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Enhancing Spatial Legibility through Building Layout Optimization: The Case of Erbil City Shopping Malls

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Abstract: This paper investigates the integration of Architectural Design Optimization (ADO) into architectural design to improve shopping mall layouts. It aims to address the research gap by developing a comprehensive framework for optimizing spatial legibility in shopping mall layouts. The methodology employed a multi-method approach, combining qualitative (researcher's checklist) and quantitative (genetic algorithm, GA) methods in data processing and statistical analysis. Seven shopping malls in Erbil City with different spatial layout typologies served as case studies. Results demonstrated significant improvements in spatial legibility through GA-optimized layouts, resulting in a substantial reduction in occlusivity, an increased visibility area, shorter path lengths, and reduced navigation times. Statistical analysis revealed a strong positive correlation between visibility and navigation efficiency, and that functional aspects of layouts contribute more significantly to spatial legibility than intangible design elements. Surprisingly, linear layouts, rather than hybrid layouts, appeared more effective in accommodating diverse user preferences. The study concluded that the use of GA provides an effective, data-driven approach to improving architectural designs, going beyond traditional qualitative judgments. The novelty of this approach lies in its pioneering application as a systematic optimization technique for the spatial planning of shopping malls, providing quantitative improvements to design elements such as spatial visibility and wayfinding, ultimately enhancing the overall user experience.

1. Introduction

1.1 General Background

The integration of optimization into architectural design processes involves developing, benchmarking, and user-testing novel computational design tools that are more efficient and better acknowledge designers' preferences than existing ones. Enhancing this integration will help architects design more resource- and energy-efficient buildings, thereby contributing to a more sustainable built environment [1]. Architectural Design Optimization

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(ADO) is a well-established area of study and application in computer-aided architectural design (CAAD) that is becoming increasingly accessible to designers. ADO provides techniques and resources for designing buildings with lower life-cycle costs [2]. Due to significant advancements in computer science and mathematical optimization techniques, numerical optimization applications have been contemplated since the 1980s and 1990s. Although the earliest attempts were discovered much earlier, most building engineering studies that integrated an algorithmic optimization "engine" with a building energy modeling program were published in the late 2000s. Wright published pioneering research on optimizing building engineering systems in 1986, using the direct search approach to optimize HVAC systems [3]. In the field of building science over the previous two decades, it can be noticed that the number of optimization publications has risen significantly since 2005. This has demonstrated a strong interest in optimization approaches across the construction research community [4].

The applications of ADO are numerous, such as Energy Efficiency and Environmental Performance, Structural Optimization, Daylighting and Visual Comfort, Acoustic Performance, Thermal Comfort and Indoor Air Quality, Cost Optimization, Façade Design and Form Finding, Crowd Flow and Evacuation Simulation, and Urban and Site Planning. In this study, the ADO focuses on the Spatial Layout Optimization of a shopping mall in Erbil city by applying a novel optimization technique called the Genetic Algorithm. It was put up by Holland in 1992 and is reminiscent of Darwin's theory of the survival of the fittest.[5]. GAs offer benefits like stochastic operators, large point consideration, accessibility, and multiple Pareto solutions for multi-objective optimization problems in a single run [6]. GA) is a powerful stochastic search tool, which is used in solving many mathematical programming problems by examining a large part of the search space, aiming to find an optimal or near-optimal solution. These genetic algorithms have shown improvements, especially in this type of problem that is characterized by a large search space [7,8]. The architectural spatial layout design process is critical for determining how buildings are seen and utilized, with an emphasis on spatial relationships and geometric shapes to suit client requirements [9]. Therefore, the spatial legibility is defined as the ease space which its parts can be recognized and organized into a coherent model, the legibility of the medium as "the extent to which it facilitates the wayfinding process". It can demonstrate the visibility and layout simplicity or complexity [10]. Wayfinding is a cognitive process encompassing orientation, decision-making, path monitoring, and destination recognition. It differs from navigation by emphasizing route assessment and cognitive mapping. Navigation refers to specific means of finding one's way, such as route, landmark, and map navigation [11]. Common navigation considerations to take into account while choosing a path include: 1) path length, 2) number of decision points, 3) number of turns, and 4) signage system [12]. The most important factor that affects wayfinding performance in the cognitive map is a mental representation of a person's knowledge [13].

1.2 Previous Related Studies

Genetic Algorithms (GA) have been applied to optimizing building layouts, demonstrating significant potential in reducing computational time and improving design efficiency. Su and Yan [14] utilized GA to decrease computational overheads in nursing unit daylighting and circulation design, while Zhu and McArthur [15] combined GA with simulated annealing for spatially efficient room layouts in shopping mall projects, highlighting GA's adaptability for complex environments. Similarly, Dalgic et al. [16] employed GA to optimize supermarket shelf layouts with an emphasis on navigability rather than mere space minimization, underscoring GA's flexibility in accommodating multiple objectives. GA's versatility was further demonstrated by Yixuan [17] through structural cost reduction and space maximization in indoor renovations, and by Hasda et al. [18], who implemented a hybrid GA approach for facility layouts with unequal compartments. Additional applications include Dubey's [19] multi-objective GA for sign placement optimization based on visual coverage and Munavalli et al.'s [20] GA-based redesign of outpatient clinic layouts to enhance patient flow and reduce waiting times.

Complementing optimization efforts, studies on spatial legibility and wayfinding have emphasized cognitive, perceptual, and technological influences on navigation performance. Zhang et al. [21] demonstrated augmented reality systems' effectiveness in fostering cognitive map development in complex buildings, while Eshruq Labin [22] identified key qualities essential for efficient wayfinding, such as clarity and distinctiveness. Li and Klippel [23] underscored familiarity and spatial ability as stronger predictors of navigation accuracy than environmental legibility alone. Nazif and Motalebi [24] expanded legibility frameworks to include temporal and emotional dimensions, advocating a multifaceted approach beyond physical characteristics. Chen et al. [25] integrated architectural phenomenology with quantitative spatial syntax analysis to enhance interpretive richness and navigation in museums, whereas Verghote et al. [26] confirmed spatial cognition's role in predicting navigation success using 3D BIM tools.

Research focused on shopping mall spatial configurations reveals their critical influence on user behavior and satisfaction. Hagberg and Styhre [27] defined shopping malls as establishments that maximize revenues while creating a welcoming social environment. Krey et al. [28] define them as retail settings that combine various retail and service establishments for leisure activities. These malls facilitate transactions, socializing, and leisure interactions, making them high-level commercial spaces [29,30]. In this context, Zhou and Liu [31] applied space syntax to optimize node configurations and accessibility within malls, highlighting diversity and humanization as key factors. Fezzai et al. [32] differentiated the spatial perception patterns of familiar and unfamiliar visitors, noting that new visitors prioritize accessibility and visual cues. Similarly, Erdoğan et al. [33] found consumer preference trends leaning towards traditional marketplaces over enclosed malls, valuing attributes like spatial freshness. Al-Juboori and Mustafa [34] demonstrated that varying spatial layouts have concrete impacts on mall functional efficiency, emphasizing interior movement organization and zoning. Meziani and Hussien [35] linked wayfinding effectiveness and environmental factors such as brand diversity and transit accessibility to mall popularity and visitor satisfaction through structural equation modeling. Moreover, Liu et al. [36] analyzed retail interactions within malls via a gravity model, showing the significance of store positioning and floor level on customer flows. Finally, Ali et al. [37] identified the economic environment's influence on consumer behavior and underscored the importance of layout, entertainment options, and service quality in fostering customer loyalty and satisfaction.

The retail environment includes both tangible and intangible elements such as furniture, music, lighting, sound, and scent. Three dimensions are delineated by Bitner [38]: ambient conditions; spatial layout and functionality; and artifacts, signs, and symbols. Customers' non-visual senses are influenced by ambient conditions, and architectural quality is influenced by spatial layout and functionality. In addition to the three dimensions, Turley and Milliman [39] suggest other dimensions of the shopping environment, including the exterior of the building (e.g., architectural style and parking area), decoration variables (e.g., pictures and artwork), and human variables, such as privacy, crowding, and employee factors [39] as cited in [40].

1.3 Research Gap, Problem, Aim, and Hypotheses

According to the studies and research presented previously related to the current research topic, it is noted that there is a gap in the absence of a comprehensive cognitive and theoretical framework for optimizing spatial legibility in shopping mall layouts, coupled with a scarcity of studies employing advanced computational-analytical methods. This gap is particularly evident in the context of balancing multiple factors such as wayfinding, navigation, visibility, circulation, tenant mix, and anchor store placement. To bridge this gap, the current research problem emerged from the fact that, while spatial visibility is imperative for shopping mall layouts, it is challenging due to the diversity of their configurations, functions, and user perceptions. This research aimed to develop an inclusive theoretical-conceptual framework on the potential causal relationship between layout optimization and spatial legibility using Erbil city's shopping malls as a case study, and adopting a valid integrated mathematical approach.

In this study, seven shopping malls in Erbil city with different spatial configurations, some with a single layout approach and some with a hybrid layout approach, were selected as case studies. The goal is to enhance shopping mall layouts by using a novel technique to get a comprehensive understanding of spatial legibility. Layout optimizations for the seven selected case studies are obtained using a genetic algorithm with comparison based on area selection and variables. By adopting a mixed-method approach, quantitatively using a genetic algorithm, and qualitatively by covering most relevant variables in a checklist designed for this purpose. To process the data, statistical methods and procedures were used to prove the following research hypotheses:

H1: Visibility and navigation exhibit the strongest positive correlation with spatial legibility and have the most significant impact on enhancing user orientation and wayfinding performance in shopping mall layouts.

H2: Functional aspects of shopping mall layouts contribute more significantly to spatial legibility than intangible design elements.

H3: A hybrid layout design that incorporates both linear and centralized configurations will better accommodate diverse user preferences than single-approach layouts.

By proving these hypotheses, this study aims to build a comprehensive theoretical and conceptual framework regarding the potential causal relationship between improved shopping mall layouts and spatial legibility, utilizing an integrated mathematical approach.

2. Methods and Tools

The methodology adopted in this research is a multi-methodology (qualitative and quantitative approaches). The researcher's walkthrough (checklist) has been used to analyze several variables and indicators to understand the satisfaction level. These variables are (spatial visibility, occlusivity, path length, time taken, wayfinding and signage system, spatial knowledge and cognition, building layout optimization, shopping habitat, the variety and quality of facilities in shopping malls) as a qualitative method. Each of these variables and their associated indicators can be evaluated on a scale from 1: low satisfaction, 2: partial satisfaction, 3: moderate/neutral, 4: mostly satisfied, and 5: highly satisfied, to provide a comprehensive description of visitor experience within shopping malls. The quantitative method in this study is the Genetic Algorithm (GA) to optimize the layout of shopping malls and solve optimization issues. According to this natural selection-based search technique, the best answer will survive. These techniques are often employed in layout optimization issues because they are strong, straightforward, and effective. The genetic algorithm's fundamentals begin with an initial collection of randomly generated solutions to the problem at hand. The population is the name given to this collection of solutions. Encoding is the representation of the population's individuals, which are referred to as chromosomes. A predetermined fitness function is used to evaluate the population's chromosomes. The chromosomes change with time in what are known as "generations." Every generation creates a new population by combining and altering the chromosomes of an existing population. This study will measure four variables (occlusivity, visibility area, path length, and time taken). This research focuses on shopping malls by adopting the following criteria: 1) diversity in spatial organization of layout arrangements, such as linear, centralized, radial, clustered, grid, and mixed combinations. 2) The function of a shopping mall building not mixed with other functions means it is not a multi-purpose building. 3) The study focuses on the main core of the shopping mall building that includes important components (main entrance, lobby, and the connection with corridors and its branches to retail or stores zones and skylight of the building). 4) The crowded area of the zone due to functional efficiency performance is preferred for the optimization process. 5) The overlapping or junctions between the concepts of different functions within the same zone are also preferred. 6) The same zone will be selected for all the case studies, and 7) the location of the zone must be the same for all these case studies; therefore, all zones are on the ground floor of the shopping mall building in Erbil. The research will exclude Retail strip (linear arrangement of stores along a street), mixed-use development (combination of retail, residential, and office spaces), Bazaar/Souk (traditional covered market with multiple vendors), Retail Quarter (district dominated by shopping), Plaza (open public space surrounded by shops), Galleria (covered shopping street with natural light), and Urban Market (open-air shopping area), In this research the number of case studies are seven.

AutoCAD drawings for four shopping malls were collected from the mall management. For the remaining three cases, detailed floor plans were drawn and measured by the researchers. The selected cases were visited on the ground to collect data. A field survey was also conducted, which consisted of a walkthrough of the buildings to complete a checklist. The optimization process is done in Grasshopper software (a visual programming language and environment that runs within Rhinoceros, developed by Robert McNeel & Associates) and IBM SPSS Statistics Version 29 (originally, SPSS stood for Statistical Package for the Social Sciences, but since IBM acquired it, the official branding is IBM SPSS Statistics) for both methods as shown in Figure 1.

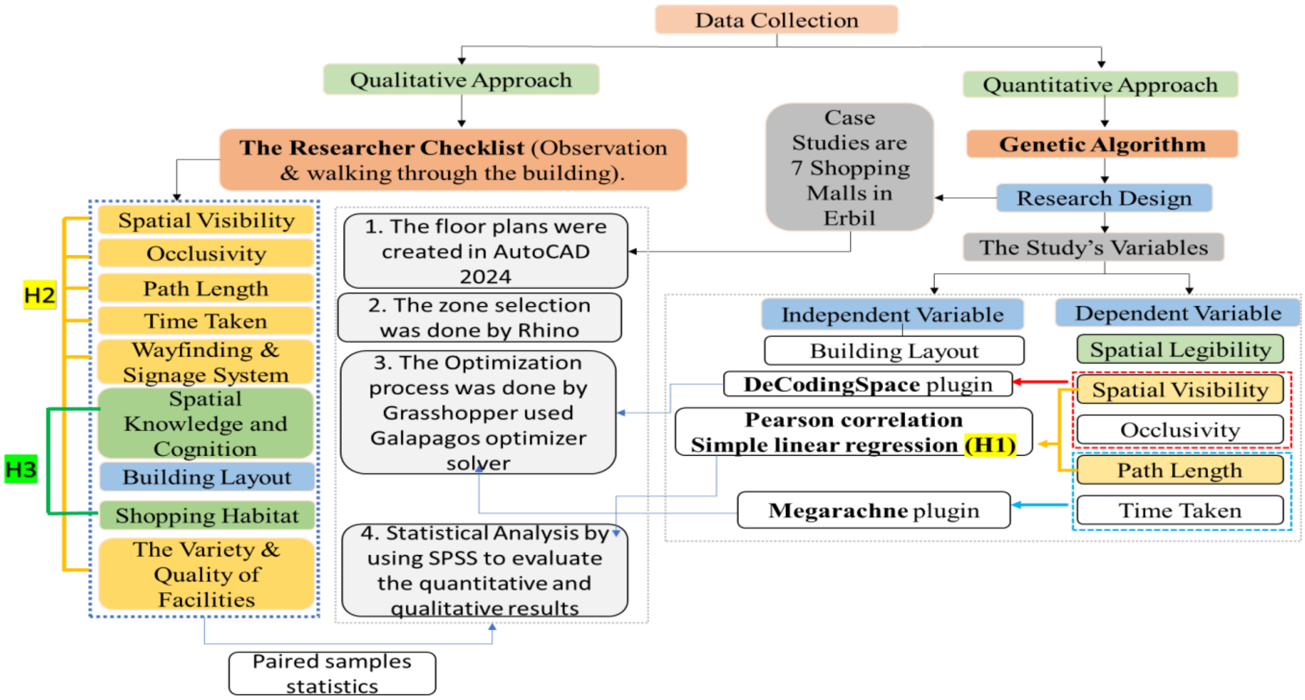
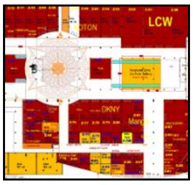
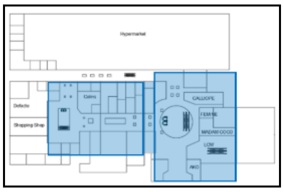
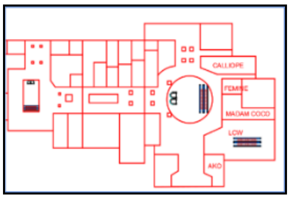
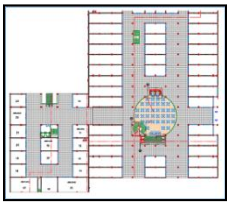
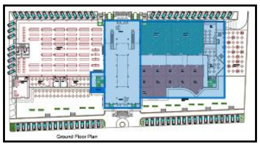
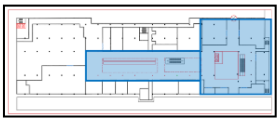
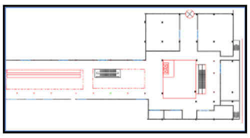
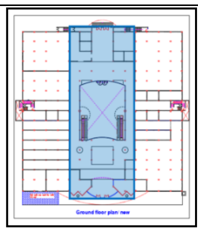
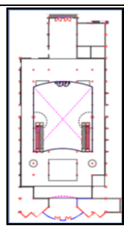
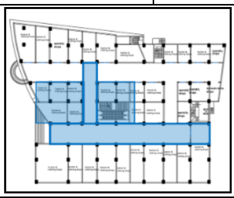
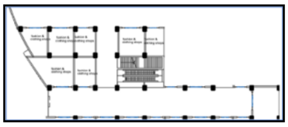
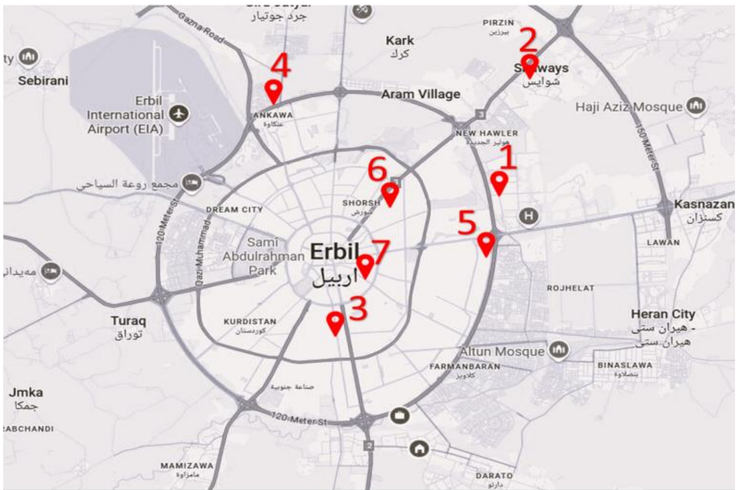


Figure 1. Research Methodology.

The optimization setup used in this study is Galapagos, a genetic algorithm solver embedded in Grasshopper (a single-objective optimizer). Galapagos automatically searches for the best solution to a problem by trying many variations, using principles inspired by natural selection (similar to biological evolution). This is achieved by specifying a fitness value—a number that Galapagos attempts to minimize or maximize. In this study, the goals of the fitness function are to maximize spatial legibility metrics, optimize wayfinding performance, minimize walking distance, and maximize visibility scores. Two types of plugins are used in Grasshopper: one called DeCodingSpaces for two variables (visibility and occlusivity), and the other called Megarachne for path length variables leading to time. Statistical analyses for this study include Pearson correlation, simple linear regression analysis, and a paired-sample t-test used to analyze the quantitative results from the GA and the qualitative results from the checklist. The case studies in this research are seven zones of seven shopping malls. The selected cases are Family Mall (mixed combination-linear & clustered organization), Grand Majidi Mall (mixed combination-linear & clustered organization), Tablo Mall (mixed combination-centralized & grid organization), Ankawa Mall (mixed combination-linear & grid organization), Majidi Mall (linear organization), Mega Mall (grid & radial organization), and Rein Mall (grid organization). All cases are hybrid layout approaches, except Majidi Mall and Rein Mall, which rely on a single layout approach presented in Table 1 and their locations in the Erbil map shown in Figure 2.

Table 1. The selected zones of shopping malls in Erbil city.

	2D Ground Floor Plan of Case Studies	The Selected Zones		2D Ground Floor Plan of Case Studies	The Selected Zones
1. Family Mall			2. Grand Majidi Mall		
3. Tablo Mall			4. Ankawa Mall		
5. Majidi Mall			6. Mega Mall		
7. Rein Mall					



1. Family Mall	4. Ankawa Mall	5.Majidi Mall
2. Grand Majidi Mall	6. Mega Mall	7. Rein Mall
3. Tablo Mall		

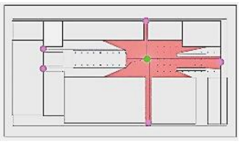
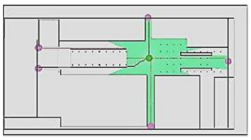
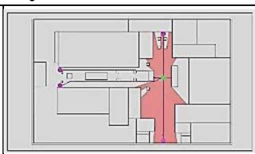
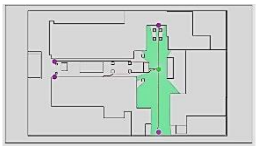
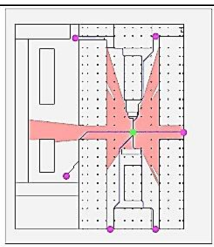
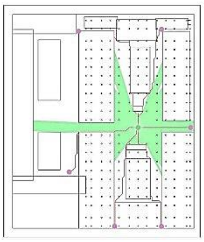
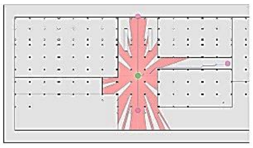
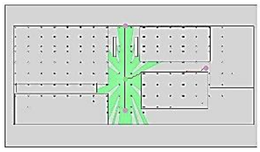
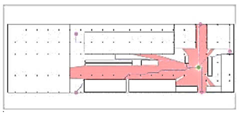
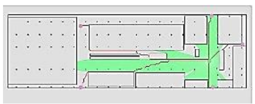
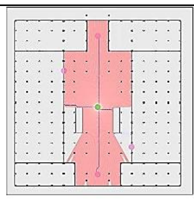
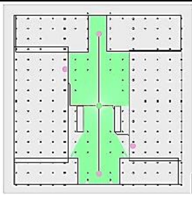
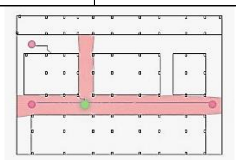
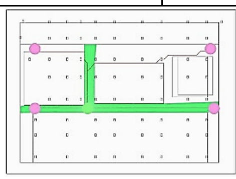
Figure 2. Case study locations on the Erbil City map

3. Results and Discussion

3.1 Results of Layout Optimization by GA

Occlusivity: The seven different case studies were compared, and the results showed significant differences between the original and optimized spatial arrangements. Green isovists indicate the optimum scenarios, whilst red isovists (polygons) describe the initial spatial conditions. Origin locations (shown in green) and destination points (shown in purple) are connected with a variety of trajectory patterns, such as linear, oblique, and zigzag paths, to form the spatial navigation framework. A clear comparative evaluation of spatial alterations is enabled by visualizing these pathways in red for the optimal scenarios and purple for the baseline settings, as shown in Table 2. The highest optimized occlusivity value was recorded at Ankawa Mall, at 296.40, while the lowest was recorded at Rhein Mall, at 33.04.

Table 2. Occlusivity results for all case studies.

A. Occlusivity					
1. Family Mall	 Original state 176.90	 Optimized state 142.48	2. Grand Majidi Mall	 Original state 170.00	 Optimized state 135.67
3. Tablo Mall	 Original state 279.55	 Optimized state 196.22	4. Ankawa Mall	 Original state 377.52	 Optimized state 296.40
5. Majidi Mall	 Original state 171.78	 Optimized state 121.00	6. Mega Mall	 Original state 125.89	 Optimized state 68.35
7. Rein Mall	 Original state 62.62		 Optimized state 33.04		

The range analysis shows that the optimized arrangement is significantly better than the original. The optimized range of values ranges from 33.04 to 296.40, while the original range was from 62.62 to 377.52. This indicates a drop in the range from 19.46% to 47.24%

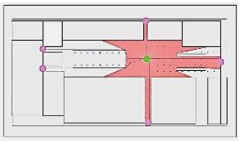
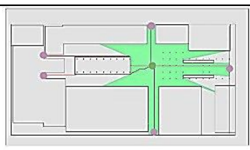
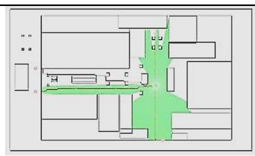
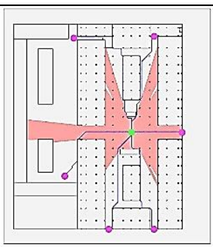
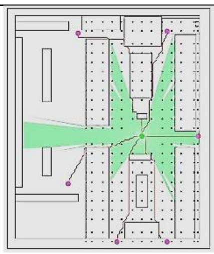
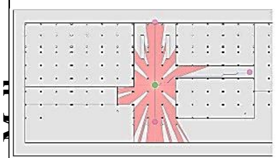
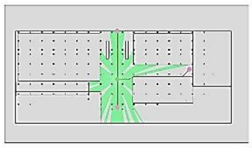
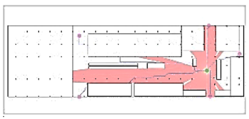
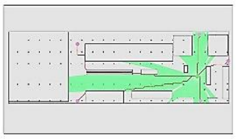
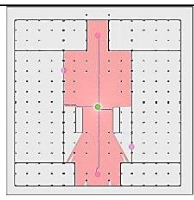
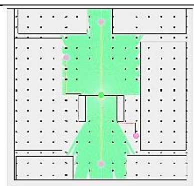
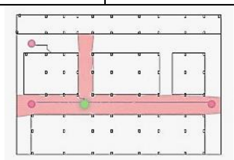
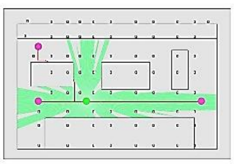
as a percentage. Family Mall achieved the least improvement at 19.46%, while Rein Mall achieved the highest at 47.24%, as shown in Table 3.

Table 3. Occlusivity ranking analysis (best to worst improvements) for all case studies.

Occlusivity Reduction	
1.Rein Mall	47.24%
2. Mega Mall	45.71%
3. Tablo Mall	29.81%
4. Majdi Mall	29.56%
5. Ankawa Mall	21.49%
6. Grand Majdi Mall	20.19%
7. Family Mall	19.46%

The visibility Area: from seven different case studies were compared, the results show that the highest optimized visibility area value was found in Family Mall at 3576.95 m², and the lowest was found in Rein Mall at 448.00 m², as shown in Table 4.

Table 4. Visibility area results for all case studies.

B. Visibility Area					
1. Family Mall	 Original state 2935.05	 Optimized state 3576.95	2. Grand Majdi Mall	 Original state 2063.90	 Optimized state 2628.98
3. Tablo Mall	 Original state 1876.87	 Optimized state 2174.05	4. Ankawa Mall	 Original state 953.69	 Optimized state 1010.00
5. Majdi Mall	 Original state 1716.64	 Optimized state 2167.43	6. Mega Mall	 Original state 1836.38	 Optimized state 2077.45
7. Rein Mall	 Original state 299.62		 Optimized state 448.00		

The range analysis reveals changes in area distribution between the original and optimized layouts. In the original layout, the area values ranged from 299.62 m² to 2935.05 m², while in the optimized layout, the range shifted from 448.00 m² to 3576.95 m². The percentage of improvement in area distribution varies from 5.90% to 49.52%. Rein Mall showed the greatest improvement with an increase of 49.52%, while Ankawa Mall showed the least improvement with a decrease of 5.90%, as shown in Table 5. Even though Rein Mall had the lowest footprint of all the cases examined, its spatial analysis revealed a noteworthy pattern in terms of visibility optimization. The relative improvement in visibility, as represented as a percentage using the comparative optimization equation, showed the highest enhancement coefficient among all the cases studied, even though its absolute visibility levels before and after optimization were both relatively lower than those of other cases.

Table 5. Visibility ranking analysis (best to worst improvements) for all case studies.

Visibility area improvement	
1. Rein Mall	49.52%
2.Grand Majidi Mall	27.38%
3. Majdi Mall	26.26%
4. Family Mall	21.87%
5.Tablo Mall	15.38%
6. Mega Mall	13.13%
7. Ankawa Mall	5.90%

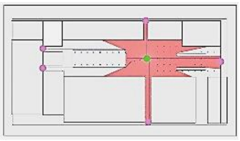
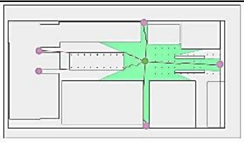
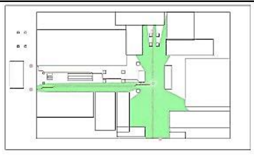
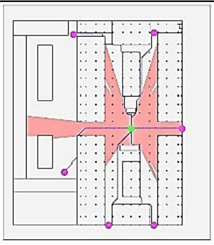
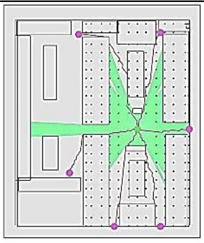
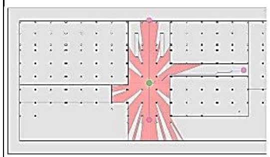
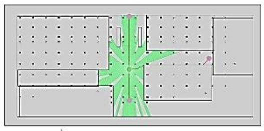
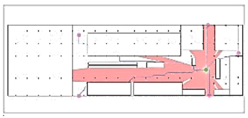
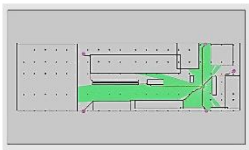
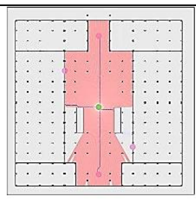
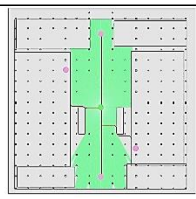
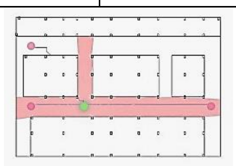
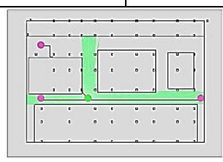
Path Length and Time Taken: The range analysis of values for both path length and time taken highlights measurable improvements following optimization. For path length, the original range spanned from 71.00 m to 384.33 m, which was reduced to 69.00 m to 375.34 m in the optimized layout. This reflects a percentage reduction ranging from 0.93% to 8.26%, with the most significant improvement observed in Tablo Mall and the least in Grand Majdi Mall. Similarly, the time taken to navigate between spaces originally ranged from 47 seconds to 4.27 minutes and was optimized to a range of 46 seconds to 4.17 minutes. The percentage reduction in time taken ranged from 0.98% to 8.13%, again showing the greatest improvement in Tablo Mall and the smallest in Grand Majdi Mall (Table 6).

Table 6. Path length and time taken ranking analysis (best to worst improvements) for all case studies.

Path Length Reduction		Time Taken Reduction	
1. Tablo Mall	8.26%	1. Tablo Mall	8.13%
2. Mega Mall	6.18%	2. Mega Mall	6.54%
3. Rein Mall	2.82%	3. Ankawa Mall	2.80%
4. Majdi Mall	2.81%	4. Majdi Mall	2.74%
5. Ankawa Mall	2.80%	5. Family Mall	2.34%
6. Family Mall	2.34%	6. Rein Mall	2.13%
7. Grand Majdi Mall	0.93%	7. Grand Majdi Mall	0.98%

The highest optimized path length value was found at Family Mall, at 375.34 meters, and the highest optimized time taken value in the same mall was 4.17 minutes. Conversely, the lowest optimized path length value was found at Rein Mall, at 69.00 m, and the lowest value for optimized path time in the same mall was 46 seconds (Table 7).

Table 7. Path length and time taken results for all case studies.

C. Path length and Time taken					
1. Family Mall	 Original state 384.33 m /4.27 mins	 Optimized state 375.34m 4.17 mins	2. Grand Majidi Mall	 Original state 274.20 m /3.05 mins	 Optimized state 271.65 m 3.02 mins
3. Tablo Mall	 Original state 365.51 m 4.06 mins	 Optimized state 335.31 m 3.73 mins	4. Ankawa Mall	 Original state 96.00 m 1.07 mins	 Optimized state 93.31 m 1.04 mins
5. Majidi Mall	 Original state 296.54 m 3.29 mins	 Optimized state 288.20 m/ 3.20 mins	6. Mega Mall	 Original state 137.58 m /1.53 mins	 Optimized state 129.08 m 1.43 mins
7. Rein Mall	 Original state 71.00 m 47 seconds	 Optimized state 69.00 m 46 seconds			

3.2 Comparative Analysis Between GA Results and The Checklist Results

To holistically assess the spatial performance of selected shopping malls in Erbil, two complementary evaluation methods were employed: numerical optimization using Genetic Algorithms (GA) and a user satisfaction checklist. Based on four important spatial legibility and navigation metrics—Occlusivity Reduction, Path Length Reduction, Time Taken Reduction, and Visibility Area Improvement, attained through layout optimization. Table 8 compares the performance of seven shopping malls. The total success of each mall in improving spatial legibility and user movement efficiency is determined by evaluating its numerical improvements and ranking them. The research provides a clear hierarchy of effectiveness to direct future debate and recommendations on layout optimization tactics by highlighting which malls showed excellent and balanced performance across criteria and other ones showed average or lower improvements.

Table 8. Comparative analysis of malls

Comparative Analysis of shopping malls		
Mega Mall	2nd Highest Occlusivity Reduction (45.71%)	**(1) Best performance**
	2nd in Path Length Reduction (6.18%)	
	2nd in Time Taken Reduction (6.54%)	
	Mid-range in Visibility Area Improvement (13.13%)	
	Consistently strong and balanced performance across metrics	
Tablo Mall	Top performer in Path Length Reduction (8.26%)	**(2) Best performance**
	Top performer in Time Taken Reduction (8.13%)	
	Moderate Occlusivity Reduction (29.81%)	
	Mid-range in Visibility Area Improvement (15.38%).	
Majidi Mall	Clear Occlusivity Reduction (29.56%)	**(3) Best performance**
	3rd Highest Visibility Area Improvement (26.26%)	
	Moderate Path Length and Time Taken Reductions (2.81% & 2.74%)	
	Overall, reliable and effective performance	
Rein Mall	Highest Visibility Area Improvement (49.52%)	**(4) Average performance**
	Moderate Path Length (2.82%) & Time Taken Reduction (2.13%)	
	High Occlusivity Reduction (47.24%), but not consistently top in all metrics	
Family Mall	Least Occlusivity Reduction (19.46%)	**(5) Average performance**
	Low-moderate Visibility Area Improvement (21.87%)	
	Slightly lower Path Length (2.34%) & Time Taken Reduction (2.34%), Consistent but lacks standout performance.	
Ankawa Mall	Moderate Occlusivity Reduction (21.49%)	**(6) Lower performance**
	Low Path Length (2.80%) & Time Taken Reduction (2.80%)	
	Lowest Visibility Area Improvement (5.90%)	
Grand Majidi Mall	Lowest in Path Length Reduction (0.93%) and Time Taken (0.98%)	**(7) Lower performance**
	Low Visibility Area Improvement (27.38%) despite being 2nd numerically	
	Occlusivity Reduction is low (20.19%)	
	Consistently poor performance across most metrics	

Table 9 presents the checklist-based evaluation, which collects user impressions across a variety of spatial legibility characteristics, including visibility, navigation, signage systems, path clarity, and facility quality. Colour-coded satisfaction scores allow you quickly grasp each mall's performance strengths and shortcomings.
Table 10 illustrates the differences between the genetic algorithm and the checklist. The checklist method ensures that these designs are easy to read, navigate, and accept by actual users, while the genetic algorithm provides powerful optimization capabilities that enable the identification of high-performance spatial layouts. In architectural design research focused on spatial legibility, these two approaches are highly complementary, working together to bridge the gap between objective performance and subjective experience.

Table 9. The case studies checklist results

Shopping Malls Checklist Results (legend: dark green = Highly Statisfied; green = Mostly Statisfied; yellow = Moderate/Neutral; red = Partial Statisfaction; dark red = Low Statisfaction)

Shopping Malls Checklist Results		The Variables and Number of Indicators								
		Spatial Visibility (6)	Occlusivity (5)	Path Length (5)	Time Taken (5)	Wayfinding and Signage System (10)	Spatial Knowledge and Cognition (12)	Building Layout (15)	Shopping Habitat (16)	The Variety and Quality of Facilities (11)
Family Mall	Average Scores	3.8	3.2	2.8	3.2	1.9	3.2	3.8	3.8	4.4
	Satisfaction Level	Mostly Statisfied	Moderate/Neutral	Moderate/Neutral	Moderate/Neutral	Partial Statisfaction	Moderate/Neutral	Mostly Statisfied	Mostly Statisfied	Mostly Statisfied
Grand Majidi Mall	Average Scores	4.3	4.4	2	3	2.9	3	3.6	4	4.1
	Satisfaction Level	Mostly Statisfied	Mostly Statisfied	Partial Statisfaction	Moderate/Neutral	Moderate/Neutral	Moderate/Neutral	Mostly Statisfied	Mostly Statisfied	Mostly Statisfied
Tablo Mall	Average Scores	3.6	4.2	3.8	4	2.3	4.1	4.2	3.8	2.7
	Satisfaction Level	Mostly Statisfied	Mostly Statisfied	Mostly Statisfied	Mostly Statisfied	Partial Statisfaction	Mostly Statisfied	Mostly Statisfied	Mostly Statisfied	Moderate/Neutral
Ankawa Mall	Average Scores	2.5	2.8	4.6	4.2	1.4	4.2	3.3	2.8	2.5
	Satisfaction Level	Moderate/Neutral	Moderate/Neutral	Highly Statisfied	Mostly Statisfied	Low Statisfaction	Mostly Statisfied	Moderate/Neutral	Moderate/Neutral	Moderate/Neutral
Majidi Mall	Average Scores	3.7	4	3.8	3.6	2.4	4	4.4	3.6	3.4
	Satisfaction Level	Mostly Statisfied	Mostly Statisfied	Mostly Statisfied	Mostly Statisfied	Partial Statisfaction	Mostly Statisfied	Mostly Statisfied	Mostly Statisfied	Moderate/Neutral
Mega Mall	Average Scores	3	3	4	4	1.4	3.8	3.7	2.9	2.5
	Satisfaction Level	Moderate/Neutral	Moderate/Neutral	Mostly Statisfied	Mostly Statisfied	Low Statisfaction	Mostly Statisfied	Mostly Statisfied	Moderate/Neutral	Moderate/Neutral
Rein Mall	Average Scores	2.7	2.8	4.2	3.8	1.5	4.1	3.5	2.3	1.2
	Satisfaction Level	Moderate/Neutral	Moderate/Neutral	Mostly Statisfied	Mostly Statisfied	Partial Statisfaction	Mostly Statisfied	Mostly Statisfied	Partial Statisfaction	Low Statisfaction

Table 10. The differences between GA and the checklist

Aspect	Genetic Algorithm (GA)	Checklist Method
Nature	Computational, objective	Human-centered, subjective
Focus	Spatial performance metrics	Perceived spatial legibility and satisfaction
Scope	Optimized scenarios with no structural redesign	Existing user experience and satisfaction levels
Role in Study	Enhances layout efficiency	Assesses real-world usability & perception
Validation	Quantifies spatial improvements	Confirms relevance to actual user needs

3.3 Statistical Analysis of GA-Checklist Results

The relationship between visibility and path length (path length is a measure used to evaluate navigation efficiency; it is a quantitative aspect of navigation, specifically a measure of the distance between two points within a layout to evaluate navigation efficiency in architectural layouts) shows a statistically significant positive relationship between them, equal to 0.780, with a sig. or p-value of 0.000, i.e., less than 0.01 and 0.05, indicating a highly significant positive relationship. Therefore, the visibility of spatial layout was closely related to navigation (path length) in shopping malls; as the visibility of the space increased, navigation also increased. This result would lead to an effect of visibility on the navigation variable in shopping mall layouts (Table 11). In this study, regression analysis was used to determine the effect of visibility as the independent variable and navigation as the dependent variable in a simple linear regression analysis. The visibility effect value was 0.098, and the R-square coefficient was 0.608, or 60.8%, which is the coefficient of determination, indicating that changes in Y (path length - navigation) are caused by X (navigation). Overall, the sample is highly statistically significant, with an F value of 62.102 and a sig. or P-value of 0.000, making this an acceptable regression model, as shown in Table 12.

Table 11. Pearson correlation analysis of visibility and path length for all case studies.

Correlations			
		Visibility	**Path length**
Visibility	Pearson Correlation	1	.780**
	Sig. (2-tailed)		.000
	N	42	42
Path length	Pearson Correlation	.780**	1
	Sig. (2-tailed)	.000	
	N	42	42
**. Correlation is significant at the 0.01 level (2-tailed).			

Table 12. Linear regression analysis between visibility and path length.

Dependent Variable	**Independent Variable - Visibility**				
Navigation	B_0	B_1	F	Sig.	R-square
	62.343	0.098	62.102	0.000	0.608

The scatterplot, shown in Figure 3, illustrates the relationship between visibility and path length across several data points (possibly zones or nodes in a shopping mall layout). Statistical analysis reveals a strong positive correlation between visibility and path length, with an R^2 of 0.608 ($R^2 < 1$). These results support the first hypothesis, which states that visibility and navigation exhibit the strongest positive correlation with spatial legibility and have the most significant impact on enhancing user orientation and wayfinding performance in shopping mall layouts.

Because of its crucial function in spatial analysis, the visibility variable is highlighted more often in this study than other variables assessed by the genetic algorithm (GA). The total efficacy of navigation and spatial clarity is enhanced by optimal visibility. In particular, less occlusivity in a location improves visibility, which promotes faster navigation and more effective movement. This relationship demonstrates how improved spatial organization can improve visibility, save navigation time and enhance user experience by creating a more visible and accessible environment. Consequently, the study's emphasis on visibility reflects its basic influence on architectural design and spatial efficiency. In other words, it can be concluded that the perfect visibility of the place means less existing of occlusivity, the perfect visibility in the place means a quicker way to find the paths or route of the circulation system, which leads to less time taken. However, it is vital to acknowledge a different viewpoint presented in commercial design discourse: longer navigation times may boost store exposure and stimulate impulse buying, which might be strategically helpful for retailers. In this study, the emphasis remains on spatial legibility and cognitive ease, which is especially important in contexts where clarity, direction, and navigation are vital to user comfort and pleasure. Nonetheless, future research might take a balanced approach, combining both navigation efficiency and commercial exposure objectives, to assess how circulation patterns can be optimized to serve both user-friendly spatial clarity and the retail environment's economic aims.

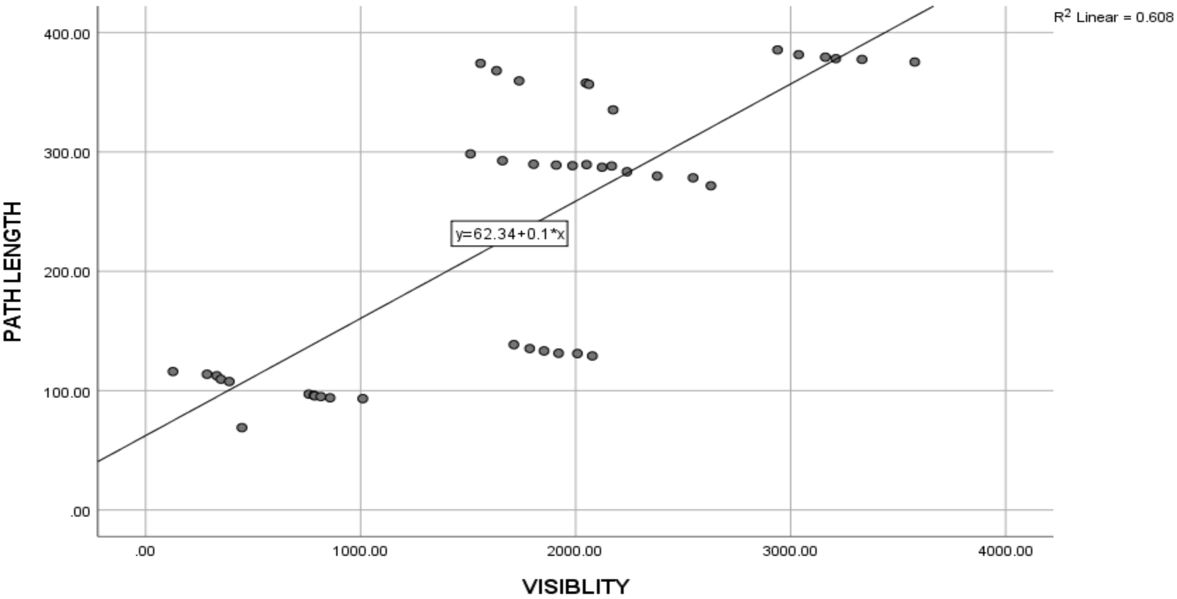


Figure 3. The scatterplot of visibility-path length/navigation.

Paired-sample statistical analysis was used to identify two aspects of the shopping environment (functional efficiency and intangible design elements, specifically the variety and quality of facilities in shopping malls, with an emphasis on aesthetics). Table 13 presents three pairs. The first pair is the functional aspect, with the variety and quality of facilities (the research focuses on shopping mall layouts). Therefore, pairs 2 and 3 will be the layout for each aspect of the mall. In pair 1, the mean for the functional aspect is 3.16, indicating moderate /neutral satisfaction. The mean for the variety and quality of facilities is 2.90, indicating partial satisfaction. The mean difference is 0.26. The relationship is not statistically significant, with a Sig. or p-value of 0.469 greater than 0.05. In pair 2, the mean for the mall layout is 3.78, indicating mostly satisfaction; the mean difference between them is 0.88; their relationship is almost significant due to sig. or the P-value is 0.053, which is slightly greater than 0.05. In the third pair, the mean for the functional aspect is 3.16, meaning it is moderately/neutrally satisfied, and the mean for the mall layout is 3.78, meaning it is mostly close to satisfied. Their means, or mean differences, are -0.62, and the value is negative in this case because the second reading (highlighted in yellow) is larger than the first reading (highlighted in blue), and their standard deviation is 0.23047. Their relationship is highly significant because the Sig. or P value is 0.000, less than 0.05 and 0.01. The functional aspect of shopping malls contributes more to the spatial legibility of mall layouts (layout is the main variable in this analysis) than the intangible design elements. Therefore, the second hypothesis is supported, which states that the functional aspects of shopping mall layouts contribute more to spatial legibility than the intangible design elements.

Table 13. Paired samples statistics of functional aspects and intangible design elements of shopping mall layouts.

Paired Samples Statistics							
Qualitative Spatial Analysis		N	Mean	Mean Differences	Std. Deviation	t	Sig. 2-tailed
Pair 1	Functional	7	3.16	0.26	0.35	0.77	0.469
	Variety & quality	7	2.90		1.01		
Pair 2	Layout	7	3.78	0.88	0.39	2.40	0.053
	Variety & quality	7	2.90		1.01		
Pair 3	Functional	7	3.16	-0.62	0.35	-7.15	0.000
	Layout	7	3.78		0.39		

Paired sample statistical analysis was also used to determine the spatial approach, organization, or configuration of seven shopping malls in Erbil that accommodate diverse user preferences. Mall layout is the key variable in this case, firstly, spatial knowledge and perception, and secondly, shopping habitat, to assess whether a single-approach layout or a hybrid approach leads to greater diversity in user perceptions. In Table 14, Pair 1, the mean for mall layout is 3.78, and the mean for spatial knowledge/cognition is 3.76; they have similar values, which means they are close to complete satisfaction. Their mean, or mean difference, is 0.01, with a standard deviation of 0.58772. They are equal, so their relationship is not statistically significant, and the p-value is 0.934, which is greater than 0.05. In Pair 2, the mean for mall layout is 3.78, which is close to complete satisfaction, and the mean for shopping habitat is 3.29, which is moderate/neutral satisfaction. Their mean is 0.48631, with a standard deviation of 0.54621. Their relationship is almost statistically significant (very weak significance), and the p-value is 0.057, which is slightly greater than 0.05 but greater than 0.01. The results show that the shopping environment has the opportunity to accommodate diversity in user perception in terms of exploration or scanning of shopping mall locations, rather than working memory, spatial knowledge, and perception. For the type of layout or organization, whether a single layout approach or a hybrid layout approach has a greater chance of creating diversity in user preferences based on shopping habitat, as Figure 4 shows (P1 = Family Mall - mixed combination - linear and clustered layout, P2 = Grand Majidi Mall - mixed combination - linear and clustered layout, P3 = Tablo Mall - mixed combination - centralized and gridded layout, P4 = Ankawa Mall - mixed combination - linear and gridded layout, P5 = Majidi Mall - linear layout, P6 = Mega Mall - grid and radial layout, P7 = Rein Mall - gridded layout). P5 has the highest value of 4.4 in Majidi Mall (linear layout), followed by P3 equal to 4.2 in Tablo Mall (centralized and grid layout), then Family Mall 3.8, Mega Mall 3.67, Grand Majidi Mall 3.6 and the last two layouts are Rein Mall 3.53 and 3.27 in Ankawa Mall. As shown in Figure 3, the third hypothesis states that a hybrid layout design combining linear and centralized arrangements will better meet diverse user preferences than single-approach layouts. Paired-sample statistics results show that the linear layout approach, as a single arrangement, has a greater chance of spatially organizing shopping mall layouts than the other single-approach layouts, compared to hybrid or mixed layouts. Therefore, this hypothesis is rejected.

Table 14. Paired samples statistics of spatial knowledge and shopping habitat.

Paired Samples Statistics							
Qualitative Spatial Analysis		N	Mean	Mean differences	Std. Deviation	t	Sig. 2-tailed
Pair 1	Layout	7	3.78	0.01	0.39	0.09	0.934
	Spatial knowledge & cognition	7	3.76		0.48		
Pair 2	Layout	7	3.78	0.49	0.39	2.36	0.057
	Shopping habitat	7	3.29		0.65		

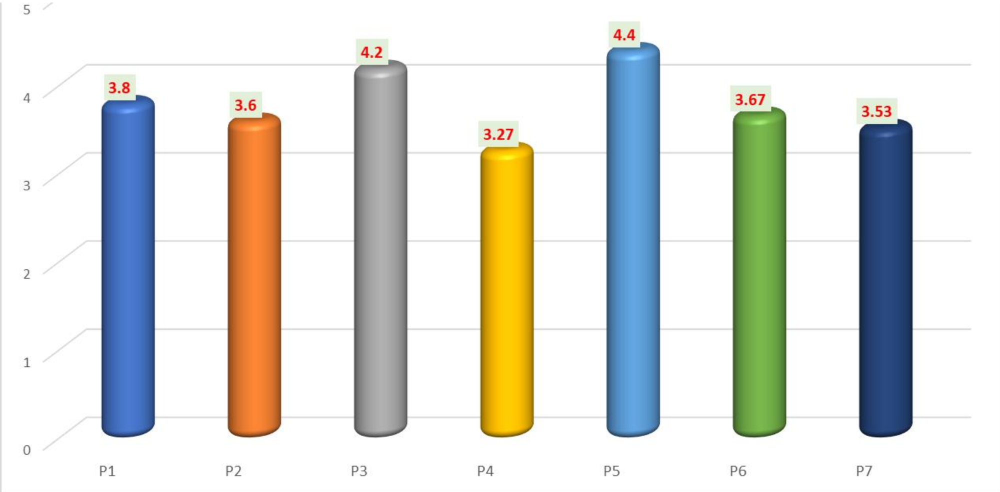


Figure 4. Bar chart of shopping mall layout approaches.

4. Findings and Conclusions

This study integrated optimization into architectural design processes, contributing to a more efficient and user-friendly built environment through Architectural Design Optimization (ADO). The research focused on the Spatial Layout Optimization of shopping malls in Erbil city, applying the Genetic Algorithm (GA) as a novel technique. The study aimed to enhance shopping mall layouts by gaining a comprehensive understanding of spatial legibility. It also intends to construct a comprehensive theoretical and conceptual framework regarding the causal relationship between layout optimization and spatial legibility, using Erbil city's shopping malls as a case study and utilizing an integrated mathematical approach. The methodology adopted a multi-methodology approach, combining qualitative (researcher's walkthrough and checklist) and quantitative (Genetic Algorithm) methods. The qualitative variables included Spatial Visibility, Occlusivity, Path Length, Time Taken, Spatial Legibility, Navigation, Wayfinding and Signage System, Spatial Knowledge and Cognition, Building Layout Optimization, Shopping Habitat, and the Variety and Quality of facilities in shopping malls, evaluated on a satisfaction scale. The quantitative method used GA to optimize mall layouts, focusing on maximizing spatial legibility, optimizing wayfinding performance, minimizing walking distance, and maximizing visibility scores. The study analyzed seven shopping malls in Erbil with varied spatial organizations. The optimization process was performed using Grasshopper software with Galapagos (a genetic algorithm solver) and IBM SPSS Statistics.

The results from the layout optimization by Genetic Algorithm showed:

- Occlusivity: All optimized spatial arrangements demonstrated significant improvements over the original states, with Rein Mall showing the largest improvement (47.24%) and Family Mall the least (19.46%).
- Visibility Area: Optimized layouts generally increased visibility area, with Rein Mall showing the most significant improvement (49.52%) and Ankawa Mall the least (5.90%). Notably, Rein Mall achieved the highest enhancement coefficient despite having a smaller absolute visibility footprint.
- Path Length and time taken: Optimization generally reduced path length and time taken for navigation. Tablo Mall showed the most significant improvements in both (8.26% reduction in path length and 8.13% reduction in time taken), while Grand Majdi Mall showed the least improvement.

From the statistical analysis, the following can be concluded:

- •Visibility and path length correlation: A strong positive correlation (0.780) was found between visibility and path length (navigation efficiency), indicating that increased visibility in spatial layouts leads to improved navigation in shopping malls. This supported the first hypothesis.
- •Functional vs. intangible aspects: The functional aspects of shopping mall layouts were found to contribute more significantly to spatial legibility than intangible design elements, supporting the second hypothesis.
- •Hybrid vs. single-approach layouts: The third hypothesis, which proposed that a hybrid layout design would better accommodate diverse user preferences than single-approach layouts, was rejected. The findings suggested that a linear layout approach, as a single organization, showed a greater chance of accommodating diversity in user perception compared to other single approaches or hybrid/mixed layouts, particularly in terms of shopping habitat.

This study successfully demonstrated the integration of Architectural Design Optimization (ADO) using Genetic Algorithm (GA) to enhance the spatial layout of shopping malls, particularly in Erbil city. The findings indicate that GA-optimized designs significantly improve spatial legibility by reducing occlusivity, increasing visibility, and shortening navigation paths and time within these commercial spaces. Statistical analysis further reinforced the critical role of visibility in improving navigation efficiency and highlighted that the functional aspects of layout contribute more to spatial legibility than intangible design elements. Contrary to initial hypotheses, the research suggested that linear layouts, rather than hybrid designs, might be more effective in accommodating diverse user preferences within a shopping environment.

The novelty of this study lies in its application of the Genetic Algorithm (GA) as a novel optimization technique specifically for the spatial layout of shopping malls. This innovative approach allowed for a data-driven enhancement of design elements such as spatial legibility, wayfinding, and overall user experience, providing a systematic method for optimizing architectural designs that traditionally rely more on qualitative judgment.

5. Study Limitations

- The study was geographically confined to shopping malls in Erbil, which may limit the findings' applicability to other urban or cultural settings.
- The study focused largely on interior spatial layout and its impact on spatial legibility, leaving out various external and experiential aspects such as public transit accessibility, urban integration, and economic background.
- The study's scope and methodological approach excluded key experiential elements that have a major impact on shopper navigation and spatial cognition, such as anchor store placement, tenant mix, natural and artificial lighting conditions, and socio-cultural user preferences.
- The analysis used a cross-sectional approach and did not include longitudinal user behaviour or post-occupancy evaluations after any layout changes.
- User perception data was gathered using a single-mode checklist instrument, which, while informative, may not capture the full complexities of user behaviour across demographics or cultural groups.

6. Future Works

- Extend the study to malls in other cities or countries to test the optimization model's validity and adaptability to different urban and cultural contexts.
- In future models, use anchor store location and tenant mix as spatial and behavioral factors to better understand how they affect navigation, attraction patterns, and readability.
- Investigate the effects of natural and artificial illumination on spatial perception and visibility, particularly with regard to isovist field modelling and visual connection.
- Address socio-cultural elements including age, gender, cultural background, and lifestyle, which might influence users' navigation choices and readability interpretation.
- Implement longitudinal studies or post-occupancy assessments to monitor changes in user behaviour and satisfaction levels after optimization initiatives.
- Use immersive technologies such as VR simulations or agent-based modelling to mimic user flow in a variety of situations and design settings.
- Pursue multi-objective optimization frameworks that encompass sustainability, cost-efficiency, energy consumption, and economic viability.
- Examine how external environmental factors (such as mall entrance orientation, parking, and nearby street connectivity) interact with interior layout to influence overall legibility and experience.

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