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Designing a Resilient Primary School in Post-War Conditions: A Neuroarchitectural Approach Emphasizing Amygdala Activation Reduction

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Abstract


Iranian primary schools have encountered a new phenomenon of "nationwide vicarious trauma" following the Minab incident and the widespread dissemination of its images across social media and national news networks, which has shattered the mental schema of "school as a safe place." From a neuroscience perspective, repeated viewing of these images via mirror neurons has activated neural circuits similar to direct war trauma and caused hyperactivation of the amygdala (the brain's fear and threat processing center) in children. This neural dysregulation directly threatens children's social cognition, essential for learning, cooperation, and peer interaction. The present study aims to develop a neuroscience-based design framework for resilient primary schools in post-war conditions. The research employed a qualitative meta-synthesis method. By analyzing three successful international case studies, including Kharkiv's underground schools in Ukraine, Lithuania's future school project, and the Bucha forest classroom, and integrating them with previous survey findings (the author's master's thesis), design variables were extracted. The findings indicate that effective resilient school design includes five key variables: 1) dual-use shelters with a 40% reduction in panic response, 2) curved corridors with a 3–4 m radius and ceiling heights exceeding 3 m leading to 28% cortisol reduction and 71% reduction in hypervigilance behaviors, 3) dual-mode lighting with gradual transition to prevent sudden dark shock, 4) nature-based open spaces with natural materials (reducing Post-Traumatic Stress Disorder (PTSD) symptoms from 82% to 34%), and 5) child-maneuverable furniture to restore a sense of agency and control. The proposed "Dual-Mode design" framework integrates neuroarchitectural principles with trauma-informed design for the first time in Iran and is adaptable to Mazandaran's warm and humid climate (relative humidity above 80%, annual rainfall over 1000 mm) and Iran's architectural culture (ivan-like spaces and straight Chaharbagh axes).

Keywords: Neuroarchitecture, Resilient school, Amygdala, Hypervigilance, Trauma-informed design, Post-war.

1 | Introduction

For a child aged 7–12, primary school is the first social habitat outside the home; a place where social cognition, the ability to understand others' emotions, predict their reactions, and appropriately regulate one's

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own behavior, develops [1]. From a neuroscience perspective, every spatial element is first evaluated in the amygdala, the brain's fear and threat-processing center, before reaching "aesthetic interpretation" [2]. The amygdala consists of two almond-shaped structures deep within the brain that continuously scan the environment for threats. Neuroarchitectural studies have shown that specific spatial features can activate or calm the amygdala. Long straight corridors (sense of being "in a shooting gallery"), dead angles and blind spots (inability to fully scan the environment), low ceiling heights (less than 2.4 m, sense of "being trapped"), and poor or uniformly flickering light (associating darkness with danger) are among factors that activate the amygdala [3]. In contrast, the ability for "prospect-refuge," curved corridors with a wide radius (3–4 m), high ceiling heights (above 3 m), and natural light with daily spectral changes, reduces amygdala activation and increases the sense of security [4].

The author's master's thesis, based on a field survey of 150 children, teachers, and parents in Abbasabad county, Mazandaran, showed that under normal, non-crisis conditions, "collaborative play space" is the first priority for children aged 7–12, with "basic safety and security" ranking second. Furthermore, "furniture layout and color" ranked third, and "natural light" ranked seventh [5]. From a neuroscience perspective, collaborative play space stimulates activity in the nucleus accumbens (the brain's reward center) and releases dopamine, which is associated with pleasure and motivation [6]. However, all these findings were obtained under conditions where "school" was still considered a "safe place" in the child's mental schema.

But the tragic Minab incident, in which several children lost their lives on school grounds, followed by the widespread and repeated dissemination of images of children's blood-stained clothes across all social media and national media, created a "nationwide vicarious trauma" [7]. From a neuroscience perspective, repeated viewing of these images via mirror neurons activates neural circuits similar to direct war trauma and disrupts "safety signal learning", the brain's ability to recognize that "this environment is safe" [8], [9]. As a result, "school" in the collective mind has shifted from a "safe place" to a "potentially dangerous place." Entering any schoolyard, even a physically safe one, can activate a child's amygdala and trigger hypervigilance behaviors, such as constantly looking back, sudden head-turning at any small sound, and difficulty concentrating [10], [11]. These neural disorders directly threaten social cognition, the core focus of previous research, because social cognition requires "cognitive ease," and a mind worried about the next threat has no capacity to understand others' states [12].

In this context, the two dominant school design approaches in Iran have encountered inefficiency. The first approach (peace-oriented design, within which the author's master's thesis falls) focuses solely on stimulating the brain's reward pathway through play, color, and light, but neglects the amygdala and threat system. In post-war conditions, a foundation for social cognition cannot be provided until the amygdala is calmed. The second approach (security-defense design) attempts to reduce actual threats with high concrete walls, small windows, and enclosed spaces; however, from a neuroscience perspective, this itself becomes a source of threat: high walls tell the amygdala "danger lies beyond these walls," narrow corridors create a sense of being trapped and confined, and lack of windows induces a sense of disconnection from the outside [13].

The present study seeks to answer the fundamental question: How can a neuroscience-based design framework be developed that both enhances children's social cognition in peacetime and reduces amygdala activation and hypervigilance behaviors resulting from indirect war trauma, a school that is both joy-inducing and resilient, without becoming a soulless military fortress?

2 | Theoretical Foundations

Neuroarchitecture is an emerging interdisciplinary field that investigates the impact of the built environment on the brain, nervous system, and human behavior. This field is based on the principle that built space is never "neutral," and every spatial feature, from ceiling height and wall colors to furniture layout and lighting patterns, directly influences the activity of specific brain regions [2].

The amygdala consists of two almond-shaped structures deep within the temporal lobe of the brain, responsible for processing emotions, especially fear and threat. This brain region is known as the "brain's

burglar alarm" because it continuously scans the environment for danger cues. Under normal conditions, the amygdala responds only to genuinely threatening stimuli. However, chronic exposure to stress and trauma, whether direct or indirect, lowers its activation threshold, causing neutral stimuli to be interpreted as "potential threats" [14].

Hypervigilance is a state of defensive over-alertness in which the brain has concluded that "the environment is dangerous" and has decided to control everything. Clinical and experimental evidence shows that hypervigilance manifests as observable behaviors: constantly looking back (to ensure no one is behind), sudden head-turning at any small sound (even the sound of a friend's backpack zipper), sitting in corners of the classroom with back to the wall (to avoid surprise from behind), intense reactions to sudden noises (screaming or freezing), difficulty concentrating on lessons (because all cognitive bandwidth is dedicated to scanning the environment), and avoiding open and crowded spaces (walking close to walls in the yard) [10], [11]. These behaviors not only make the school experience distressing for the child but also directly impair their learning capacity and social interaction.

Trauma-informed design has recently emerged as an interdisciplinary field that leverages findings from neuroscience, environmental psychology, and architecture to provide frameworks for designing healing spaces. Owen and Donnelly, in a study published in *Architecture Australia*, introduce four key domains for child-centered trauma-informed design [4]:

- I. Safety and security, including "prospect-refuge" (a space from which one can observe the surroundings without being seen) and multiple escape routes.
- II. Choice and control, the ability for children to move furniture and change spatial configurations themselves to restore the sense of agency lost in trauma.
- III. An enriched environment, a balance between sensory stimulation (to prevent boredom) and the possibility of retreating to quiet, low-stimulation spaces.
- IV. Social connection, a spectrum of interaction from silent co-presence (sitting next to another without obligatory conversation) to energetic group play.

Attention Restoration Theory (ART), proposed by Kaplan, demonstrates that exposure to nature and green spaces restores directed attention, which has been depleted by stress and fatigue. Nature, with features such as "being away," "soft fascination," "extent," and "compatibility," allows the brain to exit a state of constant alertness and return to a state of calm [15]. This theory is complemented by Wilson's Biophilia hypothesis, which posits that humans have an innate tendency to affiliate with nature and that the presence of natural elements in the built environment elicits positive physiological responses, including reduced heart rate, lowered blood pressure, and decreased cortisol [16].

3 | Case Studies

This section analyzes three examples of schools built or designed in post-war conditions in Ukraine (2022–2026). The selection of these examples was based on the following criteria: 1) implementation or design during wartime or immediately thereafter, 2) explicit attention to the psycho-neural aspects of users (war-surviving children), and 3) potential to extract design variables generalizable to the Iranian context.

3.1 | Kharkiv Underground Schools

In Kharkiv oblast (northeastern Ukraine), where half of the schools have been destroyed or damaged and daily air raids continue, the United Nations High Commissioner for Refugees (UNHCR) and the Ministry of Education of Ukraine have built underground classrooms. These schools enable in-person education without the need to run to shelters at each siren [17].



a.



b.



c.



d.

Fig. 1. Exterior and interior views of underground schools in Kharkiv, Ukraine; a. entrance and access path, b. protected corridor, c. classroom space, and d. safety infrastructure.

Table 1. Design variables of kharkiv underground schools and their effectiveness.

Design Variable	Implementation Specifications	Effectiveness Finding
Ceiling height	3.2 m (vs. 2.4 m standard for military shelters)	28% reduction in salivary cortisol levels
Curved corridors	4 m curvature radius instead of long straight corridors	71% reduction in hypervigilance behaviors (constant looking back)
Simulated lighting	Full-spectrum LED + sky-simulating light tunnels	Circadian rhythm regulation, 42% reduction in nightmares
Color palette	"Sunrise" (soft orange to light blue)	Reduced amygdala activation

A very important finding from this project was the significant difference between straight and curved corridors. In straight corridors, the average number of backward glances was 12 times per 10 minutes of passage, whereas in curved corridors with a 4 m radius, this rate dropped to 3.5 times [17]. The neural explanation for this phenomenon is that gradually curved corridors eliminate "negative surprise" and allow the brain to predict movement. Predictability reduces the need for continuous environmental scanning and consequently lowers the cognitive load imposed by hypervigilance [3].

3.2 | Future School for Ukraine Project

This project, designed by the government of Lithuania with a budget of €500,000, provides an "adaptive design" ready for school reconstruction across Ukraine [18]. The winning international competition design was completed by Scandurra Studio Architettura (Italy) and follows the new European Bauhaus principles, including beauty, inclusivity, and sustainability [19].



a.



b.



c.



d.

Fig. 2. Exterior and interior views of the future school for Ukraine project; a. adaptive school design concept, b. exterior view of modular structure, c. interior learning space, and d. design features based on European Bauhaus principles of beauty, inclusivity, and sustainability.

Table 2. Design variables of the Lithuanian Future School project.

Design Variable	Implementation Specifications	Basis of Effectiveness
Dual-use shelter	Safe room in the center of each unit (library/story room in peacetime, shelter in crisis)	40% reduction in panic response during alerts (conditioned memory modulation by hippocampus)
Modular structure	9×9 m modular grid, combinable into different configurations	Flexibility to adapt to different sites and crisis conditions
Garden courtyard	Enclosed courtyards inspired by monastic "hortus conclusus"	Reduced sympathetic activation through nature and a sense of calm
Ceiling height	3.6 m in normal mode, 2.4 m in safe room	Reduced sense of entrapment in main spaces (but weakness in safe room)

The key concept in this project is the "dual-use safe room." Children who experienced the safe room in peacetime as a positive and desirable space (a small library or storytelling room) entered the same space during alerts with 40% less panic response. This phenomenon is attributed to "conditioned memory modulation by the hippocampus": if a place is associated with positive memories, entering it during crisis conditions modulates amygdala activation [18].

3.3 | Bucha Forest Classroom

This project is located in Dyvo Park, Bucha (Kyiv oblast, Ukraine), and is the first implemented project in Ukraine under the European Commission's new European Bauhaus initiative [20]. Bucha experienced

widespread violence during the first weeks of the war, and this project has become a symbol of sustainable and healing reconstruction [21].



a.



b.



c.



d.

Fig. 3. Exterior and interior photos of Bucha forest classroom; a. site context in Dyvo park, b. exterior view, c. interior learning space, and d. sustainable healing design concept.

Table 3. Design variables of the bucha forest classroom.

Design Variable	Implementation Specifications	Effectiveness Finding
Natural materials	Compressed straw panels, heat-treated wood, and clay plaster	Reduced sensory triggers, conveyed warmth and safety
Open space	Located within a pine forest park, large windows facing greenery	Reduced PTSD symptoms from 82% to 34% over 12 months
Participatory design	Co-creation workshops with children	Increased sense of agency by 2.7 points
Elimination of blind Spots	Transparent design with full visibility to the outside	Reduced amygdala activation through the ability to scan the environment

A very interesting finding from this project was the change in the content of children's drawings as a projective tool. At the beginning of the study, 78% of drawings contained frightening elements (tall walls with barbed wire, red skies, fleeing stick figures). After 12 months of attendance at the forest classroom, 65% of drawings contained predominantly natural elements (large trees, flowers, animals) and figures with happy facial expressions [20]. Furthermore, the standardized sense of control scale showed that forest classroom children increased their scores from a mean of 2.1 out of 7 (very low) to 4.8 out of 7 at the end of 12 months [21].

3.4 | Comparative Analysis and Variable Extraction

Analysis of the three case studies indicates that international post-war school design is moving toward a common pattern: schools that are not merely "safe" (in a defensive-structural sense) but "restorative" (in a neuro-psychological sense). *Table 4* presents this pattern by identifying the strengths and weaknesses of each case.

Table 4. Comparative analysis of design variables across three case studies.

Design Variable	Kharkiv Schools	Future School Lithuania	Bucha Forest Classroom	Common Weaknesses
Dual-use shelter	X	✓ (2.4 m height)	X	Lack of attention to "prospect-refuge"
High ceiling height	✓ (3.2 m)	✓ (3.6/2.4 m)	Open space	Low height in the Lithuanian shelter
Curved corridors	✓ (4 m radius)	X (straight)	--	Straight corridors in the Lithuanian sample
Natural materials	X (cold concrete)	X (recycled materials)	✓ (straw, wood)	Lack of warm texture in industrial samples
Dual-mode lighting	X (simulated)	X (partial)	X (only natural)	Lack of a gradual transition in all samples
Participatory design	X	X	✓	No child participation in 2 of 3 samples
Connection with nature	X (underground)	✓ (moderate)	✓ (excellent)	Lack of nature in the sample with the greatest need (Kharkiv)

Based on this comparative analysis, five key design variables for resilient schools in Iran are extracted and presented in *Table 5*.

Table 5. Extracted design variables for resilient schools in Iran.

Design Variable	Proposed Specifications	Basis of Effectiveness (Source)
Dual-use shelter	6–8 m ² per classroom (positive peacetime use: small library, story room, classroom greenhouse)	40% panic response reduction [18]
Ceiling height	Minimum 3 m in classrooms and corridors	28% cortisol reduction [17]
Curved corridors	3–4 m curvature radius instead of straight corridors	71% hypervigilance reduction [17]
Dual-mode lighting	Large window + blast-resistant shutters + interior lighting with open-sky spectrum (turned on before shutters close)	Prevention of sudden dark shock [18]
Natural and warm materials	Wood, colored plaster, textured rubber flooring (instead of exposed cold concrete)	Reduced sensory triggers, conveyed sense of safety [20]

4 | Proposed Design Framework for Iran

Considering the research findings, Mazandaran's warm and humid climate (relative humidity above 80%, annual rainfall over 1000 mm), and Iran's architectural culture (iwan-like spaces, straight Chaharbagh axes), the following "Dual-Mode design" framework is proposed:

Peace mode: Under normal, non-threatening conditions, school design focuses on stimulating the brain's reward pathway (the nucleus accumbens) and enhancing social cognition. The key components of this mode include:

- I. Collaborative play space in the central courtyard with diverse equipment (children's top priority in the master's thesis [5]).
- II. Adequate natural light through large windows facing green spaces (minimum 300–500 lux).
- III. Cheerful and varied colors (warm colors prioritized in social spaces, calming colors in classrooms).
- IV. Child-maneuverable furniture (to restore sense of control and agency).
- V. Nature-based open space with shade trees and cultivable garden beds.

Crisis mode: During alerts or imminent threats, school design focuses on calming the amygdala and reducing hypervigilant behaviors. The key components of this mode include:

- I. Activation of dual-use shelters (converting small classroom libraries into shelters with outward visibility).
- II. Gradual closing of blast-resistant shutters (accompanied by interior lighting with open-sky spectrum to prevent dark shock).
- III. Guiding children toward curved corridors (pre-designed as primary circulation routes).
- IV. Use of calming color palettes (light blue, soft green) in shelter spaces.
- V. Activation of emergency ventilation systems and communication with parents.

Important Note: These two modes should not be treated as two separate designs but as a single design capable of "state transition." In other words, architectural elements (windows, shutters, furniture, circulation paths) are designed to switch from peace mode to crisis mode in less than 30 seconds, without conveying a sense of "military fortress" to the child during peacetime.

5 | Conclusion

The present study aimed to develop a neuroscience-based design framework for resilient primary schools in post-war conditions. The findings indicate that the dominant school design approaches in Iran—purely peace-oriented and purely security-defense-oriented—are ineffective in the aftermath of nationwide vicarious trauma (following the Minab incident). Analysis of three successful international case studies (Kharkiv underground schools, Lithuania's future school project, and the Bucha forest classroom) identified five key

design variables: Dual-use shelters (40% panic response reduction), curved corridors with 3–4 m radius and ceiling heights exceeding 3 m (28% cortisol reduction and 71% hypervigilance reduction), dual-mode lighting with gradual transition, nature-based open space with natural materials (reducing Post-Traumatic Stress Disorder (PTSD) symptoms from 82% to 34%), and child-maneuverable furniture (restoring sense of agency).

The proposed "Dual-Mode design" framework integrates neuroarchitectural principles with trauma-informed design for the first time in Iran and is adaptable to Mazandaran's warm and humid climate and Iran's architectural culture. This framework necessitates a redefinition of the concept of "safety" in school architecture: from purely physical safety (railings, standard stairs, distance from traffic) to neuro-psychological safety (reducing amygdala activation, restoring sense of control and agency, and symbolically rebuilding school as a "safe place"). Architecture, in this redefinition, is elevated from a "neutral envelope" to an "active agent in neural recalibration."

Future research is suggested to follow three directions:

- I. Conduct experimental neuroscientific studies on Iranian children using non-invasive tools, such as salivary cortisol measurement and eye-tracking, while exposed to simulated spaces (virtual reality).
- II. Build a prototype school based on the proposed framework and evaluate its effectiveness using behavioral markers identified in this study (backward glances, head-turning, sitting patterns, and content of children's drawings) in collaboration with the school renovation organization.
- III. Adapt neuroarchitectural variables for different climates of Iran (hot, dry regions, and cold mountainous regions) and diverse architectural cultures.

Authors' Contributions

All aspects of the research and manuscript preparation were carried out by the author. The author has read and approved the final version of the manuscript.

Data Availability

All data supporting the reported findings in this research paper are provided within the manuscript.

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