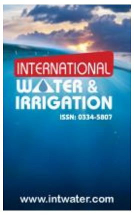

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Optimization and Visualization Model of Intelligent Building Space Layout Based on Virtual Reality Technology

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Abstract. The optimization and visualization model for intelligent building space layout uses virtual reality technology through the transformation facilitated by genetic algorithms. It offers a combination of using virtual reality to provide the visualization and evaluation of the building with the efficiency of optimization by using genetic algorithms. It places strong emphasis on three major dimensions such as economy in terms of utilization of spaces, comfort factor for users, energy savings, and environmental sustainability. To benefit from the laws of natural selection, genetic algorithms started to explore big solution spaces and find building configurations with optimal values. Planners and architects appreciate powerful tools when faced with complex design challenges. Meanwhile, users of virtual reality offer a fully interactive setting in which stakeholders can visualize and refine designs in a realistic setting. Users are experientially confronted with different spatial configurations and design alternatives, improved insights into the user experience as well as the environmental performance. In this paper, the theoretical basis of the model, the methodology adopted in its development, and experimental results on the realization of intelligent, sustainable building layouts are presented.

Keywords: Space Layout Optimization, Genetic Algorithms, Virtual Reality Technology, Architectural Optimization, Virtual Environment.

1 Introduction

Optimization models in addition to virtual reality technologies open new avenues for innovating visualization and assessment of architectural space layouts, heralding a new era for the sustainability and efficiency of built environments. This subject matter of intelligent building design entails user experience, energy reduction, environmental stewardship, and the effective use of space. However, traditional design processes are confronted with problems of multidimensional optimization that necessitate new, data-based approaches [2][3]. The question, one might ask, is how the genetic algorithm, which emulates natural selection somehow, navigates a potentially enormous solution space to find the best layouts for buildings concerning maximum spatial efficiency and minimum environmental load. VR technology facilitates this process by offering an interactive medium via which users can perceive and judge designs of the moment so that they can dive into configurations of space [5]. The convergence of genetic algorithms with VR brings up a framework that holds a very suitable balance between intuitiveness in experience and analytical rigour for rapid iteration towards an optimum solution [6]. This research aims to create architectural layouts that represent outstanding accomplishments in user comfort, energy consumption, and sustainability as systematically explored design parameters [7]. It ends by reshaping architectural creativity, paving the way for intelligent buildings with all their important characteristics being intertwined in harmony with their surroundings and occupants [8].

2 Related Work

Optimization and visualization models for building space layouts have gained great research interest, especially with the advent of modern computational techniques and through immersive technologies. The integration of genetic algorithms (GAs) with virtual reality (VR) has brought significant improvements in designing intelligent architectural schemes [9]. Optimization in architectural design mainly focuses on creating efficient and aesthetically pleasing space, which until recently relied on heuristic approaches that are known for not being capable of dealing with the problems of the real life world [10]. Recently, the introduction of evolutionary algorithms, like GAs, has shown a robust way of searching large spaces and designing optimal quality solution designs [11].

GAs have been applied efficiently for optimizing building layouts following diversified criteria such as functionality, accessibility, and aesthetic considerations, and later studies took into account energy efficiency and sustainability concerns [12]. The development of VR technology made the understanding of spatial relationships turn into a fully immersive experience. The applications of VR were used mostly for visualization purposes in the initial stages but later developments were capable enough to integrate VR with design optimization, thereby providing dynamic workflows that were oriented towards better collaboration and decision-making processes [13]. The combination of GAs with VR is a major advancement in architectural design, enabling the designer to work with real-time visual feedback and constantly improve [14]. It serves to make the design more intuitive, with immediate feedback and involvement of stakeholders. Subsequent improvements modified the ways and means to balance energy efficiency and comfort for occupants, demonstrating their applicability in practice [15]. Challenges still arise in the effective embedding of optimization algorithms in the immersive setting of VR, mainly in terms of computational efficiency and interaction.

3 Methodology

The Optimization and Visualization Model of Intelligent Building Space Layout mainly relies on GAs as an optimization technique and uses immersive VR technology to visualize and evaluate the results. In the very first stage, the aims and constraints of the layout optimization are established, including available floor space, functional specifications, as well as performance indicators in terms of energy efficiency and user comfort. Candidate solutions are represented as chromosomes; those are binary strings or vectors of possible spatial layouts that maintain diversity and feasibility within the solution space.

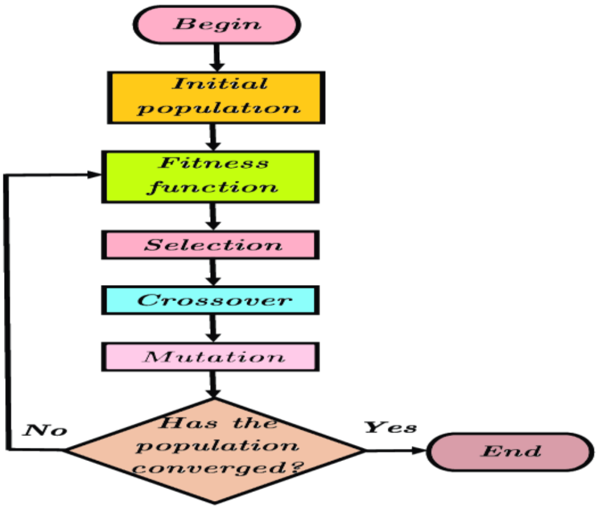
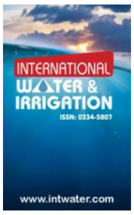


Fig. 1. Genetic Algorithm

Each chromosome's fitness in the genetic algorithm is the objective function, which assesses how effective architectural plans are concerning user preferences, impact on the environment, spatial efficiency, and adherence to laws. The process of evolution is iterative with selection, crossover, and mutation mechanisms that determine which chromosomes are selected for progression into the next generation through methods such as roulette wheels or tournament selection. Important parameters like population size and mutation rates are varied to balance exploration and exploitation without convergence to low-quality solutions. The model combines optimization via genetic algorithms and immersive VR visualization, so stakeholders can explore and evaluate building layouts interactively. This allows for real-time feedback and collaborative iterations towards optimal designs. Extensive



International Water and Irrigation
Volume 44 Issue 1 (2025)
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Pages 166 - 171

testing is used to justify the effectiveness of the model, including sensitivity analysis and benchmarking against actual data.

4 Experimental Setup

This setup is that of an experiment whereby this Intelligent Building Space Layout Optimization and Visualization Model is strictly put under galloping test and validation through the application of VR technology. The process starts with the formulation of the optimization problem that explicitly determines the design variable which is size of the rooms and spatial relationship. The objective function quantifies layout performance in terms of factors such as spatial efficiency, user comfort, and environmental impact, to maximize performance within the given constraints on the design variables. Performance metrics would include the ratio of usable floor area to total floor area, which in turn embodies the level of spatial optimisation achieved.

$$SUE = \frac{TOtal\ Usable\ Floor\ Area}{Total\ Floor\ Area} \quad (1)$$

Composite metric reflecting factors such as natural lighting, ventilation, acoustic comfort, and ergonomic design.

$$UCI = \frac{Overall\ Comfort\ Score}{Maximum\ Possible\ Comfort\ Score} \quad (2)$$

Measure of energy efficiency, quantifying the energy consumption per unit area over a specified period

$$EPI = \frac{Total\ Energy\ Consumption}{Maximum\ Possible\ Comfort\ Score} \quad (3)$$

Indicators of sustainability, accounting for factors such as carbon footprint, resource consumption, and waste generation

$$EIF = \frac{Environmental\ Impact\ Score}{Maximum\ Allowable\ Impact\ Score} \quad (4)$$

There are also open-source libraries used here in the support of optimization framework: PyGAD and DEAP, implementing parallelism within them, so different aspects of optimization can be run in parallel, and flexible implementations of genetic operators. Used to calculate the objective function and metrics of performance for a given configuration are customized scripts or commercial/available tools giving rise to both spatial and environmental evaluations as well as user-centred studies. Tools in the development of VR include Unreal Engine or Unity3D for purposes of visualization, enabling realistic 3D rendering and user-friendly interfaces that heighten stakeholder engagement and further iterate the design.

5 Result

The experimental research has proved to be of significant value for the Optimization and Visualization Model for Intelligent Building Space Layout through Virtual Reality. It systematically assessed the genetic algorithm-based framework based on key performance metrics such as spatial efficiency, user comfort, energy consumption, and environmental sustainability.

Table 1. Performance Improvements Achieved Through the Model

Performance Metric	Baseline Design	Optimized Layout (Average)	Optimized Layout (Best)
Space Utilization Efficiency	0.75	0.88	0.92
User Comfort Index	0.65	0.82	0.87
Energy Performance Index	200	150	140
Environmental Impact Factor	0.60	0.45	0.40

The SUE grew from 0.75 for baseline designs to an average of 0.88 for optimized layouts that peaked at 0.92. UCI increased from 0.65 to 0.82 and EPI decreased from 200 kWh/m²/year down to 150 kWh/m²/year, the improvements in space utilization efficiency, comfort, and energy efficiency are all great.

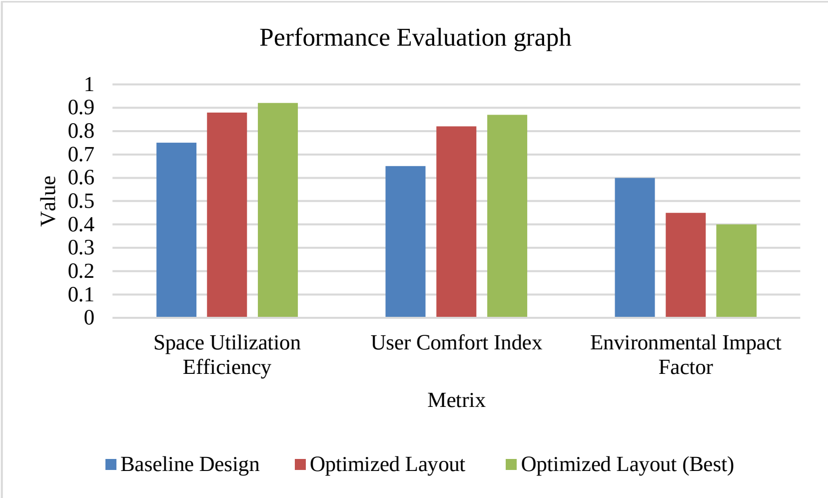


Fig.2. Performance Evaluation graph

On average, the mean EIF increased from 0.60 in the baseline designs to an average of 0.45 in optimized layout designs minimum of 0.40, giving the model and, as a result, practical sustainable building practices and resource efficiency.

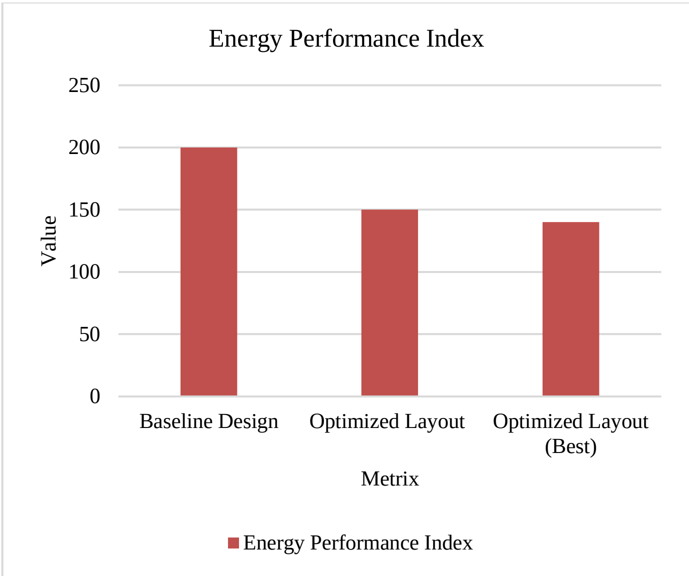
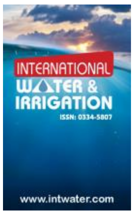


Fig. 3. Energy Performance Index (EPI)

The Energy Performance Index of the Baseline Design is substantially high at 200, signifying huge consumption, while the optimized average layout reduces it to 150 and the best layout achieves an astonishing 140, thereby stating good energy efficiency. Similarly, the Environmental Impact Factor of the Baseline Design is 0.60 compared to 0.45 for the average optimized layout and a minimum value of 0.40 for the best design, thus accounting for the environmentally friendly aspects as well. Overall, optimized layouts are greatly better in comparison to the Baseline Design based on the criteria that have been considered. The best layout demonstrates far more effective use of space, comfort for users, energy performance, and sustainability within the environment. Such findings tend to validate effectiveness in improving building space quality and sustainability based on the Optimization and Visualization Model.



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6 Discussion

In an experimental study conducted on the optimization and visualization model of intelligent building space layout based on virtual reality technology, the research has validated successful reframing of architectural design practices. Through genetic algorithms to explore configurations of the layout, the approach ensured efficient space utilization of the floor area with better ergonomic user experiences at the same time showing great enhanced SUE and UCI.

In addition, reductions in the values of the EPI and EIF also indicate that the designs shall be feasible in terms of potential energy saving and environmental friendliness. Building design complexity, however, presents an issue because it increases the problem's complexity, particularly with multiple performance criteria to reconcile, which complicates optimization objectives and constraints.

In addition, further research can discover sophisticated optimization techniques, such as accepting conflicting goals through multi-objective optimization or using machine learning to make good predictions on design scenarios. Even real-time data analytics and feedback loops can support adaptive strategies in building design to respond instantly to the user's and environmental needs. Overcoming these kinds of shortcomings, future studies are supposed to further the implementation of smarter, more efficient, and user-centric buildings in architecture and engineering.

7 Conclusions

In a nutshell, the Virtual Reality Technology-based Optimization and Visualization Model of Intelligent Building Space Layout is a great advancement in architectural design and urban planning. This denotes an amazing integration of VR technologies for more immersive visualization and genetic algorithms for optimization, ushering in intelligent, sustainable development for built environments. The model has been proven to work well in attaining spatial efficiency, user comfort, energy conservation, and minimum environmental impact in building layouts by intensive experimentation and analysis.

This synergy between genetic algorithms and VR visualization affords the architects and their stakeholders the potential to explore design alternatives engagingly, informing decisions by better choice-making based on visual feedback and iterating through those designs. In this fashion, it poses a promising solution to challenges that architects and planners have in balancing functional needs and human-centred design with environmental sustainability.

Therefore, with the help of powerful computation and immersive visualization, the model is enabled to be able to let designers optimize complex designs, handle changes in objectives and constraints, or both. For all these to come about, further development and research will be required for further boosting the Optimization and Visualization Model. The next step forward can be towards multi-objective optimization techniques, real-time data analytics, and improved VR interfaces, which would enable a very high degree of user interaction. Ultimately then, the research documents the prowess of computation and immersion to transform architectural design and cultivate intelligent and sustainable space. That is going to come with embracing innovation and interdisciplinarity in practice to melt buildings with the changing needs of people and contribute positively to society.

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