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Semiotic modelling of space in modular and memorial architecture: Experimental applications in Kazakhstan

Aray Saibulatova[1,2,3], Dana Dyussenova[1,2,3*], Kuat Kuandykov[2,3], Elmira Bagdavletova[1], Sanja Avramoska[4]

[1] Faculty of Architecture and Design, Department of Architecture, Kyrgyz State Technical University named after I. Razzakov, Bishkek, Kyrgyzstan
[2] International Educational Corporation, Almaty, Kazakhstan (IEC) (KazGASA), Almaty, Kazakhstan
[3] Faculty of Architecture, Kazakh Leading Academy of Architecture and Civil Engineering (KazGASA), Almaty, Kazakhstan
[4] Faculty of Architecture, University "Ss. Cyril and Methodius" in Skopje, Skopje, North Macedonia

*Corresponding author E-mail: d.diusenova@kazgasa.kz

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Abstract

Kazakhstani architecture must move beyond viewing modularity as an industrial necessity, treating it instead as a framework to encode and preserve cultural memory. Through experimental prototyping and semiotic modeling, this study demonstrates that modularity functions as a living language rather than a rigid standardization. We extend Dyussenova's metaphysical work on Kazakhstan's architectural "genetic code" by offering a practical implementation mechanism for the semiotic-modular matrix. Furthermore, while previous research (e.g., Ostapenko et al.) reduced architectural symbols to surface decoration, our approach embeds deep meaning into physical structures and shapes. For instance, in "The Fractured Corridor", structural "trauma" is conveyed through a broken, mismatched floor, evoking visceral disorientation in the observer. By applying Peirce's sign theory within a computer-aided design (CAD) workflow, we decompose architectural elements into iconic, indexical, and symbolic signs. This system enables architects to algorithmically design spatial environments that embody authentic cultural and emotional narratives rather than mere decorative motifs.

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Keywords: Semiotic modelling, Memorial architecture, Kazakhstan, Modular matrix, Monument

1. Introduction

Modern architecture of Kazakhstan is an intermix of its nomadic history, its Soviet era designs, as well as a modern global look [1], [2], [3]. Interestingly, memorial monuments are built not just for decorative or aesthetic purposes but also to commemorate or record historical events. Despite existing research, there is no systematic framework that would integrate semiotics into modular memorial architecture. Semiotics, pioneered by Peirce and Saussure, has been applied to analyse buildings as sign systems in architecture [4], [5], [6]. Recent studies emphasize modularity in design, but few integrate semiotics with modular architecture,

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especially in memorial contexts [7], [8].

For example, Dyussenova and Ostapenko utilised the "semantic images" of Kazakhstan's monuments in their studies [9], [10]. Thus, there exists a gap in how to transform semiotic meanings into quickly building an architectural piece using repeating parts (modularity). This study addresses that void. By designing a system of signs from cultural meanings [11], [12] into mathematical rules that can be broken down and understood (decoded), we hope to create a "modular vocabulary" that represents deep traditions when combined. Therefore, the main objective of this study is to develop and validate a semiotic-modular framework for memorial architecture in Kazakhstan.

To explore the aim of this study, we ask the crucial question: if the repetitive patterns and shapes of modern architecture in Kazakhstan actually replace traditional memorials and monuments? To this end, we therefore propose a focus on "morphological semiotics instead of decorative semiotics [13], [14]. To achieve this, traditional cultural meanings of Kazakh memorials [15], [16] are transformed into iconic, indexical, and symbolic codes. Ultimately, this study hopes to show with the aid of the proposed experimental prototypes that modularity in Kazakhstani architecture is efficient, while still deeply rooted in their cultural history. In addition, the following research questions would be looked into:

RQ1: What semiotic codes (iconic, indexical, symbolic) are present in Kazakhstani memorial architecture?

RQ2: How can these codes be integrated into a modular architectural system?

RQ3: What role does modularity play in conveying cultural semantics?

RQ4: How do experimental prototypes demonstrate the effectiveness of semiotic modelling?

Ultimately, Section 2 of this study describes the research methodology, while Section 3 describes and discusses the results obtained, and finally, Section 4 highlights the relevant conclusions of this study as well as the theoretical implications, practical significance, research limitations, and proposed future research directions of this study.

2. Research method

2.1. Research framework

Through a "research-through-design" approach, we conducted a four-stage research process [17], [18]. Four famous monuments in the two cities of Astana and Almaty in Kazakhstan were utilised for this study. We used C. S. Peirce's semiotic framework to break the monuments into three types of signs, including Iconic (What do they look like?), indexical (What do they point to or cause?), and symbolic (What abstract ideas do they represent based on Kazakh culture?), in order to understand how they communicate. The qualitative feelings such as "courage" or "loss" embedded in these monuments were then translated into quantitative design parameters as rules for computer-aided design. We then correlated emotional concepts to physical actions such as the "interlocking" of blocks to show strength or the "fracturing" of blocks to show trauma.

To test our hypotheses, we used 3D modelling software such as Rhinoceros 7.0 and Grasshopper to build four digital prototypes to see if the symbolic meanings would hold up if they were made bigger or smaller (Figure 1). Lastly, we then evaluate each prototype on a scale of 1-10 based on (i) how well it tells a story? (Semantic depth), (ii) is it easy to build? (Technical efficiency), (iii) does it look good? (Aesthetic impact), and (iv) can it be built at a large size? (Structural scalability).

This study employs a qualitative research design combining semiotic analysis and experimental design to model the architectural space of modular memorial complexes in Kazakhstan. Four research sites were selected for this study for their representativeness of cultural significance, accessibility, and typological diversity which include (i) Astana's Independence Monument (Astana) (Figure 2a) [19], (ii) The Monument to the Victims of Political Repression (Almaty) (Figure 2b) [20], (iii) Mangilik El Monument (Astana) (Figure 2c) [21], and (iv) Kazakhstan's Memorial of Glory (Almaty) (Figure 2d) [22].

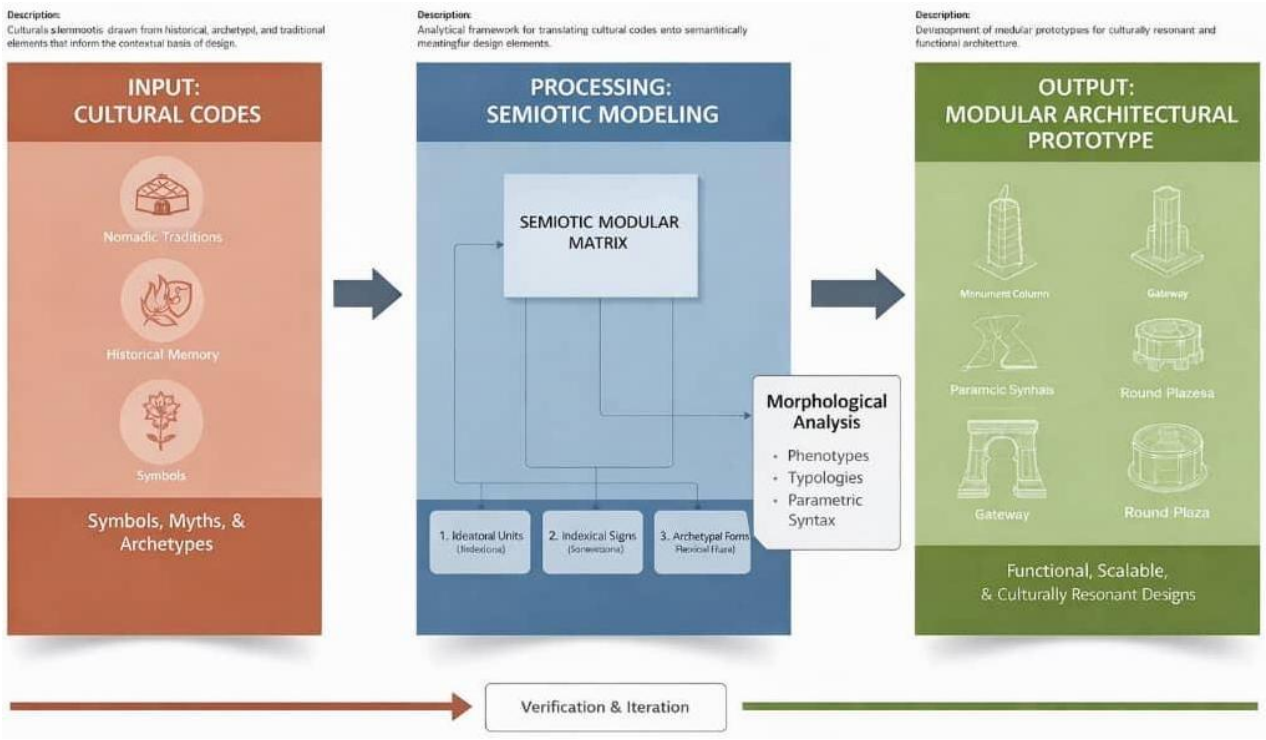


Figure 1. Flowchart of semiotic modelling

Each of the selected objects (Figure 2a-2d) will then be subjected to semiotic analysis to identify iconic, indexical, and symbolic signs using Peirce's framework and to decode cultural codes [2]. Secondly, the objects will undergo morphological analysis to analyze spatial structures, modular elements, and rhythmic sequences. Furthermore, models would be developed by creating semiotic codes with modular principles. Thereafter, the validation of the model via design prototypes with the aid of 3D visualization, modular system diagrams, and plans would be carried out, and then followed by the verification of the experimental design through the evaluation of the prototypes for semantic preservation, modularity, and aesthetic integrity.

In this study, we focused on four iconic monuments in Kazakhstan because they represent two "emotional poles" of the country. For example, we chose monuments in Astana that celebrate the triumph and the bright future of a new nation, while the memorials in Almaty honor the trauma and the memory of those lost to history. Ultimately, our work can be used as a “digital recipe” (translating abstract feelings into precise mathematical rules) that can take the unique culture of any people and turn it into a logical, modular building system of any architecture.

Figure 2a. Astana's Independence Monument

Figure 2b. The Monument to the Victims of Political Repression (Almaty)

Figure 2c. Mangilik El Monument (Astana)

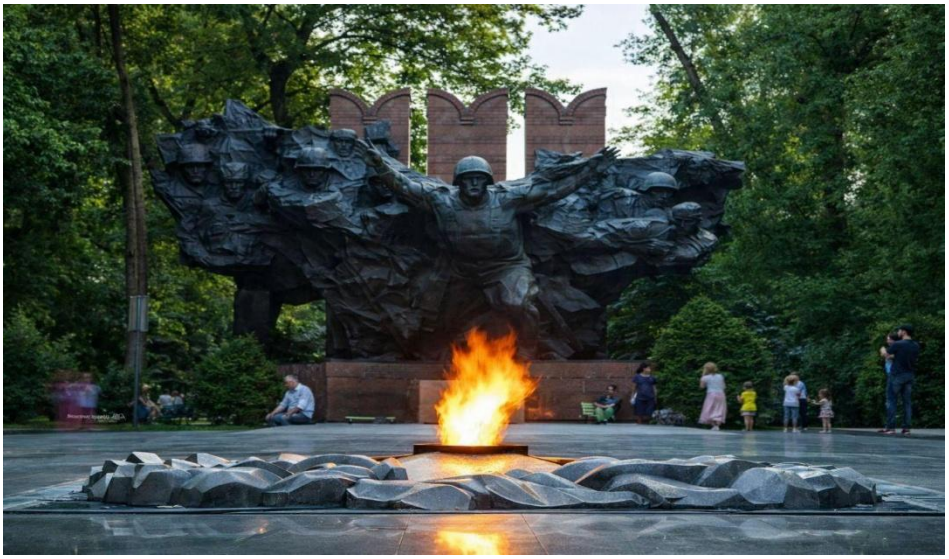


Figure 2d. Kazakhstan's Memorial of Glory

2.2. Software applications

The diagrams and prototypes were developed using a combination of the following specialised software:

i. 3D Modelling and parametric design

Rhinoceros 7.0 with Grasshopper software was used to generate the semiotic-modular matrix diagrams. ArchiCAD software was employed for the generation of the exploded axonometric views to reveal internal structural components like the "Axis Mundi".

ii. Analytical and data visualisation

Python was used to generate the radar chart. Adobe Illustrator was used for the flowchart in Figure 1 and the geometric overlays of the semiotic indicators.

3. Results and discussion

3.1. Semiotic analysis

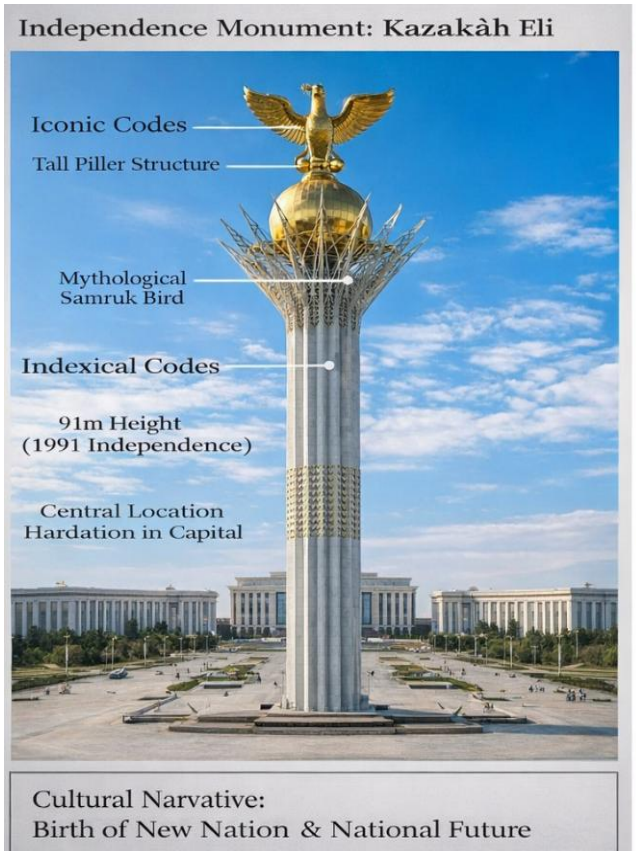
To categorize these architectural objects through the lens of semiotics [23], [24], we utilize Peirce's triad of signs of iconic (visual resemblance), indexical (causal or existential connection), and symbolic (learned cultural convention) [25] (Table 1) as depicted in Figure 3.

Table 1. Semiotic analysis of Kazakhstan memorial objects

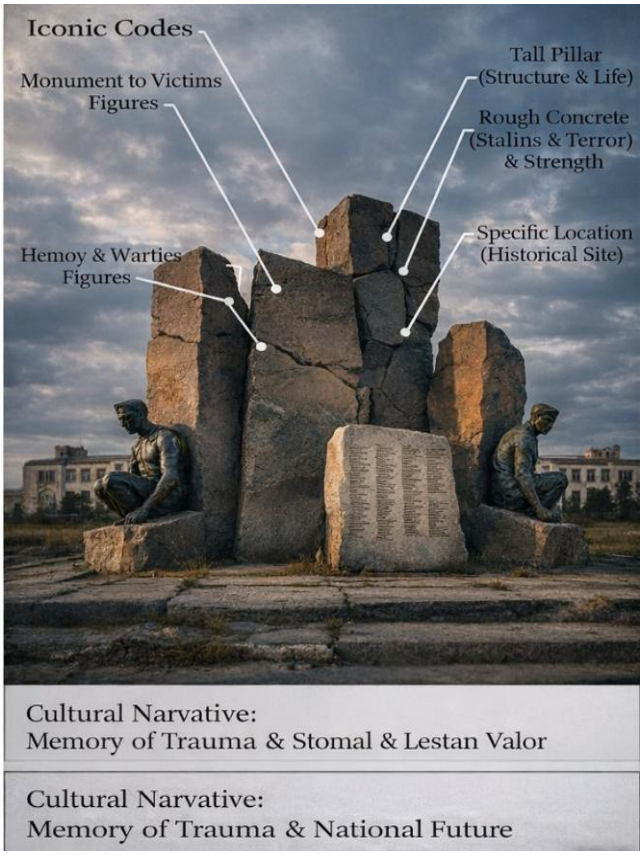
Memorial object	Iconic codes (visual similarity)	Indexical codes (connection)	Symbolic codes (convention)	Decoding cultural codes
(i) Kazakh Eli (Independence Monument)	Blue-gazed pyramid shape: Resembles a traditional Kazakh yurt + symbolizes sky/generational connection.	i. The specific height of 91 meters is an index of the year 1991, the date of Kazakhstan's independence. ii. Its central location at Independence Square indicates national importance, a hub of civic life. iii. Its materials, such as glass and metal, reflect modernity, progress, and Kazakhstan's global engagement of Kazakhstan.	i. The Winged mythical creature (Samruk bird/Qulans) at the summit echoes Kazakh/Turkic mythology and represents freedom and sovereignty,	i. The Monument serves as a symbol of national identity by asserting post-Soviet identity. ii. Its height and form signify Kazakhstan's futuristic outlook.
(ii) Monument to Victims of Political Repression	i. Stones with cracks represent broken lives and shattered hopes	i. Its location close to the former KGB prison connects to the site of historical repression. ii. The inscribed	i. Stones that symbolize enduring memory, the weight of history ii. The cracks in stones represent broken lives, trauma	i. The monument serves as a memorial for victims of political violence ii. It highlights the

Memorial object	Iconic codes (visual similarity)	Indexical codes (connection)	Symbolic codes (convention)	Decoding cultural codes
		names on the stones point to individual victims, indexing real people. iii. The expressions on the sculptures convey the emotional impact of historical events.	iii. The postures of the Figures symbolize grief, resilience, and remembrance	consequences of state repression iii. It highlights human endurance amid suffering
(iii) Mangilik El Triumphal Arch	The arch represents victory and nationhood.	Reliefs depicting historical events and figures, e.g., the Golden Warrior, index the continuity of Kazakh history.	The name Mangilik El, whose meaning is eternal nation, is a symbolic linguistic code for the ideological permanence of the state.	i. The Monument emphasizes the unity and eternal existence of Kazakhstan ii. The monument blends modern architecture with Kazakh/Turkic symbols iii. Its height and design signify a forward-looking vision of Kazakhstan
(iv) Memorial of Glory (Panfilov Park)	The triptych structure resembles a defensive shield or a phalanx of soldiers protecting the "Motherland."	The Eternal Flame serves as a continuous index of the lives lost and the enduring heat of memory.	The number 28, representing the Panfilov Guardsmen, symbolizes collective heroism and Soviet-era unified sacrifice.	i. The monument honors WWII heroes, emphasizes national pride ii. The eternal flame signifies an ongoing memory of sacrifice iii. The monuments highlight the courage of the soldiers of Kazakhstan

Both the Independence and Mangilik El monuments use vertical iconic signs that can be translated into repetitive vertical modules. Indexical signs (reliefs and inscriptions) suggest a modular system where cladding panels function as "data blocks" that can be interchanged or expanded (Figures 3a and 3b). In repression memorials (Figures 3c and 3d), the "void" (absence of modules) acts as a symbolic signifier for the missing or the dead.



a



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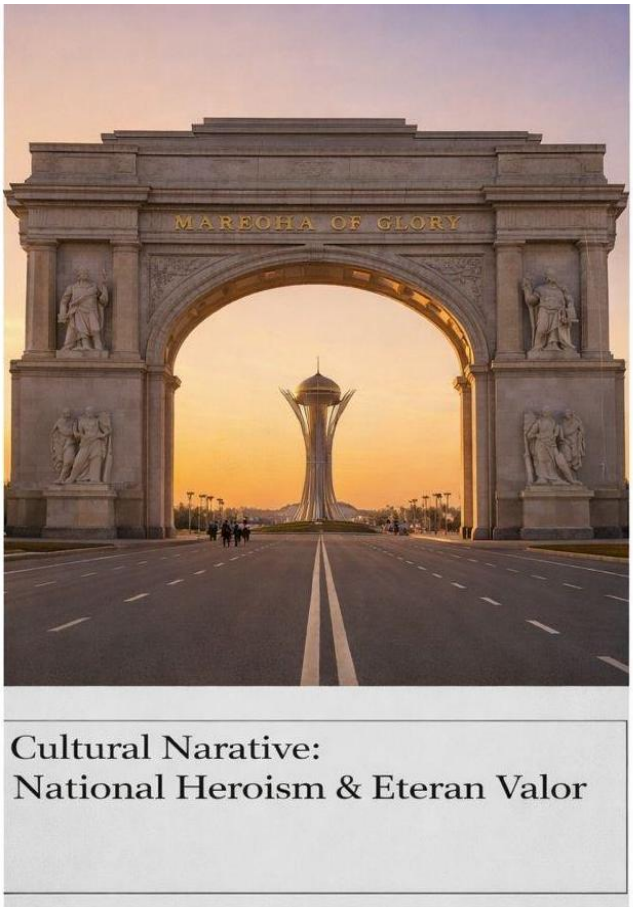


c

d

Figure 3. Semiotic analysis of: Kazakh Eli (a), Repression (b), Mangilik El (c), Memorial of Glory (d)

To bridge the gap between abstract cultural meaning and technical modular assembly, the following models were used to demonstrate how identified semiotic codes are integrated into structural systems for each object (Table 2).

Table 2. Morphological analysis of Kazakhstan memorial objects

Memorial Object	Spatial Structure	Modular Elements	Proportional Systems	Rhythmic Sequences
(i) Kazakh Eli (Independence Monument)	i. The monument stands on the central axis of Independence Square, emphasizing national significance. ii. The surrounding open space creates a public gathering area, framing the monument. iii. The 42 m height of the monument draws an upward gaze, which signifies aspiration.	i. The base of the monument is composed of repeating glass panels ii. The columns/ribs of the monument's support structure use modular metallic elements iii. The modular LED lights of the monument accentuate its form at night	i. The height-to-width ratio is 2:1, which emphasizes verticality ii. The golden ratio was likely used in the proportions of pyramid faces and the placement of the Samruk sculpture	i. The repeating glass panels of the monument create rhythm and unity in design ii. The stepped pyramid layers of the monument create a visual rhythm leading upward iii. The nighttime lighting of the monument creates a dynamic rhythm, accentuating form
(ii) Monument to Victims of Political Repression	i. The stones are arranged in a semi-circular pattern, thereby guiding visitor movement. ii. Low-lying stones create a contemplative and sombre atmosphere iii. Narrow paths between stones encourage reflection and slow movement	i. The individual stones of the monument with names and dates symbolise individual victims ii. Support structures use simple and industrial metal elements iii. The prison bars motif of the monument was repeated in the metalwork, thereby creating rhythm	i. The stones and figures of the monument relate to human size and encourage connection ii. The stones of the monument are grouped by categories, e.g., era, ethnicity	i. Create rhythm, emphasise the multitude of victims ii. The varied postures create visual rhythm and convey emotions iii. The short texts on stones create a narrative rhythm
(iii) Mangilik El Triumphal Arch	i. The 111 m Tall central element dominates the space,	i. Repeating arches form the perimeter and thus symbolise	i. The 111m height of the monument creates strong	Repeating arches create visual rhythm and guide

Memorial Object	Spatial Structure	Modular Elements	Proportional Systems	Rhythmic Sequences
	thereby drawing visitors in ii. The surrounding arches create a "gateway" atmosphere by framing views iii. The water element from the reflective pool adds symmetry and enhances monumentality	unity ii. The paired sculptures of winged leopards at the base of the monument act as modular "guardians." iii. Modular inscription panels with the "Mangilik El" phrase	vertical emphasis ii. Bilateral symmetry reinforces the grandeur and stability of the monument	movement. Nighttime lighting accentuates vertical lines and creates an upward rhythm. Paired sculptures of winged leopards create a balanced rhythm at the base.
(iv) Memorial of Glory (Panfilov Park)	i. The Eternal Flame is situated at the centre, and the stelae are symmetrically arranged. ii. The symmetrical layout creates a sense of order and solemnity iii. The surrounding space allows for ceremonies and reflection	i. The Stelae are made of repeating vertical elements with the names of heroes. ii. The central soldier figures act as focal modules iii. The modular narrative panels depict war scenes	i. The central sculpture group is very tall and therefore catches the eye ii. The Stelae are arranged in a grid, which emphasises order and respect	i. The repeating stelae create visual rhythm and guide movement ii. The sculpture grouping of the monument creates a focal rhythm and draws attention iii. The Eternal Flame, which is the central element, creates a static rhythm, thereby symbolising enduring memory

Adobe Illustrator was used in the creation of the semiotic code – modular element matrix of the selected Kazakhstan memorials (Table 3). Each model follows three-layer logic:

i Semantic Layer (Code), which addresses abstract meaning such as identity, unity, and sacrifice.

ii Syntactic Layer (Module) that is linked to the physical unit, like the frame, panel, layout, etc.

iii Pragmatic Layer (Function) addresses usage and interpretation, e.g., aspiration, remembrance, honour, etc.

Table 3. Comparative integration matrix

Memorial	Semiotic code	Modular element	Function
Independence	Iconic (yurt/pyramid)	Glass panels	Represents tradition/modernity

Memorial	Semiotic code	Modular element	Function
monument	Indexical (height)	Central axis	Emphasizes national significance
	Symbolic (blue)	LED lights	Signifies unity, sky/Tengri
Victims of repression	Iconic (stones)	Individual stones	Represents individual victims
	Indexical (location)	Semi-circular layout	Connects to the site of repression
	Symbolic (cracks)	Stones texture	Signifies broken lives
Mangilik El	Iconic (arch)	Repeating arches	Functions as a symbol of entry into a new era and national strength.
	Indexical (height)	Central Stelae	Signifies national aspiration
	Symbolic (gold)	Winged leopards	Represent strength and heritage
Memorial of glory	Iconic (flame)	Eternal Flame	Encourages ritualistic remembrance and respect for individual bravery.
	Indexical (names)	Stelae grid	Indexes individual heroes
	Symbolic (soldier)	Central sculpture	Represents bravery

3.2. Experimental prototypes

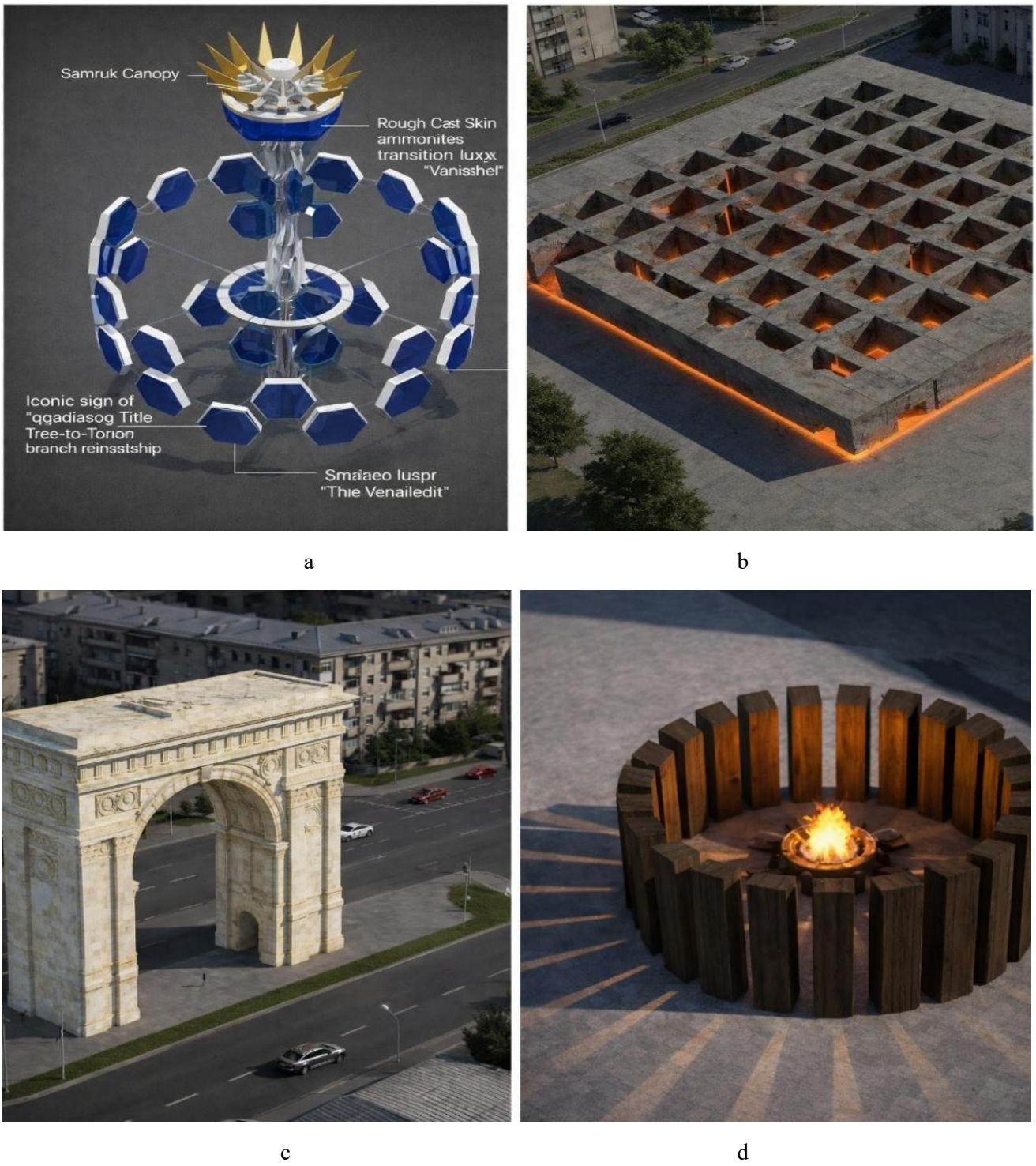
Four experimental prototypes were selected and were used to transition the semiotic analysis of Kazakhstan's landmark memorials into functional modular systems using Rhinoceros/Grasshopper for parametric assembly and Lumion for visual verification [26], [27]. Thus, the following prototypes represent a "modular translation" of the four selected memorial sites.

Prototype I: The Vertical Nexus prototype (based on Independence Monument, Astana) (Figure 4a) and the other prototypes were produced using Rhinoceros 7.0 software. Its visual composition is illustrated in Figure 4a as an exploded axonometric view with the aid of the ArchiCAD software, showing a central metallic silver structural core (the "Axis Mundi") surrounded by 35 floating Astana blue hexagonal glass modules, with each one representing each year of independence up to 2026. The "Samruk" canopy is the top module with kinetic gold fins and a modular shaft with repeatable 3 m units representing years of sovereignty. The iconic sign of the "Tree of Life" is expressed through the radial core-to-branch relationship [28], [29].

Prototype II: "The Fractured Corridor" (based on the monument to victims of political repression, Almaty) (Figure 4b). The exploded axonometric of Prototype II in Figure 4b shows a high-contrast "bird's-eye" perspective of a charcoal grey and rust red labyrinthine modular walkway with holes in the grid signifying "The Vanished", the textured modular walls creating a tactile index of hardship, while the semiotic indicator in this prototype is the indexical sign of trauma through the physical "trace" of missing structural units.

Prototype III: "The Portal of Continuity" (based on Mangilik El Triumphal Arch, Astana) (Figure 4c). Figure 4c depicts a cross-sectional view of a pale marble, white, and sand gold modular arch with a "smart skin" made of tessellated prisms. The modular Girih patterns of the prototype reflect the "Eternal Nation" ideology and the steel frame units, making it ideal for quick assembly over busy urban arteries. The semiotic indicator is the symbolic sign of victory through the classical portal form reconstructed via digital prefabrication.

Prototype IV: "The Phalanx Pavilion" (based on Memorial of Glory, Almaty) (Figure 4d). The exploded axonometric view of Figure 4d presents a radial plan and 3D perspective showing 28 dark bronze vertical blade modules representing the 28 Panfilov soldiers, protecting a central hearth with an orange Eternal flame. The semiotic indicator is the iconic sign of a "Shield" formed by the aggregation of individual modules into a collective wall.



a b

c d

Figure 4. Prototypes used to transition the semiotic analysis of Kazakhstan's landmark memorials: a - Vertical Nexus, b - Fractured Corridor, c- Portal of Continuity and d - Phanlanx Pavilion

Furthermore, the axonometric views of Prototype I to Prototype IV are presented in Figure 5 for better understanding and clarity of the prototypes.

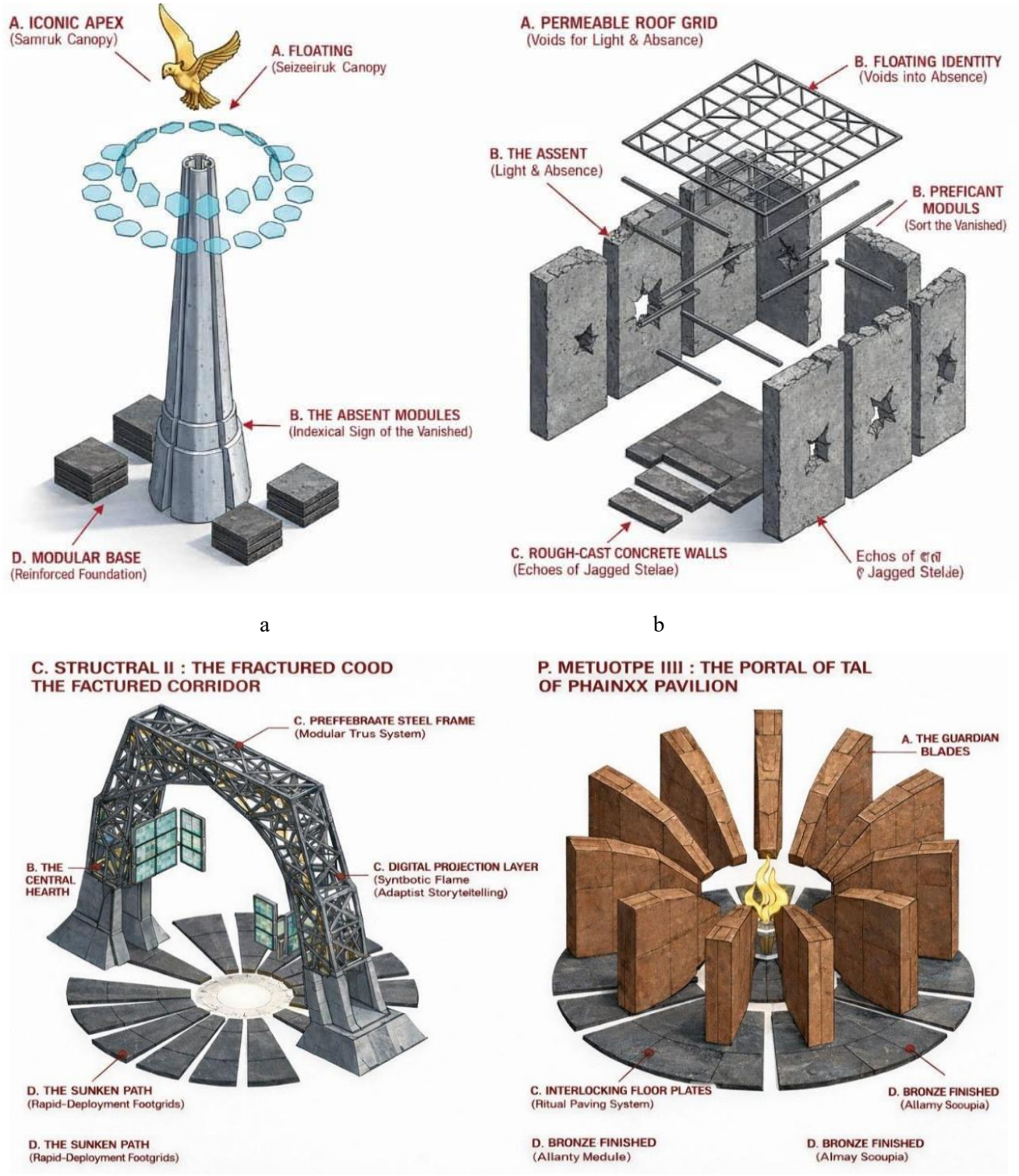


Figure 5. Axonometric view of: Prototype I (a), Prototype II (b), Prototype III (c), Prototype IV(d)

3.3. Comparative analysis

3.3.1. Evaluation of effectiveness

The effectiveness of these modular approaches adopted in this study is evaluated using a semantic differential scale (1-10) and functional modularity criteria (Table 4).

Table 4. Evaluation of the effectiveness of the modular methods

Prototype	Semiotic Precision	Modular Scalability	Aesthetic Integrity	Overall Effectiveness
I: Vertical Nexus	9	10	8	High (Ideal for landmarks)
II: Fractured Corridor	10	7	9	High (Strong emotional impact)
III: Portal	7	8	10	Medium (High technical cost)
IV: Phalanx	8	9	7	Medium (High spatial utility)

3.3.2. Comparative results matrix

The visual representation of the comparative result matrix on a scale of 1-10 is presented as a radar chart in Figure 6.

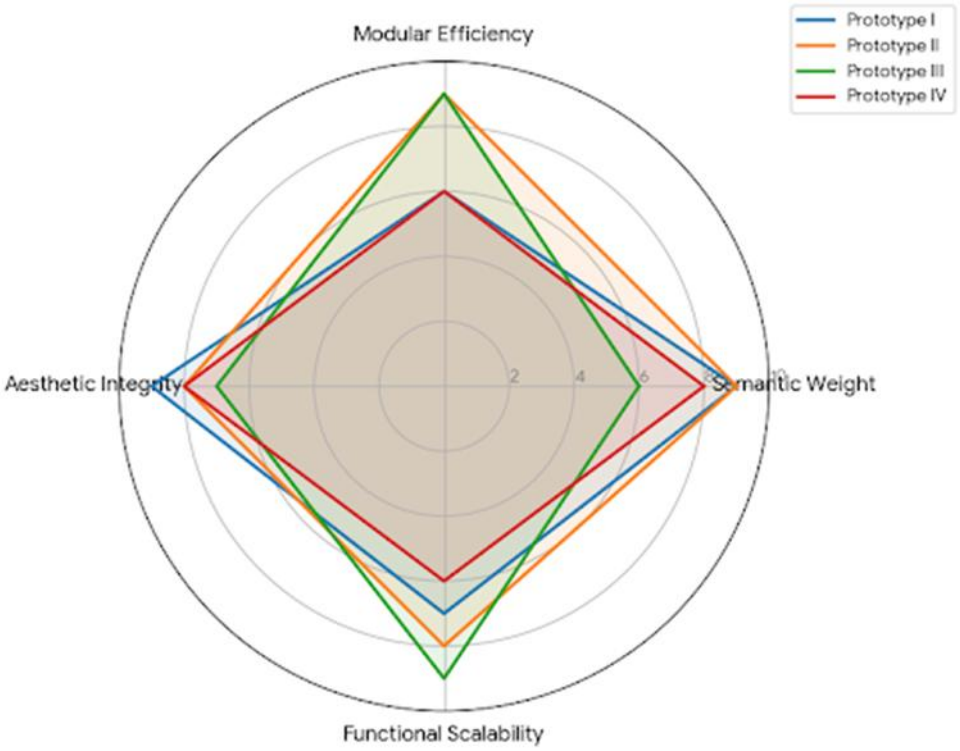


Figure 6. Radar chart of modular prototypes

3.4. Analysis of results

3.4.1. Comparative interpretation of effectiveness

In this section, we compare the different prototypes to see how each prototype conveys “their story” most effectively. Prototype II (Repression) is considered the most meaningful or "truthful," as the way it was designed perfectly matched the history it represented by using the logic of subtraction, such as void or missing

parts, to represent the historical theme of loss, while Prototype I (Independence) is regarded as the most practical by using smart stacking to attain monumental height efficiently. Hence, the research demonstrates that there is a pattern by which monuments communicate. For example, to show a “cause and effect” feeling (Indexical) like the gaps in Prototype II, the best way is through how you arrange the blocks. On the other hand, if an abstract cultural idea (a symbolic sign, like in Prototype III), a detailed, textured outer layer is required to achieve it.

3.4.2. Comparative results matrix

Overall, the most successful design is Prototype II (The Fractured Corridor) as it did not sacrifice one goal for the other. Prototype II is a “trauma landscape” where the floor and walls feel broken. Thus, it feels very meaningful with a semantic weight of 9/10, but because it is built on a simple grid, it is also very easy for its parts to be produced, thereby having a modular efficiency of 9/10. On the other hand, prototype III (The Portal of Continuity) uses a pre-made steel core, indicating that it can be carried almost anywhere swiftly (functional scalability). However, because prototype III is so “industrial” and abstract, some of the specific cultural meaning gets lost, making it feel more like a geometric piece than a historical architecture.

Meanwhile, prototype I (The Vertical Nexus), which is the most impressive to look at but the hardest to build, captures the “axis Mundi” (the centre of the world) and the “Samruk” (a legendary bird from Kazakh mythology) through its shape. Prototype IV (The Phanlanx Pavilion) design looks like an “interlocking” shield, giving it a very strong and protective feel. However, it is built in a circle (thus having a score of 8/10 for its look), making it much harder to expand compared to traditional structures such as rectangles.

4. Conclusions

This study suggests a new way to build memorials (structures meant to honor history or tragic events). We propose using modular architecture, which is not just technically efficient but can actually help tell a story better than traditional architecture. This study has demonstrated that modularity should not be viewed as a rigid building tool but rather should be seen as words in a sentence. In fact, how modules are stacked, arranged, or how you leave them out creates meaning. For example, to show strength and honor, we stack modules high to create iconic shapes that grab attention. Also, to depict feelings of loss or trauma, we remove modules to create deliberate holes or confusing layouts. The loss is felt as the structure itself is incomplete. Likewise, for the "Fractured Corridor, Instead of putting up a sign that says "This space represents trauma," we built a path that is broken and confusing. Thus, the observer feels trauma through their physical experience of moving through the space.

Taking Dyussenova’s ideas on understanding the “DNA” of nomadic architecture, we expanded them into a practical system for designing architectural pieces. However, we disagree with critics such as Ostapenko et al., who argue that architectural meaning only comes from decoration added to an architectural piece. Instead, our work shows that the true meaning of an architectural piece comes from how it is constructed and put together. Ultimately, this work has expanded on architectural semiotics by taking theories of C. S. Peirce and applying them to computer-driven design.

The practical implication for the fast-growing cities of Astana and Almaty of Kazakhstan is that our proposed method to build pre-fabricated parts quickly with less material waste to create modern monuments by combining computer-aided design (parametric design) with local culture, thereby giving Kazakhstan a unique architectural "voice". However, there are several limitations. For example, a modular architecture that means "honor" to one person might not mean the same thing to someone from a different cultural background. Also, the limited number of monuments appraised in this study limits the validity of the conclusions drawn in this.

Currently, in Kazakhstan, simple houses or offices are mostly built, so creating the specific, emotional textures needed for memorials requires new technology and investment. Moreover, the small sample size of

the different designs studied in this study is too small to conclude whether this method works in every scenario.

Future studies should look at old nomadic burial sites (mazars) to see if those ancient structures can be adapted into modern modular designs. The use of Augmented Reality (AR) should also be incorporated so visitors can look at a modular architecture through their phone and see digital archives of historical photos. In addition, future studies could incorporate quantitative methods and carry out cross-cultural comparisons.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

The contribution to the paper is as follows: Aray Saibulatova, Dana Dyussenova: study conception and design; Dana Dyussenova, Elmira Bagdavletova, Kuat Kuandykov: data collection; Aray Saibulatova, Dana Dyussenova, Sanja Avramoska: analysis and interpretation of results; Kuat Kuandykov, Elmira Bagdavletova: methodology development; Aray Saibulatova: draft preparation; Dana Dyussenova, Sanja Avramoska: revision of the manuscript for important intellectual content. All authors approved the final version of the manuscript.

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