6832-3-5>
- King, H., Ocko, S. A., & Mahadevan, L. (2015). Termite mounds harness diurnal temperature oscillations for ventilation. *Proceedings of the National Academy of Sciences*, 112(37), 11589–11593. <https://doi.org/10.1073/pnas.1423242112>
- Kuru, A., Oldfield, P., Bonser, S. P., & Fiorito, F. (2019). Biomimetic adaptive building skins: Energy and environmental regulation in buildings. *Energy and Buildings*, 205, Article 109544. <https://doi.org/10.1016/j.enbuild.2019.109544>
- Lewis, D. A., & Nobel, P. S. (1977). Thermal energy exchange model and water loss of a barrel cactus, *Ferocactus acanthodes*. *Plant Physiology*, 60(4), 609–616. <https://doi.org/10.1104/pp.60.4.609>
- Linder, B., & Huang, J. (2025). A design process framework and tools for teaching and practicing biomimicry. *Biomimetics*, 10(6), Article 376. <https://doi.org/10.3390/biomimetics10060376>
- Mauseth, J. D. (2000). Theoretical aspects of surface-to-volume ratios and water-storage capacities of succulent shoots. *American Journal of Botany*, 87(8), 1107–1115. <https://doi.org/10.2307/2656647>
- Mauseth, J. D. (2006). Structure–function relationships in highly modified shoots of Cactaceae. *Annals of Botany*, 98(5), 901–926. <https://doi.org/10.1093/aob/mcl133>

- Ng, L., Elgar, M. A., & Stuart-Fox, D. (2021). From bioinspired to bioinformed: Benefits of greater engagement from biologists. *Frontiers in Ecology and Evolution*, 9, Article 790270. <https://doi.org/10.3389/fevo.2021.790270>
- Nobel, P. S. (1980). Interception of photosynthetically active radiation by cacti of different morphology. *Oecologia*, 45(2), 160–166. <https://doi.org/10.1007/BF00346455>
- Nørgaard, T., & Dacke, M. (2010). Fog-basking behaviour and water collection efficiency in Namib Desert darkling beetles. *Frontiers in Zoology*, 7, Article 23. <https://doi.org/10.1186/1742-9994-7-23>
- Ocko, S. A., King, H., Andreen, D., Bardunias, P., Turner, J. S., Soar, R., & Mahadevan, L. (2017). Solar-powered ventilation of African termite mounds. *Journal of Experimental Biology*, 220(18), 3260–3269. <https://doi.org/10.1242/jeb.160895>
- Ouahchi, S., Ab Ghafar, N., Sahabuddin, M. F. M., Zemmouri, N., Mahaya, C., & Priya, R. S. (2025). Thermal comfort in Algeria's vernacular built environment – a systematic review. *International Journal of Environmental Studies*, 82(3), 1099–1122. <https://doi.org/10.1080/00207233.2025.2480511>
- Paredes Cubas, W. F., Dexter, K. G., Reynel Rodríguez, C., Pennington, R. T., & Marcelo Peña, J. L. (2025). Functional traits in arborescent Cactaceae: A guideline for their measurement. *Australian Journal of Botany*, 73(5), Article BT24090. <https://doi.org/10.1071/BT24090>
- Parker, A. R., & Lawrence, C. R. (2001). Water capture by a desert beetle. *Nature*, 414(6859), 33–34. <https://doi.org/10.1038/35102108>
- Pearce, M. (2005). From Eastgate to CH2: Building on the energy watershed. In E. Charlesworth (Ed.), *City edge: Case studies in contemporary urbanism* (pp. 180–197). Architectural Press.
- Schmidt-Nielsen, K., Schmidt-Nielsen, B., Jarnum, S. A., & Houpt, T. R. (1957). Body temperature of the camel and its relation to water economy. *American Journal of Physiology-Legacy Content*, 188(1), 103–112. <https://doi.org/10.1152/ajplegacy.1956.188.1.103>
- Shahrokhian, A., Chan, F. K., Feng, J., Gazzola, M., & King, H. (2024). Geometry for low-inertia aerosol capture: Lessons from fog-basking beetles. *PNAS Nexus*, 3(2), Article pgae077. <https://doi.org/10.1093/pnasnexus/pgae077>
- Singh, K., Muljadi, B. P., Raeini, A. Q., Jost, C., Vandeginste, V., Blunt, M. J., Theraulaz, G., & Degond, P. (2019). The architectural design of smart ventilation and drainage systems in termite nests. *Science Advances*, 5(3), Article eaat8520. <https://doi.org/10.1126/sciadv.aat8520>
- Snell-Rood, E. C., & Smirnoff, D. (2023). Biology for biomimetics I: Function as an interdisciplinary bridge in bio-inspired design. *Bioinspiration & Biomimetics*, 18(5), Article 052001. <https://doi.org/10.1088/1748-3190/ace5fb>
- Soudian, S., & Berardi, U. (2021). Development of a performance-based design framework for multifunctional climate-responsive façades. *Energy and Buildings*, 231, Article 110589. <https://doi.org/10.1016/j.enbuild.2020.110589>
- Tibary, A., & El Allali, K. (2020). Dromedary camel: A model of heat resistant livestock animal. *Theriogenology*, 154, 203–211. <https://doi.org/10.1016/j.theriogenology.2020.05.046>
- Velivela, P. T., & Zhao, Y. F. (2022). A comparative analysis of the state-of-the-art methods for multifunctional bio-inspired design and an introduction to Domain Integrated Design (DID). *Designs*, 6(6), Article 120. <https://doi.org/10.3390/designs6060120>
- Verbrugghe, N., Rubinacci, E., & Khan, A. Z. (2023). Biomimicry in architecture: A review of definitions, case studies, and design methods. *Biomimetics*, 8(1), Article 107. <https://doi.org/10.3390/biomimetics8010107>
- Wagermaier, W., Razghandi, K., & Fratzl, P. (2025). A bio-inspired perspective on materials sustainability. *Advanced Materials*, 37(22), Article 2413096. <https://doi.org/10.1002/adma.202413096>