INCREASING SPACE EFFICIENCY IN SMALL APARTMENTS THROUGH FURNITURE TRANSFORMATION

Samidullo Elmurodov, *professor*
Nigora Mametova, *Master’s student*
Tashkent University of Architecture and Civil Engineering

Abstract: *This article is dedicated to the optimization of small-scale apartment spaces through furniture transformation and innovative interior solutions within the context of rapid urban growth. The central problem of the research involves a topological and ergonomic analysis of how traditional furniture occupies nearly half of an apartment's usable area, often failing to meet the cultural, domestic, and familial needs of the population of Uzbekistan. Using modern graph-analytical methods - such as space syntax, visibility graph analysis , and justified plan graphs - the layouts of new multi-story residential buildings in Tashkent were analyzed in depth. The results indicate that implementing three-stage transforming furniture systems and flexible functional solutions can drastically increase visual and circulatory efficiency while allowing for the dynamic management of boundaries between private and social zones. Furthermore, the article details the potential for optimizing inter-room movement flows by integrating AI-based binary filtering technologies and fundamental human anthropometric data into the architectural design process. The findings provide practical and design recommendations for improving small-apartment architecture within current urban planning norms to create a comfortable living environment for the population.*

Keywords: *small apartments, furniture transformation, spatial efficiency, graph-analytical method, architectural ergonomics, visual control, space syntax.*

INTRODUCTION

In the field of modern urban planning and architecture, maximizing the efficiency of every square meter-both within the existing housing stock and in newly constructed buildings-is becoming one of the most pressing socio-economic challenges. This is driven by increasing population density, demographic growth, and the unprecedented acceleration of urbanization processes. Global experience indicates that in dense metropolises such as New York, Tokyo, London, and Hong Kong, traditional spacious dwellings are actively being replaced by micro-apartments designed for young professionals, students, and small families (Deptho.ai. 2025). This global trend has not bypassed the architecture and real estate markets of Uzbekistan, particularly its capital, Tashkent. According to statistical indicators and economic analyses, the volume of multi-story buildings commissioned in Uzbekistan's housing market grew by an average annual rate of 14% between 2020 and 2024. Based on expert assessments, the annual volume of residential multi-story housing completions is projected to reach 13.8 million square meters by 2030 (yakovpartners.com). At the same time, specific limits on mortgage loans allocated for housing (for example, the

equivalent of $26,000 in the Republic of Karakalpakstan and other regions, and $33,000 in Tashkent city) have naturally led to a sharp increase in demand for compact apartments. These units typically range from 16 to 50 square meters in total area (Ospanov T. Prodanova N. 2024). Consequently, studio-type or small-scale one-bedroom apartments are emerging as the dominant architectural typology in newly constructed residential complexes (Rakhmatillaeva Z. 2025).

However, the architectural structure and interior solutions of these compact spaces often fail to fully meet the traditional lifestyle, socio-cultural needs, and domestic activity dynamics of Uzbek families, which have been shaped over centuries. Because the planning of small apartments often involves the direct transplantation of "open-plan" principles popular in Western Europe or Northern America, a number of functional and psychological inconveniences arise. Specifically, the integration of the kitchen, guest area, and bedroom into a single space without physical boundaries causes heat, humidity, and strong odors-such as those produced when preparing national dishes like palov or fried foods-to spread unimpeded throughout the entire apartment. Furthermore, the hospitality culture of the Uzbek people requires strict visual and spatial boundaries between the family's private, intimate zones (bedrooms, children's areas) and the public zone where guests are received (mehmonxona). In a studio format, the fact that guests have a direct view into the family’s private territory creates a conflict with cultural norms (Elmurodov S. 2025). To eliminate these sharp inconveniences and to ensure the most productive and logical use of strictly limited physical space, modern design and architecture necessitate the introduction of transformable furniture systems-flexible equipment capable of changing its function and volume based on necessity. Research results show that when traditional and unchangeable static furniture is installed in small-scale apartments of less than 50 square meters, it permanently occupies an average of 40-50% of the available useful floor area. This situation hinders free movement and creates a sense of visual confinement and overcrowding (Li P. Hazim Z. 2025). Consequently, investigating mechanisms for increasing spatial efficiency through dynamic transformation solutions that facilitate the flexible modification of functional zones is considered one of the most urgent tasks in the practice of integrating architecture, interior design, and furniture design today.

The primary objective of this research is to develop innovative architectural and design models-and to substantiate them scientifically and metrically-that ensure functional efficiency, ergonomic comfort tailored to the human physique, and a balance between visual-psychological openness and privacy by implementing furniture transformation technologies and smart circulation planning solutions in small-scale urban apartments.

To achieve this objective and provide a comprehensive analysis of the problem, three distinct and logically connected tasks have been identified:

1. First Task: To conduct a deep analysis of small apartment and studio typologies in both foreign and local practice using Space Syntax and advanced graph-analytical methods, identifying the fundamental circulatory and morphological deficiencies in traditional planning.

2. Second Task: To develop a system of specific ergonomic parameters and metric indicators for the design and interior placement of transformable furniture and dynamic barriers, based on precise human anthropometric dimensions and cognitive perception characteristics.

3. Third Task: To establish principles for flexible interior design and present a final conceptual model that fully complies with Uzbekistan’s national cultural characteristics and current urban planning norms (specifically the lighting, spatial area, and circulation requirements set forth in SHNK 2.08.01-05), allowing for the effortless integration or separation of functional zones as needed.

The object of this scientific research is defined as the architectural envelope and interior space of small-scale apartments-including micro, one-bedroom, and studio-type units-currently being designed and constructed in modern multi-story residential buildings within the context of rapid urbanization. The subject of the research encompasses the principles of spatial efficiency, variable functional zoning, and the laws of ergonomic comfort affecting human perception, all of which are generated through the application of mobile and transformable furniture mechanisms and technologies within these compact residential environments.

The scientific novelty of this research lies in the first-time comprehensive application of modern spatial syntax and mathematical architectural tools-such as the Justified Plan Graph and Visibility Graph Analysis -specifically adapted to the unique climatic, cultural, and regulatory conditions of Uzbekistan (ShNK 2.08.01-05) to study movement flows within small apartment interiors (Huang Y. 2026). Furthermore, the study utilizes mathematical calculations and layered visual modeling to demonstrate how the functional levels of transformer furniture (including mobile units, multifunctional integrated pieces, and central "living cubes" for spatial zoning) positively impact circulation nodes through filtering algorithms based on artificial intelligence and binary logic (Ospanov T. Prodanova N. 2024).

The practical significance and implementation potential of this research are exceptionally high. The analytical results, the developed table of ergonomic parameters based on human proportions, and the design recommendations for dynamic barriers can serve as a direct technical manual for architects, interior designers, urbanists, and large construction companies (developers). These tools enable the design of "smart" apartments that-despite their small footprint-are market-competitive, functionally superior, and fully aligned with the national cultural requirements for hospitality and privacy. Ultimately, these advancements will fundamentally improve the living conditions and psychological well-being of young families and students, while promoting a sustainable and rational approach to the use of land and spatial resources in urban planning.

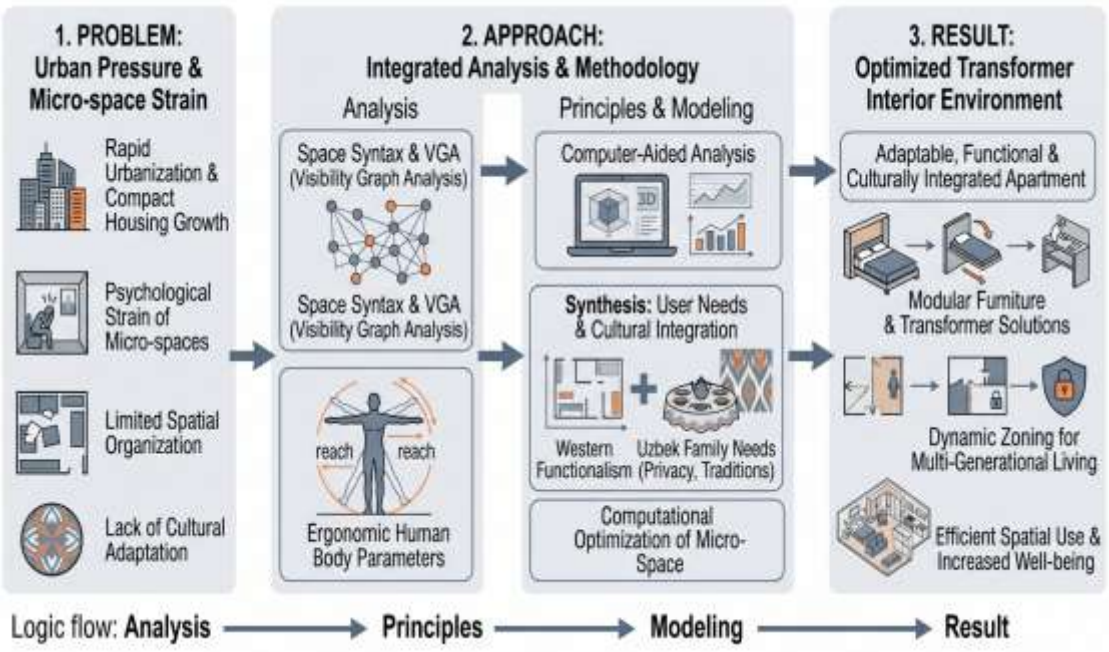

Figure 1. Conceptual framework of spatial and ergonomic optimization in compact apartments

METHODS

To achieve an objective, metrically accurate, and comprehensive assessment of architectural spatial efficiency and living comfort in small apartments, this research utilized four logically complementary scientific methods: comparative analysis, computerized graph-analytical methods, case studies based on local materials, and future-oriented design modeling. Each of these approaches is firmly rooted in the principle of viewing the architectural environment not merely as a physical or geometric volume, but as a complex and dynamic system of human movement, psychological perception, and socio-visual interactions.

In the first stage, the comparative analysis method was employed to continuously compare numerical and qualitative indicators-such as visual spaciousness, spatial dimensions, and area distribution-between standard small apartments equipped with traditional static furniture and those featuring specially designed multifunctional, flexible (transformer) furniture and sliding structures. This analysis involved an extensive review of international practices through scientific literature, including micro-apartment developments in Russia and Kazakhstan with areas ranging from 16 to 30 square meters (Ospanov T. Prodanova N. 2024), observations of 258 apartments in the "Zaniary Towers" residential complex in Erbil, Iraq (Husein H.A. 2021), and compact housing typologies in high-density regions like Hong Kong (Shuai Chen, 2024) and Shijiazhuang, China (Li P. Hazim Z. 2025).

Within the framework of the comparative analysis, the role of transformer furniture in architecture was investigated across three distinct levels of complexity and transformation:

- First Level: Furniture that is easily movable, foldable, or stackable within the space without fundamentally altering its original function.

- Second Level: Hybrid systems that integrate multiple domestic functions through complex rotating, pulling, or sliding mechanisms (e.g., a bed transforming into a writing desk).
- Third (Highest) Level: Solutions involving large-scale central "living cubes" that independently zone the entire apartment space and incorporate sanitary units, kitchens, and sleeping areas (Ospanov T., Prodanova N., 2024).

These international levels and solutions were cross-referenced with the requirements of Uzbekistan’s regulatory framework, specifically ShNK 2.08.01-05 "Residential Buildings." In particular, the study highlighted how foreign transformation solutions could be optimized within the context of strict minimal area requirements for living rooms (e.g., 20–24 square meters for a family of 2–3 people) and designated kitchen zones, supported by objective numerical data (Abdujabborova M. 2015).

The graph-analytical method constituted the most fundamental and scientifically significant portion of this research. At this stage, the principles of Space Syntax theory-an advanced direction in modern architectural analysis founded by Bill Hillier and Julienne Hanson in 1984-were fully applied (Dawes M. Ostwald M. 2013). The essence of this methodology lies in modeling each functional room or zone of the apartment (e.g., bedroom, kitchen, hallway) as a node of a mathematical graph, while doors, open passageways, or transformable barriers serve as the edges connecting these nodes. Specifically, to evaluate the internal topology of the apartments, a Justified Plan Graph was constructed to calculate the networks of human circulation within the space. For each node in the graph, critical topological variables were calculated, including:

- Total Depth: The openness of a specific space relative to all other points in the system.
- Mean Depth: A metric for measuring transit costs.
- Relative Asymmetry: The degree of non-symmetry within the graph (Huang Y. 2026).

One of the primary challenges in small apartments-narrow transit areas such as long hallways or dark corridors (typically represented as nodes K and I)-was analyzed as a central factor strictly determining overall freedom of movement and room integration (Huang Y. 2026).

The JPG methodology of Space Syntax was deeply synchronized with Visibility Graph Analysis (VGA), which digitizes the degree of visual openness within the apartment's interior. The VGA analysis was performed using DepthmapX, a specialized architectural software. A 10-centimeter virtual grid was overlaid onto the floor plans, and the maximum areas visible from every point through open doors and transparent barriers (isovist areas) were calculated (Yunitsyna A. 2023).

During the analysis, the visual control indices of different zones were visualized using a heat map. In this visualization red and yellow zones represent "social hotspots" where visual communication and control are extremely high, blue and green zones represent secluded, hidden, and private (intimate) areas (Yunitsyna A. 2023). This methodology

provided the scientific foundation necessary to understand the boundaries between open, collective guest rooms and strictly private family bedrooms within the context of Uzbekistan’s unique architectural traditions.

To bridge theoretical knowledge with local conditions, the third stage involved empirical observations using the Case Study method. The floor plans and architectural drawings of more than eighty one-bedroom and studio-type apartments, which have been rapidly constructed and commissioned in Tashkent in recent years, were directly analyzed (Rakhmatillaeva Z. 2025).

Architectural assessments confirmed that these local apartments frequently suffer from recurring circulation issues, such as:

- One-sided natural lighting (light entering from only a single exterior window);
- Highly inefficient use of the entrance hallway, leading to a significant loss of usable area;
- Cramped and inconvenient layouts for kitchen and sanitary units, which hinder movement (Rakhmatillaeva Z. 2025).

These fundamental planning problems were re-examined through the lens of specific models successfully applied internationally. For instance, technological and spatial solutions-such as Transformer Table designs that extend from a simple 18-inch console to a nearly 10-foot dining table, specialized expandable seating, and foldable bed-sofas (Murphy beds) that can be concealed during the day-were virtually integrated into the floor plans of Tashkent residences to test their effectiveness (Chen E., 2024).

Finally, in the fourth stage of the research-Project Modeling-a binary filtration system based on artificial intelligence networks and Computer-Aided Design (CAD) tools was actively employed. In this phase, circulation connections that open or close as a result of furniture transformation or sliding walls were encoded into the computer memory in a binary format: a value of "1" was assigned if a connection existed between spaces, and a value of "0" if the path was obstructed by a wall or barrier. By filtering out redundant and overly complex multi-door connections through various computational iterations, the algorithm generated the most optimal and clean spatial configuration (optimal suite layout) for the small-scale apartment. During the project modeling phase, to study furniture not merely as spatial objects but as potential barriers to human movement, fundamental anthropometric data of the human body were integrated into the system. Specifically, physiological dimensions in a sitting position, 5th and 95th percentile measurements, and popliteal height (a key metric for determining ergonomic chair and surface heights) were programmed into the model. This ensured strict control over the minimum clearance distances required for a person to pass, bend, and move freely without congestion, even when transformer furniture is in its fully expanded state (Dainoff M. Gordon C. 2003). The scientific harmony of these four interconnected and complex methods allowed for the verification of theoretical graphical knowledge through real empirical data and anthropometric measurements. Ultimately, this synergy made it possible to transform abstract findings into definitive, "textbook-level" design conclusions.

RESULTS

As a result of long-term and multifaceted complex research, the analysis of dozens of architectural drawings, and the application of AI filtering algorithms, several definitively confirmed fundamental patterns were identified regarding the functional role, spatial integration, and ergonomic impact of transformer furniture within the small-apartment environment specifically for the "Uzbek model." These established laws fully proved that such solutions fundamentally alter not only the dry physical dimensions of the space-measured by gypsum and brick walls-but also the human psychological and visual perception of that environment.

The first law identified within the scope of this research pertains directly to the economy of spatial geometry and its optimization. Calculations strictly demonstrated that in standard, widely distributed small apartments (ranging from approximately 30 to 40 square meters), if a static, immovable bed, a large dining table, and a workspace are all simultaneously placed within a single studio space, a significant portion-averaging 40 to 50 percent-of the total habitable floor area remains permanently occupied (Li P. Hazim Z. 2025). Consequently, internal circulation lines intersect, the quality index of the visibility graph drops sharply, and the apartment effectively turns into a "spatial labyrinth." However, when third-level transformer systems are applied-specifically "living cubes," wall-mounted Murphy bed structures that can be folded away during the day, and flexible transformation tables capable of reducing their length several-fold (Chen E. 2024)-it becomes possible to preserve and protect up to 70–75 percent of the free movement area. This spatial gain successfully serves to make the apartment appear visually much more spacious, airy, and well-lit. Most importantly, it creates the necessary "void" for the family's daytime social and domestic activities, such as children playing or receiving guests, which are vital in the local cultural context.

The second and crucially important law pertains directly to socio-cultural functional zones and their visual openness, as vividly illustrated by the heat maps obtained through Visibility Graph Analysis (VGA).

1. Privacy and Visual Control. Mathematical indicators prove that installing sliding rail partitions or ceiling-mounted panels instead of permanent brick walls allows for the successful preservation of the boundaries between the intimate "privacy" zone and the collective "guest area" (*mehmonxona*) - a distinction characteristic of families in Uzbekistan-even within extremely cramped studios (Elmurodov S. 2025). In traditional planning, visual coverage from the guest area typically encompasses up to 70% of the apartment, often leaving sleeping zones exposed. However, when closed sliding panels are deployed, the visibility index is concentrated strictly within the collective territory, successfully isolating the sleeping area.

2. Connectivity and Spatial Integration. Based on the metric results of the Justified Plan Graph , it can be concluded that eliminating dark entrance hallways and integrating the kitchen into specialized architectural alcoves (alcove kitchen) drastically increases the

Connectivity Value of the project's central node (Ospanov T. Prodanova N. 2024). While traditional layouts often suffer from low connectivity values, the implementation of a "transformer interior" can raise the CV of areas indexed as K and I to a value of 3. This ensures stable circulation and effectively eliminates the psychological perception of narrowness and overcrowding within the home (Huang Y. 2026).

Table 1. Anthropometric and spatial efficiency parameters of multifunctional furniture

Type of furniture or activity function (Zone)		Traditional static indicators		Transformer-level indicators	
		Volume / Footprint (m^2)	Minimal anthropometric requirements for human movement (mm, references ShNK)	Calculated percentage of space savings (%)	Visual spaciousness index (VSI, 1-10)
Sleeping zone	Bed, deployed	3.2	2100x1600 mm (Bed) + 600 mm (Passage) (Ref: ShNQ 2.08.01-05)	0% (deployed)	3
	Bed, folded (Wall-bed)			92% (as folded unit)	9
Kitchen zone		6.5	1500 mm (Frontal work) (Ref: ShNK)	35% (Compact modular)	7
Working zone		1.8	800 mm (Seating and knee space)	60% (Foldable desk)	8
Circulation and transition corridor		1.2	900 mm (Main corridor width) (Ref: ShNK)	20% (Shared with deployed furniture)	6
VSI: 1=Cramped, 10=Spacious				Ref: ShNK = Building Codes and Regulations	
Total spatial efficiency (example 20m^2 apartment)		Traditional = 12.7 m^2 (63.5%)		Transformer = 5.8 m^2 (29.0%)	Space Saving = 54.3%

To systematize and simplify the extensive findings from practical research for architecture and design professionals, a brand-new spatial efficiency and ergonomic parameters table for small apartments was developed. This table embodies human anthropometric indicators, body physiology, and modern spatial requirements. In this analytical table *(Table 1)*, the disparities between conventional traditional approaches and new transformation technologies, as well as the gained "habitable intervals," are expressed in precise numerical quantities.

It is evident from the comprehensive table and observations presented that merging and displacing furniture functions along a single vertical or horizontal axis not only ensures drastic spatial economy but also significantly reduces the risk of ergonomic collisions. In narrow spaces, such collisions-where body parts like knees and shoulders strike hard furniture corners-are a major concern. Specifically, the circulation aisles between traditional hard-edged, L-shaped kitchen tables in small studios often become permanent hazardous obstacles at the human popliteal (back of the knee) and waist heights, causing physical discomfort (Dainoff M. Gordon C. 2003). The introduction of intelligent Transformer table and seating systems that can extend and retract creates a solid foundation for keeping central

circulation areas completely open and free during the day. For instance, these systems can stand as a compact 18-inch console when not in use, yet extend up to ten feet via a rail system and the addition of specially stored panels to accommodate six to eight guests. Furthermore, the hidden storage of seating panels within the primary furniture unit eliminates the logistical "headache" of searching for additional storage space (Chen E. 2024).

Figure 2. Implementation of Level-2 and Level-3 transformer systems in a 35 sqm flat

To further clarify the comparative analytical approach of this research, ensure objectivity, and present architectural metrics in an easily digestible format, a multi-vector comparative diagram was formulated. This diagram *(Diagramm 1)* illustrates the fundamental spatial differences between a traditional static interior and an innovative, dynamic transformable environment. The graphic visualization clearly reflects five key performance parameters: percentage of area savings achieved, topological visibility coverage, efficiency of unobstructed natural light distribution, ergonomic comfort, freedom of circulation.

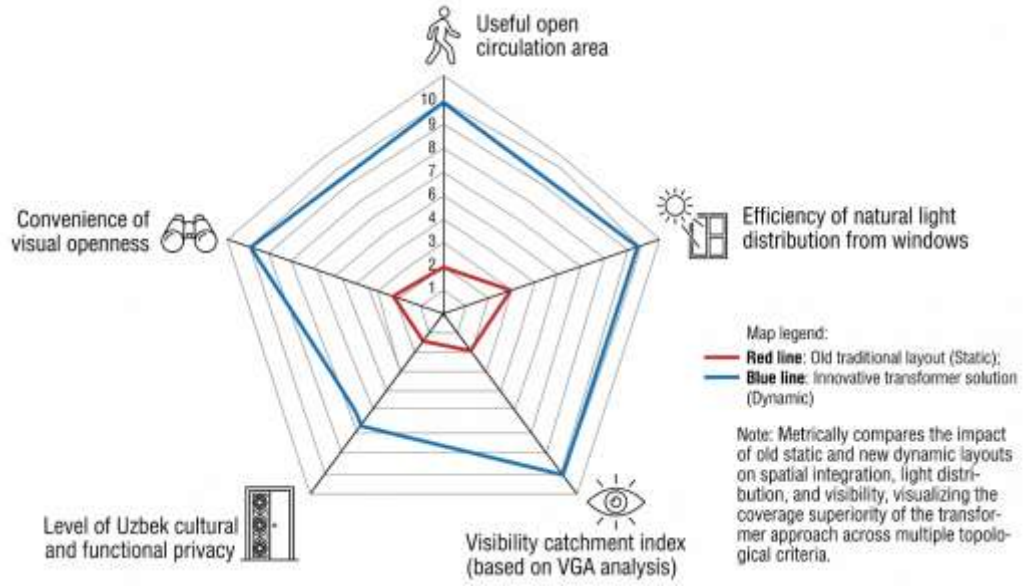

Diagramm 1. Comparison of spatial fluidity and visibility indexes (Static vs. Dynamic layouts)

The definitive conclusions drawn from the design and modeling analyses emphasize that today’s architects and structural engineers must mandatorily account for the parameters of moving furniture, sliding door tracks, and specialized niches during the very first stages of building design and massing. Fields such as urban planning, architecture, and interior design should not be treated as isolated, sequential tasks, but rather as a holistic, symbiotic complex developed together from start to finish. This approach is further reinforced by national regulations. As strictly mandated in Uzbekistan's ShNK 2.08.01-05, the daylight factor-specifically the ratio of window area to floor area-must typically be no less than 1:5.5 (and no less than 1:8 in certain climatic zones) to ensure the sanitary conditions of living spaces (Abdujabborova M. 2015). Utilizing transformable, transparent, or semi-transparent sliding partitions instead of heavy brick walls, combined with furniture positioned primarily below the horizontal eye level, allows natural sunlight from a single window to penetrate freely into the deepest and darkest corners of the apartment, including the entrance hallway, without obstruction (Ospanov T. Prodanova N. 2024). In conclusion, the final design model derived from these results rejects the outdated notion of merely "filling" a rectangular void with decorative objects. Instead, it demonstrates that modern design must rely on the principles of generative architecture: the "conscious management" of space to adapt to the fluid sequence of time and daily human needs.

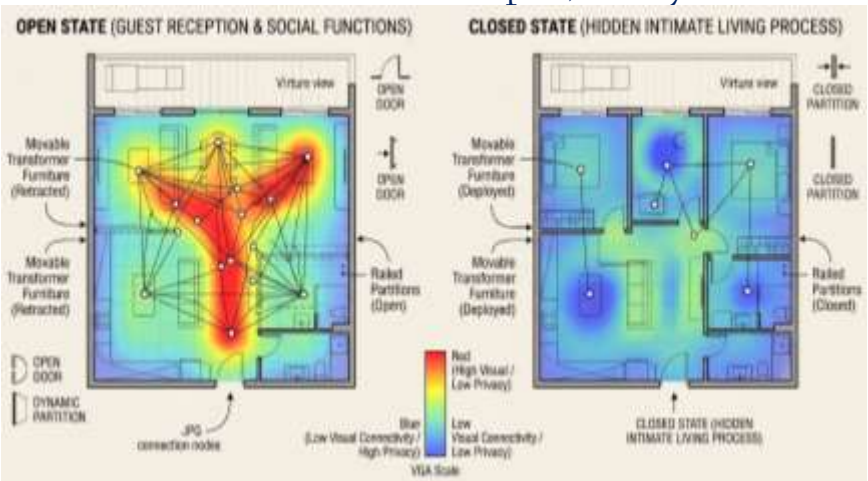

Figure 3. Visibility Graph Analysis (VGA) mapping of a compact

DISCUSSION

The practical and academic interpretation of these extensive scientific results indicates that the strategy for achieving furniture and spatial efficiency in small-scale apartments is not merely a policy of physically reducing furniture or leaving rooms empty. Rather, it is a civilizational approach that requires accounting for human behavior, lifestyle, and deep-seated cultural and sociological paradigms. The formation of traditional Uzbek architectural masterpieces-specifically courtyard houses built from ancient *paxsa* (rammed earth) and mud bricks-was dominated by the principles of flexible, void-centric, and polyfunctional open space (Pronina A. 2022). In historical monuments and common residential dwellings alike, the most prominent rooms (such as the central *mehmonxona* for receiving guests) were kept entirely open and empty; bedding and daily household items that would otherwise occupy space were neatly concealed within taxmon (deep wall-integrated niches) and specialized shelves. Furthermore, internal room areas were culturally and symbolically divided into invisible functional zones: the poygoh (the entry area near the door for shoes and active movement) and the peshgoh (the honorary zone at the head of the room for elders and guests) without the need for physical barriers (Fayzullayeva N. Khudayarova Z. 2023). From this perspective, the modern transformer furniture, wall-mounted beds, and hidden storage systems-which may seem like Western imports-are, in reality, a renaissance of our thousand-year-old traditions. They represent the adaptation of ancient concepts to the materials (metals, polymers), high-level mechanical engineering, and dense urban conditions of the modern era. This explains why the "open-plan" studio model popular in Western societies as a symbol of personal independence often fails when directly transplanted to Uzbekistan. The primary cause of discomfort is a lack of visual privacy and the hierarchy of respect essential to the Uzbek mentality (Elmurodov S. 2025). It is important to emphasize that the lightweight sliding walls proposed in this study-based on Visibility Graph Analysis (VGA) and binary visual filtering-maintain the physical advantages of open-plan layouts, such as maximum natural light penetration and air circulation. Simultaneously, they allow for the creation of temporary and mobile psychological boundaries that satisfy Uzbek domestic needs. A practical example confirmed during the research discussion is the functional necessity of hermetically isolating the

kitchenette during the preparation of traditional Uzbek dishes. The ability to temporarily partition the cooking zone to block the intense heat and strong odors characteristic of *qozon* (cauldron) cooking from the rest of the living space is of immense practical, sanitary, and visual importance (Elmurodov S. 2025).

Comparing the results and measurements obtained in this study with the conclusions of advanced foreign research and international publications sheds deep light on several critical aspects and differences regarding the spatial problem. Western and American scholars-notably Boeckermann and colleagues in their 2019 research-primarily link the world-renowned "tiny house" movement to voluntary minimalism, a quest for mental relief, and principles of sustainable consumption (Boeckermann et al., 2019). In our case, however, a completely different picture emerges. Drawing parallels with the extensive research conducted by T. Ospanov and N. Prodanova on the Russian and Kazakhstani real estate markets, small studio spaces in the Uzbek context are not a philosophical choice. Instead, they manifest as a pragmatic economic consequence (necessity) of a sharp capitalist market, limited mortgage funds, and high urbanization pressure. Compared to the ultra-cramped micro-apartments in Chinese megapolises like Shanghai, Beijing, and Hong Kong-where living space averages a mere 21 square meters per person (and often less)-Tashkent still maintains a certain relative spaciousness, with current studios ranging from 30 to 50 square meters.

However, by applying advanced Space Syntax computer algorithms to this 30–50 square meter range, we have witnessed how the shift in the "Social Logic of Space"-a theory pioneered by architects Hillier and Hanson (Dawes & Ostwald, 2013)-can be successfully mitigated through transformer furniture, thereby reducing social friction. While Chinese researchers in their long-term JPG (Justified Plan Graph) and AI-filtering analyses focused on optimizing complex corridors in large three-bedroom apartments (Huang, 2026), we have adapted and successfully tested this advanced methodology for the "heavy topology" of one-bedroom homes where everything is packed into a single room. The scientific findings confirm that in these small physical voids, the transition of furniture from one distinct function to another is not merely a geometric contraction of wood or metal. It is an architectural medicine-a psychological tool that regulates the socio-psychological climate and mutual relations of family members, granting them a sense of "freedom to breathe." This distinguishes our work in a manner similar to VGA (Visibility Graph Analysis) studies conducted in Tirana, Albania, which compared visibility axes in low-cost versus high-cost housing (Yunitsyna, 2023). Our research differentiates the traditional approach from an innovative one. Comparisons with Western furniture revolutions, such as the Transformer Table brand mechanisms (Chen, 2024), and the multifunctional solutions successfully implemented in the "Zaniary Towers" in Erbil, Iraq (Husein, 2021), demonstrate that a similar technological revolution in Uzbekistan is fully possible from both objective and subjective perspectives.

The rising potential of Uzbekistan's furniture and woodworking industry serves as positive economic evidence. According to data from the end of the first seven months of

2025, the export volume of furniture and its components reached nearly $10.5 million (stat.uz, 2025). This indicates a high economic capacity for the mass production of such innovative, complex structures locally using affordable raw materials, providing a complete path for import substitution.

While this research provides a comprehensive framework for spatial optimization, several key constraints must be noted: Acoustic and Engineering-Physics Constraints: All analyses and research conducted in this study were primarily focused on the spatial, metric, anthropometric, and architectural-compositional characteristics of the interior (measuring visual boundaries physically and via computer). However, purely engineering-physical issues, such as acoustic shifts and noise isolation between rooms when sliding walls are deployed or furniture is transformed, were not fully encompassed within the scope of this work. It is well-known that lightweight transformable panels and open-track partitions generally possess significantly lower sound absorption compared to foundational brick, concrete, or foam-block walls. This could potentially create acoustic conflicts between a person sleeping and another watching television in the same unit. The Affordability Gap: Implementing third-level transformer systems-such as intelligent beds with hydraulic motors-typically requires a high initial investment from the client compared to traditional, low-cost static furniture available on the market. This raises critical questions regarding affordability for the demographic most in need of social protection, such as students and young families. For those relying on state mortgage and subsidy programs (specifically the $26,000 state aid limit mentioned previously), these high-tech solutions may remain financially out of reach without further industrial optimization. Mechanical Life-Cycle and Wear: Our binary filtration model (1 and 0) used in the computational analysis currently only calculates the presence or absence of a wall/barrier. It does not account for long-term factors such as mechanical wear and tear, dust accumulation in rail mechanisms, or the material deformation of moving parts over several years. Consequently, future research is required in collaboration with material scientists to conduct a thorough life-cycle analysis (LCA) and determine the true operational durability of these systems.

CONCLUSION

In light of the rapid urbanization occurring in our country, the comprehensive architectural, ergonomic, and socio-sociological study of spatial efficiency in small-scale apartments has revealed several fundamental findings of significant practical importance. Modern global urbanization processes do not demand a radical abandonment of the centuries-old, courtyard-based residential typology and customs of the Uzbek people; instead, they call for preserving these traditions while elevating them to a new intellectual stage rooted in scientific advancement. Precise metric data derived from heat maps-generated through advanced architectural mathematical methods such as Space Syntax and Visibility Graph Analysis (VGA)-have definitively proven that smart furniture transformation is the primary and most effective architectural tool for mitigating social and physical discomfort in small studios and cramped one-bedroom homes. Properly planned

transformable furniture does more than just economize purchased square footage and protect nearly 75% of the open floor area; it establishes multi-layered visual and spatial boundaries. This approach prevents the psychological strain and claustrophobia often caused by confined spaces while fully accommodating national customs-specifically the strict cultural requirement to distinguish between private sleeping quarters and open guest-reception zones without conflict.

Based on the patterns identified throughout this research, the following specific practical and design recommendations are proposed for architects, interior analysts, designers, local furniture manufacturers, and large-scale real estate developers:

1. Early-Stage Architectural Integration It is strongly recommended that the inclusion of specialized architectural niches for transformable furniture, recessed rail tracks for sliding walls, and deep cabinetry systems for transformer tables be made mandatory during the earliest stages of design (urban planning sketches and BIM modeling). The load-bearing concrete elements, structural columns, and utility networks (water, HVAC) of multi-story buildings must be planned discreetly so as not to obstruct the flexible and dynamic circulation of the interior.

2. Cultural Adaptation of "Open-Plan" Layouts Developers should move away from the blind and absolute implementation of Western "open-plan" formats under the guise of cost-reduction. Instead, the use of dynamic, transparent, or opaque sliding partitions-which provide essential visual barriers and acoustic/olfactory filtration-should be incentivized and integrated into subsidy programs. For the hot climate and culinary traditions of Uzbekistan (such as the high-heat preparation of *palov*), constructing kitchens in a partially recessed "alcove" format is the most functional and optimal solution.

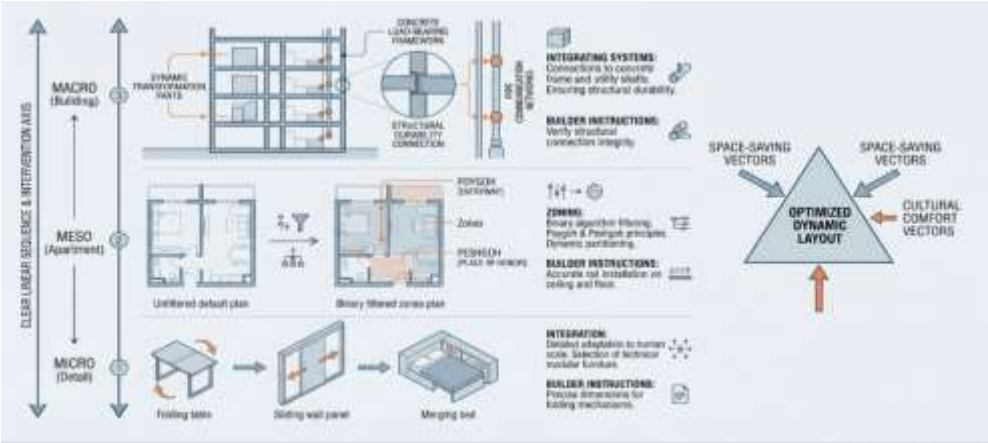

Figure 4. Generative principles of dynamic layout optimization for

3. Development of National Anthropometric Furniture Standards Furniture designed for small spaces and low-cost housing must not rely on imported standards. Instead, it should be designed at a national level based on the specific anthropometry and body physiology of the Uzbek population. This includes precise calculations in centimeters for popliteal height (back-of-the-knee), waist height, and body curvature amplitudes in both working and resting positions. Uzbekistan’s furniture export potential-which reached nearly

$10.5 million in 2025-should be strategically channeled into the mass production of these intellectual transformer systems to drastically lower costs for the general population.

Future scientific research directions should prioritize the broad integration of Generative Artificial Intelligence (AI) and architectural design technologies with Space Syntax theory. A primary task involves the mathematical development of automated spatial generation tailored to the specific needs, family size, and daily schedules of Uzbek clients. Furthermore, it is essential to conduct laboratory investigations in materials science to improve the mechanical lightness, annual wear resistance, and acoustic insulation of systems by utilizing affordable and sustainable locally sourced raw materials. The strategic goal for future scholars and young architects should be the synthetic merging of traditional local practices-such as centuries-old wood carving, master door-making techniques, and *paxsa* (rammed earth) craftsmanship-with innovative metal frameworks and modern mechanical components. By doing so, Uzbekistan can proudly present the concept of a "traditional Uzbek transformable space" to the global architectural market-a model that is not only highly functional and economical but also carries a profound aesthetic and national identity.

REFERENCES:

1. Elmurodov S. (2025) *The significance of social factors in the architectural design of housing in Uzbekistan.* Finland Academic Research Science Publishers https://farspublisher.com/index.php/fars/article/download/443/876

2. Ospanov T. Natalia Prodanova N. Sarvut T. Matytsin A. Hajiyev H. Hajiyev E. Shichiyakh R. Akhmetshin E. (2024) *Developing Architectural Design Solutions and the Interior Organization of Compact Apartments with a Comfortable Living Environment.* https://www.hrpub.org/download/20240530/CEA6-14836577.pdf

3. Deptho.ai. (2025) *Micro-apartments: Design strategies, multifunctional furniture, and technology for urban spaces* https://deptho.ai/en/blog/micro-apartment-design-small-space-strategies

4. Shuai Chen (2024) *The implication of transformable space saving furniture on the interior design in small living units* https://openaccess.wgtn.ac.nz/articles/thesis/The_Implication_Of_Transformable_Space_Saving_Furniture_On_The_Interior_Design_In_Small_Living_Units/25807507

5. yakovpartners.com Russian developers are entering the Uzbek real estate market - Yakov and Partners https://yakovpartners.com/publications/uzbekistan-real-estate/

6. Rakhmatillaeva Z. (2025) *Spatial analysis of contemporary one-room apartment layouts in tashkent’s new residential buildings.* International multidisciplinary journal for research & development https://inlibrary.uz/index.php/imjrd/article/download/126573/128128/184257

7. Li P. Hazim Z. Abdul Aziz M. Lim S.B. (2025) *Mechanisms of spatial efficiency: how multifunctional furniture drives space-saving in shijiazhuang's urban compact homes.* International Journal of Business and Technology Management.
https://mysitasi.mohe.gov.my/uploads/get-media-file?refId=ad91acf9-3c61-4ca2-a281-b098ab05797a

8. Huang Y. (2026) *A Justified Plan Graph Analysis of a Typical Apartment in China.* https://www.mdpi.com/2075-5309/16/2/364

9. Yunitsyna A. (2023) *Evaluation of the Spatial Quality of Apartments from Different Price Categories Using the Visibility Graph Analysis.* International Journal of Real Estate Studies. https://www.researchgate.net/publication/372053321_Evaluation_of_the_Spatial_Quality_of_Apartments_from_Different_Price_Categories_Using_the_Visibility_Graph_Analysis_A_Case_of_Tirana_Albania

10. Husein H.A. (2021) *Multifunctional furniture as a smart solution for small spaces for the case of Zaniary towers apartments in Erbil city, Iraq.* International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies
https://tuengr.com/V12/12A1H.pdf

11. Abdujabborova M. (2015) *Turar-joy binolarini loyihalash (o’quv qo’llanma)*
https://ru.scribd.com/document/825897177/Turar-joy-Binolarini-Loyihalash-Abdujabborova-M

12. Dawes M. Ostwald M. (2013) *Applications of graph theory in architectural analysis - open research*
https://openresearch.newcastle.edu.au/articles/chapter/Applications_of_graph_theory_in_architectural_analysis_past_present_and_future_research_/29021591/1/files/54417164.pdf

13. Chen E. (2024) *Maximizing space with multifunctional design: the transformer table*
https://desis.osu.edu/seniorthesis/index.php/2024/09/16/maximizing-space-with-multifunctional-design-the-transformer-table/

14. Dainoff M. Gordon C. Robinette K. Strauss M. (2003) *Guidelines for using anthropometric data in product design*
https://www.hfes.org/Portals/0/Publications/Guidelines_AnthropometricData.pdf?ver=2020-12-23-083000-033

15. Pronina A. (2022). *The clay architectures of Uzbekistan*
https://easteast.world/posts/512

16. Fayzullayeva N. Khudayarova Z. (2023) *Architecture and landscape design of traditional dwelling houses in the historic cities of Uzbekistan.* Journal of Engineering, Mechanics and Modern Architecture
https://jemma.innovascience.uz/index.php/jemma/article/download/24/22/22

17. Stat.uz (2025) Uzbekistan exported furniture and furniture products to 18 countries. https://stat.uz/en/press-center/news-of-committee/63694-zbekiston-18-ta-davlatga-mebel-va-mebel-ma-sulotlarini-eksport-ilgan-4

18. 4.Jahan I. Hossain SH. Aayaz R. (2024). *Optimizing small spaces: A comprehensive study on interior design challenges, perceptual experiences, and innovative solutions*. https://www.researchgate.net/publication/378526360_OPTIMIZING_SMALL_SPACES_A_COMPREHENSIVE_STUDY_ON_INTERIOR_DESIGN_CHALLENGES_PERCEPTUAL_EXPERIENCES_AND_INNOVATIVE_SOLUTIONS

19. 1.Thogersen K. (2017). *Small spaces need smart solutions*. Department of Design Norwegian University of Science and Technology https://www.ntnu.edu/documents/139799/1279149990/31+Article+Final_krithog_fors%C3%B8k_2017-12-07-22-08-50_TPD4505+-+Designteori+-+Small+spaces+need+smart+solutions+-+Kristoffer+Th%C3%B8gersen.pdf/11a2f430-986b-4da8-9b44-14b204436e01

20. Azadi Sh. Bai N. (2024). *Ergonomics of spatial configurations: A voxel-based modelling framework for accessibility and visibility simulations*. https://www.researchgate.net/publication/378714732_Ergonomics_of_spatial_configurations_a_voxel-based_modelling_framework_for_accessibility_and_visibility_simulations

21. Remizov A. Memon SH.A. Kim.J.R. (2023*). Climate zoning for buildings: From basic to advanced methods-A review of the scientific literature* https://doi.org/10.3390/buildings13030694

22. Ahmed F. Hafijur Rahman S.M. (2024). *Evaluation of thermal comfort in residential buildings: A case study of Wari, Dhaka*. International Journal of Science and Research Archive. https://ijsra.net/sites/default/files/fulltext_pdf/IJSRA-2024-2576.pdf

23. Lee Junsoo, Koo Chongwan (2024). *Investigation of individual differences in thermal comfort of elderly residential spaces: Utilizing IoT-based physiological model.* Korean Journal of Construction Engineering and Management. https://koreascience.kr/article/JAKO202404357601173.do

24. Tokajuk A. (2023). *Optimization of the functional concept of the minimum apartment - a study on a selected example: The role of functional details*. https://www.researchgate.net/publication/369961735_Optimization_of_the_functional_concept_of_the_minimum_apartment_-_a_study_on_a_selected_example_The_role_of_functional_details