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AI-BASED INTERIOR DESIGN OPTIMIZER

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Abstract: This study introduces a hybrid optimization framework that integrates principles of *Vastu Shastra* with modern artificial intelligence techniques, including convolutional neural networks and genetic algorithms, for interior design generation. The proposed system translates traditional spatial guidelines into a rule-based scoring mechanism, while leveraging machine learning models to evaluate aesthetic quality and evolutionary algorithms to explore multiple design possibilities efficiently.

The experimental results indicate a significant improvement in performance, achieving an average fitness score of 82.4 compared to a random baseline score of 61.2, reflecting a 34.7% enhancement. Furthermore, expert assessments reported a cultural compliance rating of 7.8 out of 10, while user feedback showed a 78% preference for the generated designs.

These findings highlight the potential of combining traditional design philosophies with advanced AI methodologies, demonstrating that culturally informed and optimized interior layouts can be effectively generated using an integrated computational approach.

Index Terms: Interior Design Optimization, Vastu Shastra, Convolutional Neural Networks (CNN), Genetic Algorithms (GA), Hybrid AI Framework, Cultural Computing, Space Planning, Evolutionary Computation, Aesthetic Evaluation, Smart Design Systems.

I. INTRODUCTION

Interior design optimization is inherently a multi-dimensional problem that involves balancing aesthetic appeal, functional efficiency, and cultural relevance. *Vastu Shastra*, an ancient Indian architectural philosophy, provides a structured framework for spatial organization based on directional alignment and the harmonious integration of natural elements. Despite the advancements in computational design, most existing optimization systems treat cultural considerations and aesthetic evaluation as isolated components, resulting in designs that may lack contextual coherence.

To address this gap, this research proposes a unified hybrid framework that integrates traditional knowledge with modern artificial intelligence techniques. The system consists of three core components: (1) a Vastu-based rule engine that quantifies cultural compliance through structured scoring, (2) a convolutional neural network (CNN) that evaluates functional and visual aesthetics using learned representations, and (3) a genetic algorithm (GA) that explores the design space and iteratively refines solutions through evolutionary processes.

By combining these elements, the proposed approach enables robust multi-objective optimization, ensuring that generated layouts are not only visually and functionally effective but also culturally aligned.

This integration demonstrates the potential of bridging heritage-driven design principles with data-driven methodologies to achieve more holistic and context-aware interior design solutions.

II. BACKGROUND AND RELATED WORK

A. Vastu Principles and Computational Design

Vastu Shastra provides a systematic approach to spatial organization by defining relationships between directions, elements, and human activities. It emphasizes the alignment of built environments with natural forces, where each direction is associated with specific functional and energetic attributes. Recent studies have offered partial empirical support for these principles; for instance, exposure to natural light from the east and north directions has been linked to improved cognitive performance, while placing sleeping areas in the southwest zone has been associated with better sleep quality.

Despite its rich theoretical foundation, the computational application of Vastu principles remains relatively underexplored. Early efforts, such as the development of rule-based expert systems using CLIPS by Gandi et al., attempted to formalize these guidelines into programmable logic. More recent work by Jariwala et al. has explored the integration of augmented reality with deep learning techniques to enhance user interaction and visualization in design systems.

In parallel, optimization techniques—particularly genetic algorithms—have been widely adopted for interior layout design due to their ability to handle mixed-variable constraints and navigate complex, non-convex solution spaces. However, most existing approaches focus either on rule-based validation or data-driven learning in isolation.

The key contribution of this research lies in bridging this gap by integrating rule-based reasoning, machine learning-based evaluation, and evolutionary optimization into a unified framework. This combined approach enables a more comprehensive and balanced design process that simultaneously accounts for cultural principles, aesthetic quality, and spatial efficiency.

III. SYSTEM ARCHITECTURE

The proposed system is designed as a hybrid framework consisting of three tightly integrated modules that collectively enable culturally-aware interior layout optimization. The first module, the **Vastu Rule Engine**, encodes traditional spatial principles by dividing the layout into nine zones corresponding to cardinal and intercardinal directions. Each zone is evaluated using a weighted scoring mechanism, allowing flexible representation of cultural constraints.

The second module, the **CNN-based Layout Scorer**, is responsible for assessing the functional and aesthetic quality of generated layouts. It operates on a multi-channel grid representation of size 32×32 and utilizes a lightweight architecture comprising two convolutional layers followed by activation and pooling operations, with a sigmoid output layer producing a normalized score between 0 and 1. The model is trained on synthetically generated layout data (approximately 2000–5000 samples) over 30–50 epochs to capture spatial patterns and design quality.

The third module, the **Genetic Algorithm (GA) Optimizer**, explores the design space by evolving furniture configurations through iterative generations. It employs a population size of 120 and runs for 60 generations using tournament selection and uniform crossover. The optimization objective is defined through a composite fitness function that balances cultural compliance and aesthetic quality:

$F = 0.4V(\text{configuration}) + 0.6C(\text{configuration})$

where V denotes the Vastu compliance score and C represents the CNN-based aesthetic evaluation.

Additionally, a computer vision component based on **YOLOv4** is incorporated to automatically detect furniture elements from input images, enabling real-world applicability. The overall system is orchestrated using a Flask-based REST API, while a React-based user interface provides interactive visualization and user control.

Table 1: System Component Specifications

Component	Architecture	Parameters
Vastu Engine	Weighted rule aggregation	9 zones, configurable weights
CNN Scorer	Conv-ReLU-Pool×2, GlobalAvgPool, Dense	Input: 32×32×6, Output: [0,1]
GA Optimizer	Tournament selection, uniform crossover	Population: 120, Generations: 60, 3 genes/item

Table 2: Vastu Scoring Rule Weights

Rule Category	Weight
Entrance orientation	0.20
Bedroom position (SW zone)	0.20
Kitchen position (SE zone)	0.15
Study position (E zone)	0.10
Bed head direction	0.15
Circulation/clearance	0.20

IV. EXPERIMENTAL EVALUATION

A. Evaluation Metrics and Protocol

To assess the effectiveness of the proposed framework, a comprehensive evaluation strategy was adopted using multiple performance metrics. These include Vastu compliance (scored on a scale of 0–100), CNN-based aesthetic evaluation (0–100), functional efficiency (measured in terms of space utilization and circulation), and computational time (in seconds).

The experimental study was structured into three key phases. In **Experiment 1**, the optimization capability of the proposed hybrid genetic algorithm was compared against baseline approaches, including random search and greedy heuristics, across 30 independent runs. **Experiment 2** focused on component-level analysis through ablation studies, isolating the individual contributions of the Vastu rule engine and the CNN model, as well as their combined effect. **Experiment 3** evaluated real-world applicability by testing the system on 20 residential layouts. This phase included expert assessment by 15 Vastu practitioners using a 10-point rating scale, along with user satisfaction surveys to capture occupant preferences.

Table 3: Optimization Performance Comparison

Method	Fitness	Time (s)	Std.Dev
Random	61.2	32.5	8.7
Greedy	71.3	18.2	6.2
Hybrid GA	**82.4**	**52.3**	**5.3**

Table 4: Component Ablation Results (n=30)

Configuration	Fitness	Std.Dev	Diversity
Vastu Only	74.6	7.2	0.51
CNN Only	76.8	6.9	0.54
Hybrid (Proposed)	**82.4**	**5.3**	**0.58**

V. RESULTS AND VALIDATION

A. Performance Metrics

The proposed hybrid genetic algorithm demonstrates strong optimization performance, achieving an average fitness score of **82.4 (±5.3)**. This represents a significant improvement over the random baseline (**61.2**), with a gain of 34.7%, and also outperforms the greedy heuristic approach (**71.3**) by 15.6%. The optimization process shows stable convergence around the 50th generation, indicating efficient exploration and refinement of solutions.

In terms of computational efficiency, the system requires approximately 45–60 seconds per run, which is practical for semi-interactive design applications. The ablation analysis further highlights the complementary strengths of the integrated approach. The Vastu-only model (**74.6 ± 7.2**) ensures cultural alignment but lacks modern design appeal, while the CNN-only model (**76.8 ± 6.9**) produces visually appealing layouts but overlooks traditional constraints. In contrast, the hybrid framework successfully combines both aspects, resulting in superior overall performance.

Additionally, the observed solution diversity (**0.58 ± 0.12**) indicates effective exploration of the design space, reducing the risk of premature convergence and enabling the generation of multiple meaningful layout alternatives.

Table 5: Real-World Deployment Results (n=20)

Evaluation Criterion	Optimized Layout	Random Baseline
Expert Vastu Rating (1-10)	7.8 ± 0.6	5.2 ± 1.4
Occupant Preference (%)	78%	—
Adoption Rate (%)	89%	—

B. Benchmark Analysis

To further validate the practical applicability of the proposed system, a real-world evaluation was conducted involving 15 expert Vastu practitioners under blinded conditions. The optimized layouts received an average rating of **7.8 out of 10**, compared to **5.2 out of 10** for randomly generated layouts, reflecting an approximate 50% improvement in perceived cultural alignment.

User-centric evaluation also yielded encouraging results, with **78% of occupants preferring** the system-generated layouts. Moreover, an **89% adoption rate** was observed, indicating that users were willing to either directly implement or adapt the recommended designs.

These findings demonstrate that the proposed framework is not only effective in controlled experimental settings but also delivers practical value in real-world scenarios. By successfully integrating cultural principles with computational optimization, the system achieves a balance between tradition, usability, and modern design expectations.

VI. DISCUSSION AND CONCLUSION

The results of this study clearly demonstrate that a multi-objective optimization approach yields significantly better outcomes compared to single-objective methods. By simultaneously considering cultural alignment, aesthetic quality, and functional efficiency, the proposed hybrid framework produces more balanced and context-aware interior design solutions. Moreover, the computational cost of approximately 45–60 seconds per run indicates that the system is efficient enough to support semi-interactive or real-time design applications.

Despite these strengths, certain limitations remain. The CNN model relies on synthetically generated training data, which may not fully capture the complexity of real-world interior layouts. Additionally, the encoding of Vastu principles is based on generalized interpretations, which can vary across practitioners. The evaluation scope, although meaningful, is relatively limited in scale, and the current system focuses on static layout optimization without incorporating temporal or adaptive design dynamics.

Future work can address these limitations by exploring data-driven approaches for learning Vastu rules, integrating occupant preference modeling, and extending the framework to multi-room or full-building optimization. Further validation across diverse cultural design systems and the incorporation of augmented reality for enhanced visualization and interaction also present promising directions.

Table 6: Comparison with Existing Approaches

Approach	Vastu	ML	GA	Integrated
Gandi et al. (2022)	✓	—	—	—
Liu & Xu (2021)	—	✓	—	—
Watanabe et al. (2007)	—	—	✓	—
This Work	✓	✓	✓	✓

In conclusion, this research successfully demonstrates the integration of traditional architectural knowledge with modern computational techniques. The proposed hybrid framework combines rule-based reasoning, machine learning-driven evaluation, and evolutionary optimization to achieve measurable improvements in design quality.

The real-world validation further confirms the practical applicability and cultural relevance of the system, highlighting its potential for deployment in real-life interior design scenarios. Additionally, the flexibility of the framework suggests that it can be extended to other cultural contexts and design domains, making it a promising direction for future research at the intersection of artificial intelligence and human-centered design.

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