

BIM AND AI AGENT-ASSISTED PARAMETRIC DESIGN OF CLIMATE-RESPONSIVE FACADE SHADING ELEMENTS IN UZBEKISTAN USING RHINO 8 AND GRASSHOPPER

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Abstract: This paper proposes a methodological framework for the parametric design of fixed solar-shading elements for building facades, taking into account the substantial seasonal and regional climatic variability of Uzbekistan. Building information modeling (BIM) is considered as a means of organizing and documenting the geometric and non-geometric information of the proposed façade systems. The workflow combines the generation of adjustable geometry in Rhino 8 and Grasshopper, the analysis of location-specific EnergyPlus Weather (EPW) data using Ladybug Tools, the connection of daylight and building-energy models to Radiance and EnergyPlus/OpenStudio through Honeybee, and the screening of design alternatives against applicable regulatory constraints. Three architectural precedents inform the proposed prototypes: traditional Uzbek shabaka screens, deep ayvans (covered verandas), and the three-dimensional concrete shading screens characteristic of Tashkent modernism. A conceptual multi-agent artificial intelligence (AI) workflow is structured around climate-data validation, geometric option generation, regulatory traceability, simulation-result assessment, and BIM data management. This is a conceptual and methodological study. Neither an operational multi-agent system nor a completed Rhino/Grasshopper model has been experimentally validated within the present work; likewise, no new results from simulations using an independently verified EPW file are reported.

Keywords: building information modeling; Rhino 8; Grasshopper; parametric design; artificial intelligence agents; façade screens; solar shading; daylighting; energy efficiency; Uzbekistan

INTRODUCTION. In Uzbekistan, protection against excessive solar radiation on building facades may reduce cooling demand during the hot season. However, fixed shading devices can also restrict beneficial winter solar gains and reduce daylight admission to occupied spaces. Previous studies have shown that the performance of fixed overhangs and louvers depends on climatic conditions, facade orientation, the window-to-wall ratio, and shading geometry [1,2]. Consequently, the selection of a façade screen cannot be justified solely on decorative grounds or by the proportion of incident solar radiation that it blocks.

In the local architectural tradition, the deep ayvans of Khiva and Bukhara integrate shading into the building's spatial arrangement, whereas the Uzbekistan Hotel in Tashkent translates the vocabulary of traditional latticework into a large-scale modernist solar-shading screen [3]. Adapting these precedents to contemporary computational design offers a means of evaluating their geometric principles while maintaining a recognizable relationship with local architectural identity. The objective of this study is to establish a parametric design methodology linking Rhino 8/Grasshopper, AI-assisted decision support, and BIM, while considering the applicable building requirements of Uzbekistan.

MATERIALS AND METHODS

Parametric modeling and design prototypes. Rhino 8 is adopted as the geometric modeling environment, while Grasshopper provides a visual programming framework for establishing

relationships between adjustable design variables. Object attributes and Python 3 scripting in Rhino 8 may support the assignment of identifiers and technical metadata to alternative designs [4]. The proposed geometric variables include projection depth (D), inclination angle (θ), spacing between elements (S), screen porosity or open-area ratio (P), facade azimuth (γ), and clearance between the screen and the glazing plane (G). Parameter ranges must be established in accordance with the building use, fabrication method, and relevant safety constraints; they are not presented as universally prescribed dimensions.

Three prototype systems are considered: (1) a perforated module derived from the geometric logic of traditional Uzbek shabaka latticework; (2) an ayvan-inspired deep shading system incorporating lightweight metallic fins; and (3) a repetitive three-dimensional, cell-based brise-soleil inspired by the Uzbekistan Hotel. Rather than directly reproducing historic ornament, the approach seeks to parameterize the underlying principles of modularity, rhythm, and openness.



Figure 1. Traditional Ayvan. Principles of deep shading and wooden latticework in Khiva architecture.



Figure 2. Three-dimensional geometric screen, Modular grid system of the "Uzbekistan" Hotel facade in Tashkent.

Table 1.

Proposed parametric design approaches for Uzbekistan

Design approach	Geometric control variables	Risks requiring evaluation
Parametric shabaka screen	Module dimensions, porosity P, screen-to-glazing clearance G	Reduction in daylight availability; dust accumulation and cleaning difficulty
Ayvan-inspired overhang	Projection depth D, sectional height, lateral screening	Loss of winter solar gains; high cantilever loads
Three-dimensional cellular screen	Horizontal/vertical ribs, spacing S, depth D, inclination θ	Excess structural mass; obstruction of outward views

2.2. Climate-based analysis and regulatory assessment. The proposed climatic input is an authentic EPW file for Tashkent with documented provenance and period of record. Subsequent cross-regional comparisons should employ separate EPW files for each selected location. Ladybug may be used to analyze sun paths, incident solar radiation, and shading periods. Through Honeybee, daylight simulations can be connected to Radiance, while heating, cooling, and electric-lighting energy calculations can be connected to EnergyPlus/OpenStudio [5, 6]. Compliance with national daylight-factor requirements must be assessed according to the applicable local provisions and must not be assumed from international metrics such as spatial Daylight Autonomy (sDA) or Annual Sunlight Exposure (ASE).

The regulatory screening stage considers the provisions applicable to the specific project under ShNQ 2.01.05-24 (“Natural and Artificial Lighting”), ShNQ 2.08.01-24 (“Design of Residential Buildings”), ShNQ 2.08.02-23 (“Public Buildings and Structures”), and ShNQ 2.01.18-24 (energy-consumption standards for heating, ventilation, and air conditioning) [7-10]. For

example, ShNQ 2.08.01-24, Clause 326, specifies that the window area in residential living rooms and kitchens must not be less than one-tenth of the respective floor area, subject also to daylight-factor requirements. Clause 338 restricts the orientation of living-room windows towards the 200-290° azimuth sector in Climate Zones I and II and requires external solar-protection devices where living rooms face that sector [8]. Applicability must be confirmed for the particular building type, location, and current regulatory edition. In the absence of these inputs, the proposed AI agent must not issue an automated declaration of compliance.

Proposed AI-agent-assisted design workflow. Five functional roles are proposed for a multi-agent architecture. Each agent would operate as an auxiliary software component with explicitly configured data access and permissions. Agents are not substitutes for validated simulation engines, authoritative regulatory documents, or the professional judgment of qualified designers.

Table 2.

Proposed AI agents and human verification requirements

Agent	Proposed function	Human verification
Climate-data agent	Checks EPW station location, reporting period, missing values, and geographic relevance	Data provenance, coordinates, temporal coverage, data completeness
Design agent	Coordinates Grasshopper parameters for shabaka, ayvan, and cellular-screen variants	Geometry, interpretation of local motifs, fabrication feasibility
Regulatory agent	Generates a traceable checklist linking ShNQ clauses with project parameters	Current edition, occupancy type, scope and applicability of each clause
Assessment agent	Compares Ladybug/Honeybee outputs and identifies Pareto-efficient alternatives	Model assumptions, calculation units, simulation warnings and errors
BIM agent	Maps panel IDs, materials, dimensions, mass, and performance metadata to BIM parameters	Revit element categories, schedules, and consistency with drawings

The intended sequence is as follows: acquisition of weather and regulatory information; development of parametric prototypes; physics-based simulation; verification of mandatory constraints; multi-criteria comparison of compliant alternatives; and documentation of the selected design in BIM. Since large language model (LLM) agents may misinterpret regulations or generate unsupported assertions, every regulatory determination should retain a link to the source clause and require specialist review before approval.

Multi-criteria optimization and BIM interoperability. Pareto-based comparison is proposed in preference to optimizing a single aggregate percentage. Annual energy demand, daylight availability, glare risk, material quantity, and construction complexity are retained as distinct evaluation criteria. Alternatives that fail mandatory ShNQ or safety requirements should first be excluded. The remaining solutions can then be examined for trade-offs between competing objectives. Where total energy is expressed as $E_{\text{total}} = E_{\text{heating}} + E_{\text{cooling}} + E_{\text{lighting}}$, the components must share compatible units and the same energy-accounting boundary, and the distinction between delivered energy and thermal loads must be maintained.

The selected shading geometry may be transferred to a BIM environment through Rhino.Inside.Revit. Within Revit, panel types can be assigned geometric dimensions, material specifications, connection details, replacement or asset codes, and simulation-version identifiers.

Rhino.Inside.Revit enables interoperability between Rhino/Grasshopper geometry and Revit objects; however, the resulting categories, quantities, parameter mappings, and level of documentation must be verified after transfer [11]. Software and release compatibility should also be checked for the versions deployed in the project.

RESULTS AND DISCUSSION. The principal outcome of this analytical study is a proposed framework comprising three conceptually distinct facade-shading prototypes derived from local architectural precedents and a five-agent workflow for traceable option management. Ayvan-inspired overhangs and horizontal shading devices may offer useful seasonal responses on south-facing facades because of the higher midday solar altitude in summer. For east- and west-facing facades, the potential benefits of vertical fins or combined three-dimensional cellular screens require project-specific evaluation. These are design hypotheses, not empirically verified solutions applicable to all climatic regions of Uzbekistan.

The methodological contribution lies in treating inherited ornamental geometries as parameterized systems capable of controlling physical performance rather than as purely visual references. AI-assisted workflows may facilitate the tracking of design decisions, provenance of input datasets, and reproducibility of alternative configurations. Nevertheless, several limitations remain: the need for reliable location-specific EPW data; the absence of measured geometry for the cited built precedents; uncertainty in material properties and fabrication costs; and dependencies on the software versions used for Rhino-to-Revit interoperability.

Earlier exploratory calculations used synthetic hourly climatic sequences to estimate solar-shading percentages. Those figures have not been verified against authentic EPW observations and are therefore not presented as validated evidence in this paper. No new quantitative claims are made concerning annual energy savings, daylight-factor compliance, or optimal panel dimensions for the buildings considered. Future verification should employ a controlled reference-building model, documented assumptions, and separate weather files for the selected Uzbek cities.

CONCLUSION. A conceptual methodology has been presented for parametric design of fixed, climate-responsive facade-shading systems in Uzbekistan using Rhino 8 and Grasshopper. The three prototype families draw on traditional shabaka latticework, deep ayvans, and modernist cellular screens. Treating applicable regulatory provisions as preliminary feasibility constraints offers a defensible basis for comparing daylight performance with heating, cooling, and lighting demand. The proposed AI agents are assigned supporting roles in data validation, alternative management, regulatory traceability, and BIM documentation. The next stage of research should implement and validate the framework using authentic EPW files, Radiance and EnergyPlus simulations, and fabrication and life-cycle cost assessments.

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