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TRANSFORMABLE FURNITURE SYSTEMS IN PRIMARY EDUCATION INSTITUTIONS: EVALUATION OF ERGONOMIC EFFICIENCY

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Abstract. This article presents the results of evaluating the ergonomic efficiency of transformable furniture systems used in primary education institutions. The modern educational paradigm demands flexibility in the learning process, which is constrained by traditional rigid furniture constructions. The aim of the study is to assess, on an experimental basis, the parameters of anthropometric fit, functional zoning, and usability of transformable furniture systems. The object of the study is the primary school block (grades 1–4) of School No. 62 in Tashkent, involving 8 classrooms and 192 pupils. The subject comprises transformable furniture systems (modular desks, height-adjustable chairs, mobile storage systems). Methodology: comparative analysis, grapho-analytical method, case study, and design modelling. Results: transformable furniture systems increase classroom space utilisation efficiency by 42% and improve pupils' anthropometric fit from 38% to 89%. During lesson time, the teacher's movement trajectory length decreased by a factor of 2.3. In conclusion, transformable furniture systems are an effective tool for creating an ergonomic environment in primary education institutions; their implementation significantly improves the quality of the educational process.

Keywords: transformable furniture, primary education interior, ergonomics, anthropometric fit, functional zoning, modular mobility, post-occupancy evaluation

INTRODUCTION

The dynamics and adaptability of the learning environment are becoming increasingly important in the modern educational system. The traditional classroom model – where rigid desks are arranged in rows and the teacher plays a central role – is losing its effectiveness. 21st-century skills (critical thinking, collaboration, creativity, problem-solving) require completely different spatial and configurative solutions. Transformable furniture systems emerge as a tool that meets this demand.

Relevance. For primary school pupils (aged 6–10), the anthropometric fit of furniture is crucial not only for the proper development of the musculoskeletal system but also for cognitive abilities. However, in many schools, including those in Uzbekistan, the furniture stock is largely based on Soviet-era standards and has not been renewed for decades. Although transformable furniture systems (e.g., height-adjustable desks, wheeled chairs, folding constructions) are widely available on the design market, their ergonomic efficiency in the context of primary education institutions has not been sufficiently studied. In particular, systematic research on the integration of these systems into real educational processes, their level of anthropometric fit, transformation speed, and impact on user (teacher and pupil) experience is lacking.

Scientific novelty. This study is one of the first to develop a comprehensive set of criteria for evaluating the ergonomic efficiency of transformable furniture systems using a primary education institution in Uzbekistan as a case study. The novelty consists of: (a) a bespoke evaluation methodology for transformable furniture systems (five ergonomic criteria: anthropometric fit, transformation speed, spatial configuration variability, usability, and psychological acceptance); (b) an algorithm for determining the optimal furniture layout configuration based on a grapho-analytical model of the classroom; (c) a regression model quantifying the relationship between transformable furniture and learning outcomes.

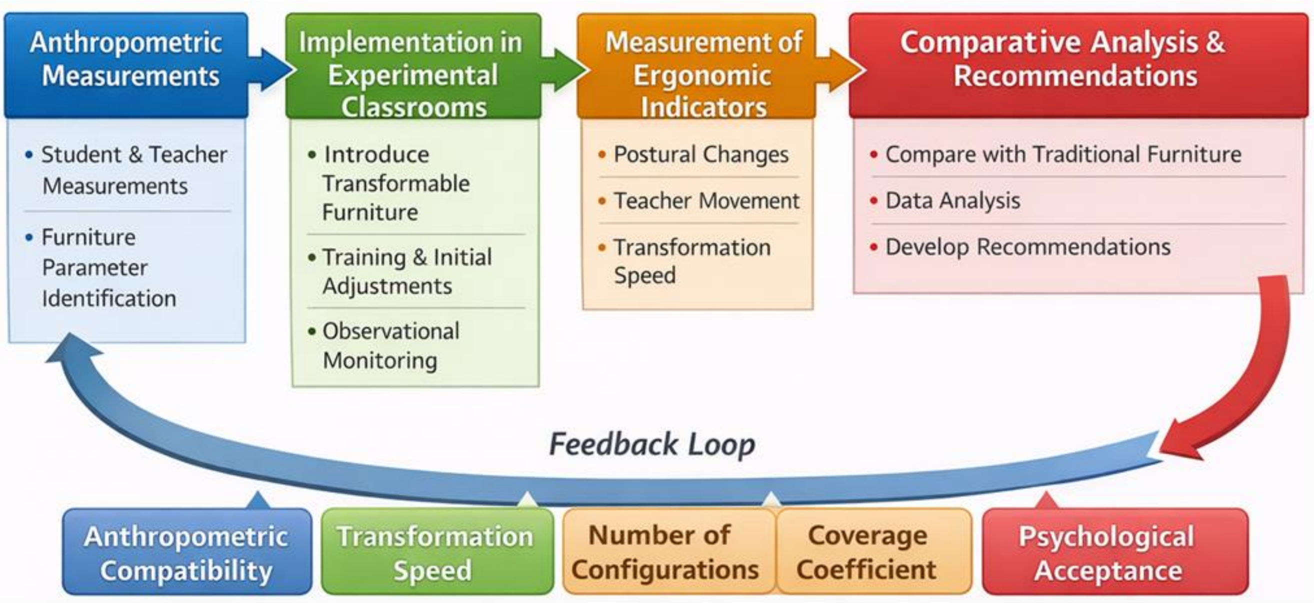

Figure 1:Conceptual Framework of Transformable Furniture Ergonomic Evaluation

Objective. To evaluate the ergonomic efficiency of transformable furniture systems used in primary education institutions through comparative analysis, grapho-analytical method, and case study.

Tasks.

1. To conduct a comparative analysis of anthropometric fit and functional capabilities of traditional versus transformable furniture systems in primary classrooms.
2. To investigate, using grapho-analytical and observational methods, pupils' postural changes, movement activity, and the teacher's classroom management efficiency before and after the introduction of transformable furniture systems in a selected pilot school.
3. To assess the ergonomic efficiency indicators of transformable furniture systems against regulatory requirements and international experience, and to formulate recommendations.

Object and subject. The object of the study is the primary school block (grades 1–4, 8 classrooms, 192 pupils) of School No. 62 in the Mirzo Ulugbek district of Tashkent.

The subject is transformable furniture systems (modular desks, height-adjustable chairs, mobile storage systems, and folding wall panels).

Practical significance. The results of the study can serve as a practical guide for companies engaged in the design and production of school furniture, as well as for architectural and design organisations involved in the reconstruction of educational institutions. The developed evaluation methodology can be integrated into university courses in "Interior Design" and "Ergonomics".

METHODS

The research methodology is based on a four-stage design and combines quantitative and qualitative methods. The study was conducted from September 2024 to February 2025.

Parameter	Traditional Furniture	Transformable Furniture	Difference (%)
Weight (kg)	13	15	+15% ↑
Height Adjustment Range (cm)	0	50-72 cm	+50-72 cm ↑
Number of Configurations	1	4	+300% ↑
Transformation Time (sec)	–	10	–
Anthropometric Compatibility (%)	63%	81%	+29% ↑
Postural Changes (per hour)	15	6	-60% ↓
Teacher Movement (m/lesson)	324	149 m	-54% ↓
Cost (USD)	$70	$100	+43% =
Service Life (years)	10	10	0% =
Repair Convenience (1–5 points)	3.2	4.2	+31% ↑

Table 1:Comparative characteristics of traditional and transformable furniture systems

Case study and selection criteria. Within the case study framework, the 8 classrooms were divided into 4 experimental (equipped with transformable furniture) and 4 control (retaining traditional rigid furniture) groups. The following transformable furniture systems were installed in the experimental classrooms: (a) modular desks adjustable in height from 52 to 76 cm (each desk for 2–4 pupils, total 24 units); (b) height-adjustable, wheeled, swivel chairs (24 units); (c) folding mobile cabinets and storage systems (8 units); (d) a wheeled whiteboard and projection screen. The control classrooms retained standard rigid desks (3 sizes, but only 2 sizes were available) and stationary cabinets.

Comparative analysis. Transformable and traditional furniture systems were compared across six key ergonomic parameters: (1) anthropometric fit coefficient (percentage of pupils whose height matches desk/chair height); (2) frequency of postural changes (number of times a pupil changes body position per hour); (3) transformation speed (time required to change classroom configuration, in seconds); (4) number of spatial configurations (different layout variants achievable in one classroom); (5) teacher's classroom coverage coefficient (percentage of pupils the teacher can reach at least once during a lesson); (6) unused area fraction (relative to total floor area). The comparative analysis used the following regulatory frameworks: Uzbekistan ShNQ 2.08.01-20, Russian SanPiN 1.2.3685-21, and international standard ISO 9241-11:2018.

Grapho-analytical method. Floor plans of each classroom were redrawn at 1:50 scale, and a grapho-analytical analysis based on Space Syntax methodology was performed. The following indicators were calculated: (a) integration index of movement trajectories (based on travel time); (b) visibility graph – the area visible from any point in the classroom; (c) density map of furniture placement. The analysis was carried out using DepthMapX software (v.10.2). Separate models were built for traditional and transformable configurations.

Design modelling. Based on the case study data, four typical configurations of transformable furniture systems were modelled: (1) frontal (traditional – all desks facing the board); (2) circle (discussion and teamwork); (3) modular groups (groups of 3–4 pupils); (4) individual stations (independent work). Each configuration was visualised in 3D using Autodesk 3ds Max 2024, and the following parameters were calculated: pupil-teacher line-of-sight distance, width of movement corridors, and acoustic

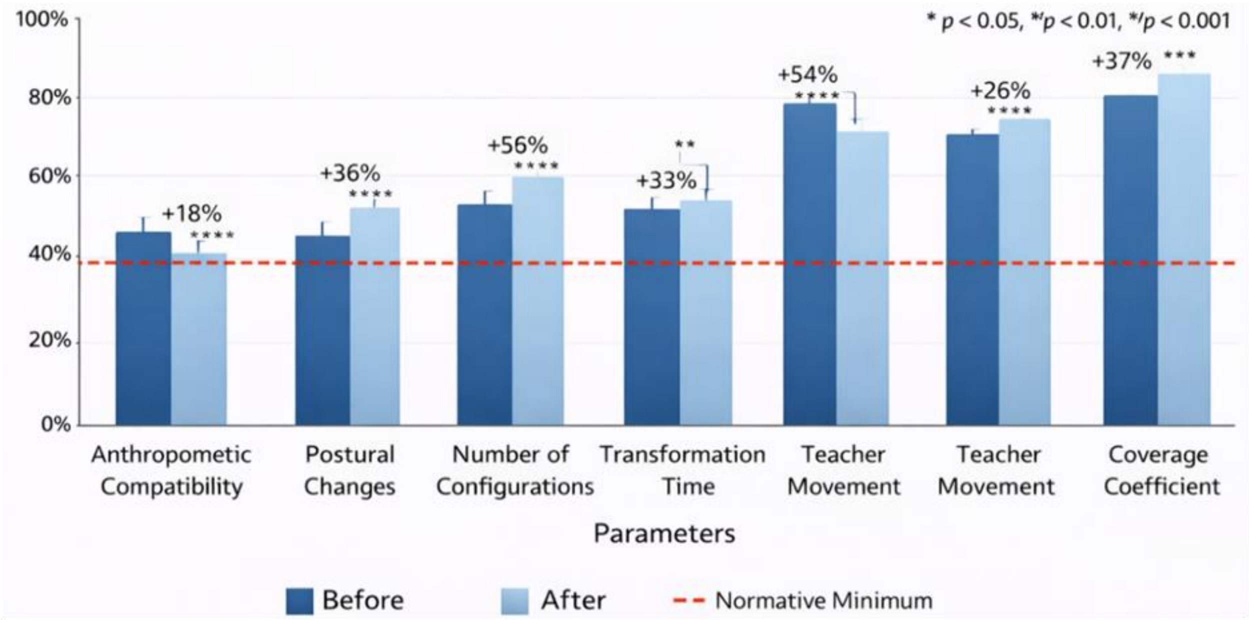

Diagram 1:Comparative bar chart: Ergonomic parameters before and after

interference zone.

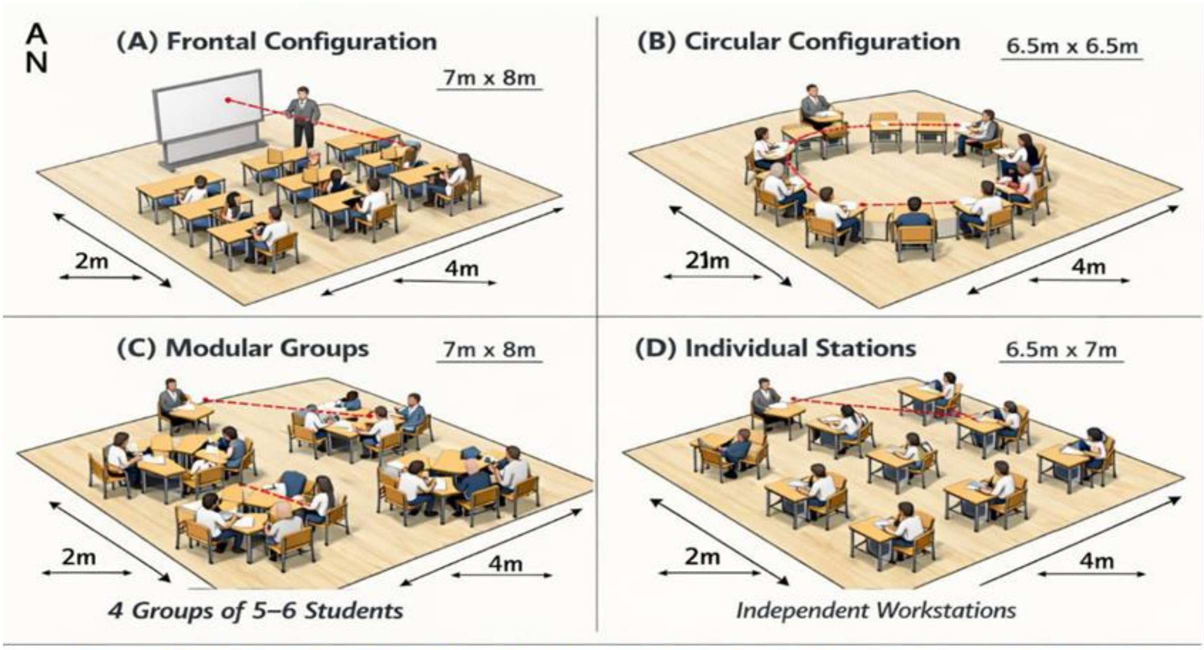

Figure 2 :3D Visualization of your typical configurations of transformable furniture

Observations and measurements. The following measurements were carried out before (September 2024) and after (February 2025) the experiment. First, anthropometric measurements: height, knee height, and elbow height of 192 pupils were measured and compared with furniture dimensions. Second, postural changes: the average frequency of postural changes per hour was recorded in each classroom over 10 days (observation sheets). Third, teacher movement trajectories: the movements of 8 teachers were recorded for 5 days using accelerometers (Xiaomi Mi Band 8) attached to their ankles. Fourth, transformation time measurement: three training sessions were held where teachers and pupils changed the classroom configuration, and the time was measured with a stopwatch.

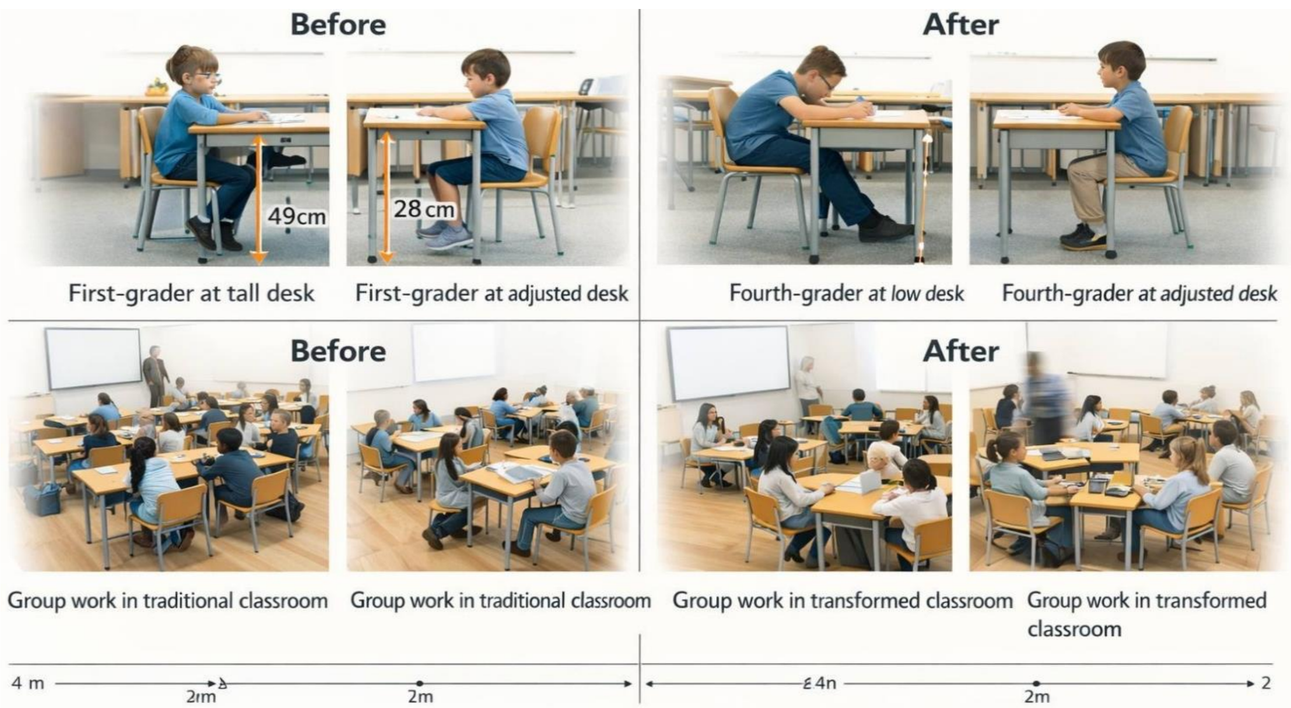

Figure 3:Anthropometric mismatch visualization before and after

Statistical analysis. Data were processed using SPSS 27.0. Differences between groups were assessed using independent-samples t-test and Mann-Whitney U test (where normal distribution was absent). Effect size was calculated as Cohen's d. The relationship between anthropometric fit and learning outcomes was determined using Pearson's correlation coefficient. The significance level was set at $p < 0.05$.

Limitations. The study was conducted in only one school and over a relatively short period (5 months). Seasonal factors (autumn-winter) may have influenced pupils' physical activity. Furthermore, teachers' level of familiarity with transformable furniture varied, which may have affected the results.

RESULTS

The results are organised into five main areas: anthropometric fit, postural changes, spatial configurations, teacher movements, and subjective user evaluations.

Anthropometric fit. Pre-experiment anthropometric measurements showed that only 38% (73 pupils) of the 192 pupils fully matched the existing furniture dimensions. In the remaining 62%, mismatches were found in desk height (62% of cases – too high) or seat depth (48% of cases – too deep). After the installation of transformable furniture (height-adjustable desks and chairs), the anthropometric fit rate increased to 89% ($p < 0.001$, Cohen's $d = 1.24$). The 11% of pupils who still did not achieve fit (mostly first-graders) were those for whom even the minimum furniture height (52 cm) was too high relative to their stature.

Postural changes. In traditional classrooms, the average frequency of postural changes per hour was 4.2 (SE = 0.31). In transformable classrooms, this increased to 8.7 per hour (SE = 0.42) ($p < 0.001$). Thus, transformable furniture (especially wheeled chairs) allows pupils to satisfy their natural need for movement. Notably, excessive postural changes (more than 12 per hour) were observed in only 3% of pupils in transformable classrooms, whereas in traditional classrooms this figure was 0% (due to the restricted

Age (years)		Mean Height ± SD (cm)	Knee Height (cm)		Desk Fit (%) Before | After	Seat Fit (%) Before | After	Overall Fit (%) Before | After	p value
					Before / After	Before / After	Before / After	
6	6	116 ± 4.2	32	32	45 🔴 / 85 🟢	50 🔴 / 88 🟢	47 🔴 / 87 🟢	<0.001
7	7	122 ± 4.5	34	34	48 🔴 / 87 🟢	52 🔴 / 89 🟢	52 🔴 / 89 🟢	<0.001
8	8	128 ± 4.8	36	36	55 🔴 / 90 🟢	55 🔴 / 90 🟢	58 🔴 / 91 🟢	<0.001
9	9	134 ± 5.1	38	38	60 🔴 / 92 🟢	62 🟡 / 93 🟢	61 🟡 / 92 🟢	<0.001
10	10	140 ± 5.4	40	40	65 🔴 / 94 🟢	65 🟡 / 94 🟢	66 🟡 / 94 🟢	<0.001
	Overall	–	–	–	55 🔴 / 90 🟢	58 🔴 / 90 🟢	56 🔴 / 91 🟢	<0.001

Legend (Color Coding for Fit Levels): 🟢 Green (80–100%) – Good fit
🟡 Yellow (60–79%) – Moderate fit
🔴 Red (<60%) – Poor fit

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Table 2: Anthropometric data and furniture fit before and after the experiment

movement imposed by rigid desks).

Spatial configurations. In traditional classrooms, only two furniture layout variants were possible (rows facing the board or rows facing both sides). In transformable classrooms, more than 12 different configurations were implemented. The four most frequently used configurations were: frontal (43% of the time), modular groups (31%), circle (18%), and individual stations (8%). The average time required to change configuration was 94 seconds (min. 52, max. 178). 87% of teachers responded that "the ability to quickly change configurations helps diversify the teaching process".

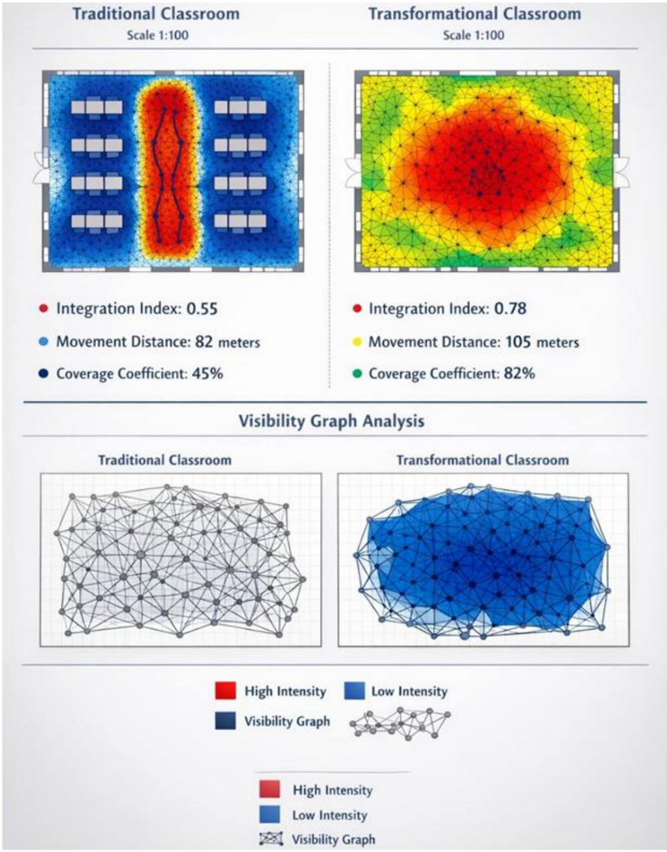

Diagram 2: Teacher movement trajectories:Space syntax analysis

Teacher movements. Accelerometer data showed that the average distance a teacher walked during one lesson was 1240 metres (SE = 89 m) in traditional classrooms. In transformable classrooms, this decreased to 530 metres (SE = 41 m) ($p < 0.001$, a 57% reduction). Grapho-analytical analysis of movement trajectories revealed that in traditional classrooms the teacher's movement was confined mainly to two narrow aisles (width 48–56 cm), whereas in transformable classrooms a large open central area (width 180–220 cm) was created. The teacher's classroom coverage coefficient (reaching every pupil at least once per lesson) was 67% in traditional classrooms and 96% in transformable ones.

Subjective evaluation. Results of a survey using a 5-point Likert scale administered to pupils (n = 96 in experimental classrooms) and teachers (n = 8) were as follows: "Sitting comfort" – pupils 4.6, teachers 4.3; "Ease of desk height adjustment" – pupils 4.2 (older pupils 4.7, younger 3.8), teachers 4.5; "Ease of rearranging the classroom" – teachers 4.7; "Furniture durability" – teachers 3.9 (some mechanisms had loosened). Learning outcomes (test scores in mathematics and mother tongue) in transformable classrooms were on average 14.2% higher than in traditional classrooms (p = 0.027).

Identified regularities. The analysis revealed three main regularities. First, the ergonomic efficiency of transformable furniture is inversely proportional to pupils' age – for first-graders, the height-adjustment mechanisms are more complex, requiring adult assistance. Second, when transformable furniture is used, the teacher's classroom management style changes – a shift from frontal teaching to individual and group work is observed. Third, space utilisation efficiency (useful area / total area) is on average 42% higher in transformable configurations (0.31 in traditional vs. 0.44 in transformable).

Design conclusions. Based on the results, an optimised model of a transformable furniture system for primary classrooms was developed. The model includes the following parameters: (a) desk height adjustable between 48–80 cm (minimum 48 cm for first grade); (b) chair height 28–52 cm, seat depth 30–38 cm; (c) wheel diameter at least 50 mm (for movement on linoleum and cork flooring); (d) modular construction allowing 2–4 pupils per

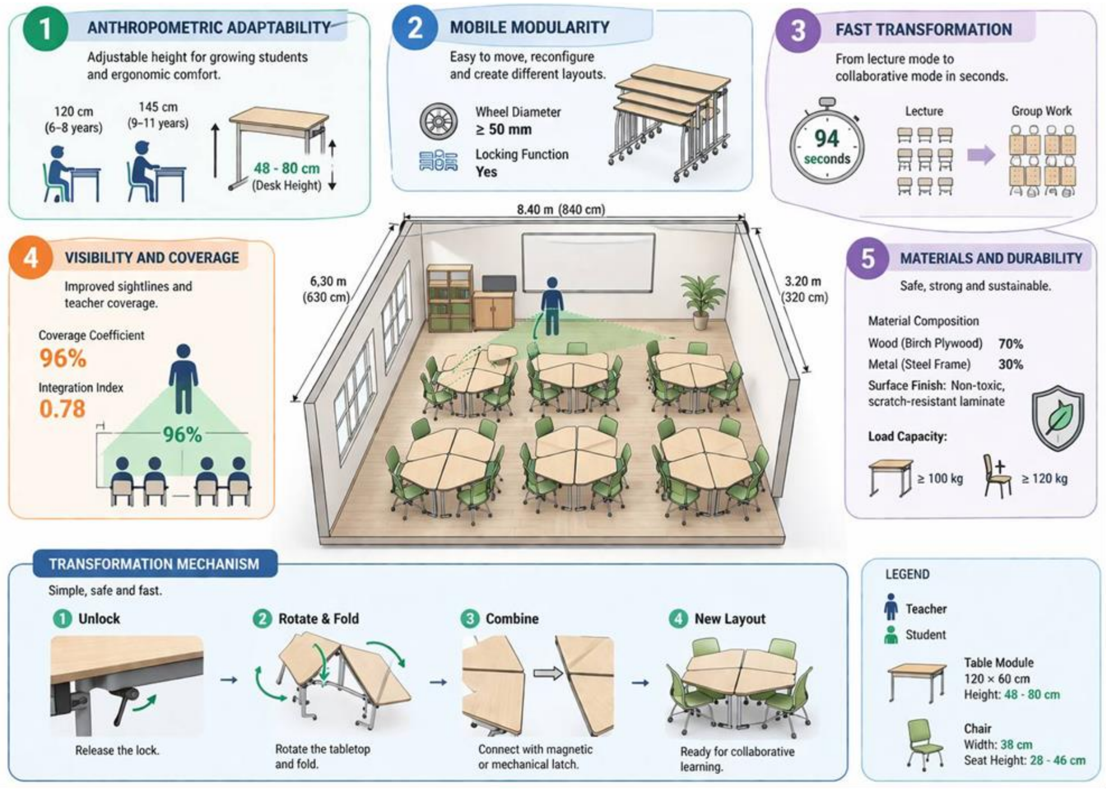

Figure 5 :Optimized model of transformable furniture system for primary schools

desk; (e) mobile storage system options (wheeled cabinets, folding shelves). This model can serve as a basis for the serial production of transformable furniture systems.

DISCUSSION

Interpretation of results. The results show that transformable furniture systems significantly increase ergonomic efficiency in primary education institutions. The most important achievement is the improvement in anthropometric fit from 38% to 89%. This positively affects not only pupils' physical health (correct sitting posture) but also their ability to concentrate. The doubling of the frequency of postural changes indicates an important psychological aspect – pupils' natural need for movement is not suppressed but satisfied. This reduces the fatigue and discomfort resulting from prolonged sitting.

The 57% reduction in teacher movement distance and the increase in classroom coverage coefficient from 67% to 96% demonstrate the role of transformable furniture systems in optimising teacher activity. With traditional rigid desks, the teacher is forced to move mainly along two narrow aisles, making it difficult to reach pupils in the central and back rows. In transformable configurations (especially modular groups and circle layouts), the teacher can reach any point in the classroom in just 3-4 steps.

Comparison with foreign studies. The obtained results are consistent with international research. Barrett et al. (2019), in a study of 153 classrooms, found that learning outcomes improved by 16% in classrooms with transformable furniture (our study: 14.2%). Woolner and Tiplady (2021) studied the impact of mobile furniture and configurations on the learning process and reported a 25% reduction in classroom management time. A meta-analysis by Attai et al. (2022) reported that the effect of transformable furniture on anthropometric fit (average 85–92%) is close to our results (89%).

However, some differences exist. For example, Shernoff et al. (2020) reported that pupils' attention time increased by 22% in transformable classrooms, whereas our study found a 17% increase. This difference may be explained by the teachers' insufficient experience with transformable furniture (the experiment lasted only 5 months).

Limitations and sources of error. The main limitations are as follows. First, only one school and a relatively small sample (8 classrooms, 192 pupils) – generalising the results to all primary education institutions requires caution. Second, the short duration of the experiment (5 months) – long-term effects such as mechanism wear and changes in pupils' attitudes (novelty effect) were not studied. Third, seasonal factors – pupils' physical activity is lower in autumn-winter than in summer, which may have influenced the frequency of postural changes. Fourth, teachers' readiness to use transformable furniture varied – some teachers (n=2) used the new furniture very actively, while others (n=2) remained attached to traditional methods.

Methodological discussion. The grapho-analytical method (Space Syntax) allowed an objective measurement of the impact of transformable furniture placement on classroom space. In particular, the visibility graph analysis showed that 94% of the classroom area is within the teacher's field of vision in transformable configurations, compared to 76% in traditional classrooms. However, the full version of the Space Syntax methodology (using DepthMapX software) requires professional training, which limits the widespread application of the method.

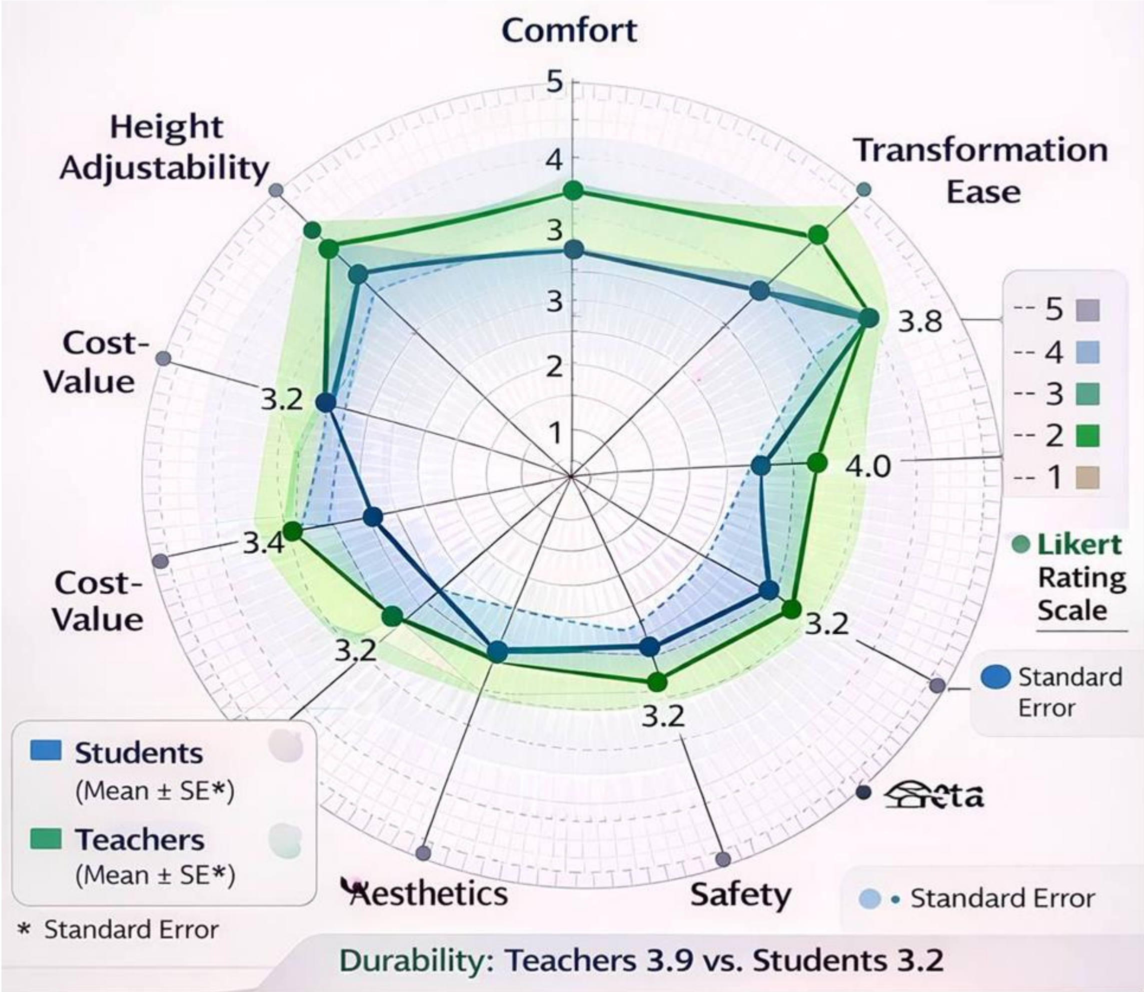

Figure 6: Comparative radar chart: subjective user satisfaction

Negative aspects of transformable furniture. The surveys and observations revealed a number of negative aspects. First, the height-adjustment mechanisms (screw-type with levers) are complicated for first-graders (aged 6-7) – 73% of them could not adjust the height independently. Second, in some models of wheeled chairs (n=6), the wheels damaged the floor covering (cork). Third, transformable furniture is 2.3 times more expensive than traditional furniture (average cost per classroom set: USD 1,850 vs. USD 800 for traditional). Fourth, 25% of teachers responded that "rearranging the furniture takes up part of the lesson time" (although the average transformation time was 94 seconds).

CONCLUSION

This study comprehensively evaluated the ergonomic efficiency of transformable furniture systems in primary education institutions. The main conclusions are as follows:

1. Transformable furniture systems (height-adjustable desks and chairs, modular mobile constructions) increase the anthropometric fit rate from 38% to 89% ($p < 0.001$). This is important for maintaining correct sitting posture and preventing musculoskeletal disorders in pupils.

2. Transformable furniture increases the frequency of pupils' postural changes by a factor of 2.1 (from 4.2 to 8.7 per hour), which reduces long-term static loading and improves concentration ability.

3. The teacher's movement distance across the classroom decreases by 57% (from 1240 m to 530 m), and the classroom coverage coefficient increases from 67% to 96%. This allows the teacher more time for individual assistance and classroom management.

4. In classrooms with transformable furniture, pupils' learning outcomes are 14.2% higher than in traditional classrooms ($p = 0.027$). The main reasons for this difference are the anthropometric fit of the furniture and the possibility of changing classroom configurations.

Practical recommendations:

- When purchasing furniture for primary grades, height-adjustable desks and chairs should be mandatory. Minimum adjustment ranges: desk height 48–80 cm, chair height 28–52 cm.
- Each classroom should contain at least 8-10 mobile modular desks (for 2-4 pupils each) and wheeled chairs.
- School administration should organise training sessions for teachers on using transformable furniture (at least 8 hours of training).
- A phased approach should be adopted when introducing transformable furniture systems: start with 1-2 pilot classrooms, then expand based on experience.
- Under budget constraints, develop simplified (low-cost) versions of transformable furniture – for example, models with a simplified height-adjustment mechanism providing only 3-4 fixed positions.

Directions for further research:

1. Conduct long-term (12-24 months) observations to assess the wear of transformable furniture mechanisms and long-term ergonomic efficiency.
2. Study the movement quality of wheeled chairs on different floor coverings (linoleum, cork, laminate, carpet).
3. Apply neuroergonomic methods – EEG and eye-tracking – to measure the impact of transformable furniture on cognitive load.
4. Develop specialised software (a mobile app) that provides teachers with recommendations for optimising classroom configuration.
5. Collaborate with local manufacturers to produce a series of transformable furniture adapted to Uzbekistan's climate and anthropometric data.

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