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Semiotic modeling of space in modular and memorial architecture (practical modeling)

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ABSTRACT

Memorial architecture serves as a memory and transmissions system of cultural memorization and collective identity into a space. Nevertheless, in many cases, architectural semiotics has been at an interpretative level with little translation into overt spatial or modular design reasoning. This paper discusses a semiotic modeling theoretical framework of modular memorial building, which is studied based on experimental design research, in the context of the Kazakhstani culture. The approach combines structural and spatial semiotic analysis, where architectural elements are treated as systems of codes of symbols and functions and cultures that are interrelated. To actualize these meanings, semantic zoning, sign-code classification, and form-meaning mapping have been used in the study, which allow translation of the abstract semiotic structures into the spatial parameters in a systematic way. These parameters are investigated based on modular spatial modeling and design-based research (DBR) based on conceptual memorial prototypes based on Kazakhstani memorial traditions. These results reveal how the architectural form can be analytically built up as a semiotic system and can be effectively translated into modular forms that express memory, ritual and national identity. The work presents a theory-informed methodology to apply to the architectural semiotics and modular design practice and develop semiotic studies into generative and culturally responsive design usage.

Keywords: architectural semiotics; structural–semiotic analysis; modular spatial modeling; memorial architecture; cultural memory.

1. Introduction

Memorial architecture is a specific practice in architecture where space serves as a code of transmission and conveying of cultural memory, ritual and communal identity. Memorial spaces are intended to be built in order to embody the immaterial meanings, historical narratives and collective feelings by organizing space, using material symbolism, and creating a hierarchical structure [1]. Architectural features like axes, thresholds, voids and monuments are signs that present visitors with layers of meaning. Memorial architecture can in this respect be interpreted as a semiotics practice, and built form can be considered as a structured system of signification that is contextually constructed and conscious of the historical past [2].

The phenomenological interpretation of this communicative aspect of architecture is given by architectural semiotics. Based on the linguistic and cultural theory, it imagines architecture as a system of signifiers, forms, materials and spatial relationships, and signified meanings, which are associated with memory, identity and ideology [3]. Although semiotic methodologies have played significant roles in trying to give interpretative readings of built environments, a lot of the literature in existence is still descriptive and retrospective. Semiotic analyses usually describe the manner of perceived meaning once it has been constructed, providing minimal directions of how symbolic content can be strategically integrated throughout the very process of designing it [4]. Therefore, the creative potential of the semiotic theory concerning architectural design is not fully developed.

This is especially limited in modular architecture. Modular systems are characterized by efficiency, repetition, and flexibility that is provided by a standardized unit to allow a flexible and scalable construction [5]. But when used in memorial architecture, modularity creates extremely important issues of the symbolic depth, uniqueness and cultural particularity [6]. Memorial spaces require deathly seriousness, greatness, and the tellingness of stories, which are aspects that become hard to combine with equal cellular repetition. The theoretical deficiency of modular techniques in memorial architecture is that there are no organized mechanisms for coding the symbolic and cultural significance into the modular spatial logic [7].

Kazakhstan is an interesting place to fill this gap in methodology. Its landscapes of the memorial architecture underwent stratified cultural histories, such as nomadic spatial customs, Soviet monumentality and post-independence identity construction, out of which a dense semiotic terrain has emerged [8]. Meanwhile, modern architectural activity in Kazakhstan is becoming more and more modularized due to urban, economic and technological pressures. It is against this backdrop that the current paper will delve into a semiotic modeling framework that will bridge the gap between architectural semiotic theory and the modular design practice. The study uses structural-semiotic analysis, semantic zoning, sign-code classification and form-meaning mapping to explore the way that cultural and symbolic meanings are operationalized as spatial parameters in modular memorial architecture.

2. Related Works

Studies of architectural semiotics, memorial architecture, and modular spatial systems have evolved on considerably parallel paths, and very few methodology integrations have occurred between symbolic theory and generative design practice. The initial works of architectural semiotics were mainly aimed at understanding buildings as systems of signs, which give importance to the meaning, representation, and cultural symbolism hidden in the architectural form. Within the framework of architectural memorials, researchers have discussed the role of space, materiality, and spatial sequencing in terms of their contribution to the memory of a collective, ritual behaviors, and national identity. Newer literature has explored the idea of modular and parametric design, where its effectiveness, flexibility, and formal flexibility are noted. Nevertheless, such studies tend to focus on the technical optimization, rather than the symbolic articulation. This has created a significant gap in the literature of systematic approaches to transferring semiotic meanings to systematic spatial logic, especially in culturally specific memorial contexts. In Table 1, the most significant related works, their core research interest, methods of study, highlighting key findings, and their contribution are summarized, and the lack of an operational semiotic modeling framework, which would bridge theory, modular design, and memorial architecture, is also indicated.

Table 1. Summary of Related Works on Architectural Semiotics, Memorial Architecture, and Modular Design

Ref.	Main Focus / Methodology	Key Findings / Contributions
[16]	Ontology of semiotic activity in heritage, memory, and identity practices; semiotic ontology and epistemic modeling	Establishes heritage and memory as semiotically constructed systems shaping collective identity
[17]	Semiotic analysis of memorial museum communication; qualitative spatial and narrative analysis	Demonstrates that memorial spaces operate as integrated sign systems guiding visitor interpretation
[18]	Spiritual architecture and cultural memory; digital heritage modeling and narrative analysis	Shows that virtual narratives enhance symbolic continuity and perception of spiritual architectural heritage
[19]	Multimodal discourse analysis of memorial museum websites; visual grammar approach	Identifies coordinated visual and textual modes as central to constructing memorial meaning
[20]	AR-based visual narrative systems for culturally embedded spaces; system design and interaction modeling	Introduces immersive narrative tools for integrating regional culture and memory into spatial experience

Taken together, research [16] through [20] determines that physical, digital or hybrid memorial environments work as cohesive semiotic systems where meaning is formed as a result of spatial arrangement, narrative sequencing, symbolic representation and cultural reference. The heritage is understood as dynamically built around intermediated sign systems by Kirtiklis et al. [16], and it is important to note that collective identity is

formed based on systematic semiotic correlations instead of singular signifiers. For instance, Guardado [17] transfers this understanding to the occasion of "Physical memorial museums", where he displays that guest understanding and sensitive participation are built by the usage of spatial sequencing and architectural enunciation. This standpoint is further supported by De Marco [18], Guo et al. [19], and Du and Yu [20], who reveal that the transmission of memorial meaning requires the presence of narrative coherence, multimodal coordination, and cultural encoding.

The combination of these works validates three common assumptions:

(1) memorial meaning is a spatial construction and not just its representation;
(2) semiotic coherence relies on the interaction between several elements as opposed to one-to-one iconic forms; and
(3) The cultural memory is a system of organized signs that directs the perception and ritual activity.

Simultaneously, the shared methodological limitation is manifested in the literature in general. Although these works provide profound interpretative information on the communication or conception of meaning by semiotic structures, they do not go as far as defining the possible translation of semiotic structures into generative spatial logic, especially in physical, modular architectural systems. Semiotic analysis is used retrospectively to explain an existing space, digital environment, or narrative interface, in most instances, as opposed to being a prospective design mechanism.

This gap is additionally reinforced by the focus on digital, virtual, and augmented space in some of the chosen works [16,18–20]. Despite the demonstrations of digital modeling, AR stories, and virtual heritage platforms of how abstract cultural meanings could be organized and visualized, their results are not often generalized to the possibilities and limitations of material, constructible architectural space. Consequently, the semiotic theory implications on modular spatial arrangement, bodily repetitions, and architectural scalability are not well studied. This detachment is especially imperative with respect to the architecture of the memorial, where symbolic fullness has to exist in a relationship with organizational sense, materiality, and spatial expression.

The articles included in Table 1 were chosen due to their incorporation of the major thematic areas concerning this study: semiotic theory of memory and identity [16], spatial communication in memorial architecture [17], narrative and symbolic continuity across the media [18,19], and system-based methods of culturally embedded spatial experience [20]. Instead of giving comprehensive coverage, all these studies involve an overall definition of the conceptual boundaries within which the current research falls. Their choice is explained by their common interest in meaning construction, construction of cultural memory, and space narration, which are the main issues that serve as the backbone of semiotic modeling in architecture. A preceding study on Kazakhstani commemorative centers has established that architectural imageries form multifaceted semantic constructions in which spatial, artistic-plastic, and scenery mechanisms are planned into a united organization of a picture of ancient reminiscence and cultural uniqueness [42].

The missing part of the current literature is that there is no structured and replicable way of introducing symbolic, functional, and cultural values into the reasoning of modular architectural design. Earlier research elucidates what meanings memorial spaces represent and how they are understood, but it does not explain how they can be operationalised as spatial parameters, which are managed and maintained through modular repetition and variation.

Conversely, the current research contributes to the development of the discipline because it shifts architectural semiotics to a different context, where it is no longer an interpretative process but a design tool. It does not evaluate the finished spaces or the computerized form of the space, but suggests a systematic semiotic modeling strategy that will assist in the transfer of cultural meaning into physical modular constructions at the very beginning of the design process. In this way, the study fills a pivotal methodological lapse that has been noted among the previous literature and how memorial architecture can be both symbolically rich, culturally specific and modular at the same time in a consistent spatial framework.

Despite the fact that the existing studies effectively prove that memorial spaces are the type of semiotic systems of meaning, they still tend to be analytical and retrospective in their character. Taken together, the earlier literature describes the perception, telling, or computerization of meanings, but they do not present a repeatable process to produce physical architectural form based on semiotic structures, especially on the modular processes. Moreover, there is still no answer to how the symbolic, functional, and cultural codes are integrated into material, constructable, and repeatable spatial units, as there is currently the dominance of digital and virtual

case studies. This work is not identical to the research conducted in the past in that it repositions architectural semiotics as a generative model of modular memorial design, providing a concretized process through which cultural meaning is transferred into spatial parameters, modular units and configurations based on rules in physical architectural space.

In order to achieve transparency and replicability, the current study is designed as a systematic procedure of a design-based research where semiotic perception is applied in a systematic translation into architecture. The major unit of analysis is the element of architecture and its composition into semantic areas in memorial space. Every architectural element is considered a semiotic element that consists of formal qualities, connotations, and cultural codes, and semantic areas are groupings of higher order that structure narrative development and rite experience.

3. Projected methodology: The semiotic modelling outline for segmental memorial architecture

The investigation aims to use a semiotic model of the social understanding, codes of representation and commemorative divisions to architectural modularity through a ranked, design-inspired process. Architectural space is conceived as an organization of symbols whereby the connotation of arrangement, geometry, physicalness and dimensional association discusses the reminiscence, the sacramental, and the communal distinctiveness. The method will involve a structural-semiotic examination to identify the occurrence of representative, practical and cultural cyphers within the background of their honoring and position into semantic extents and form-meaning connections. Such intellectual meanings are then decoded in a prepared way into dimensional limits that are measurable, like gage, amount, alignment and segmental recurrence. The subsequent constraints are utilised to produce segmental dimensional shapes, which are tested and enhanced with the assistance of investigational strategy samples inscribed in the background of the Kazakhstani values. The outline secures a see-through answerability among semiotic explanation, dimensional decision-making, and segmental architectural crops, as exposed in Figure 1.

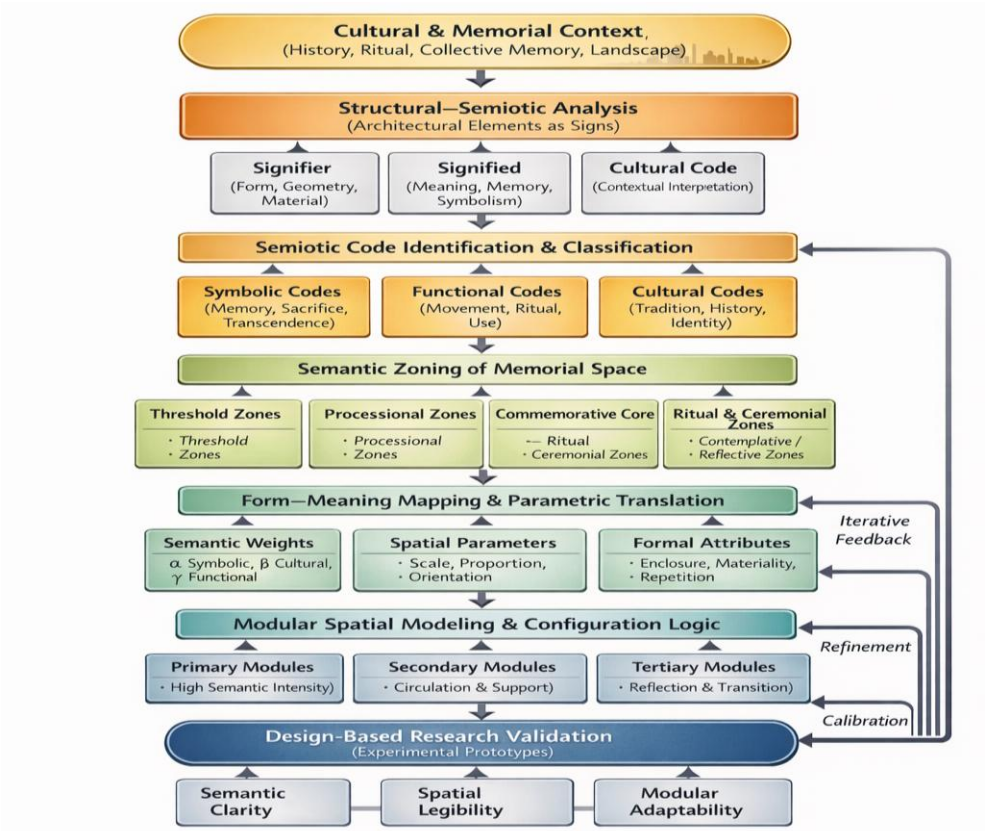

Figure 1. Conceptual Architecture of the Semiotic Modeling Framework for Modular Memorial Design

3.1. Research design, unit of analysis, and replication protocol

To guarantee the proofness this paper a structured design-based study procedure was accomplished. The protocol permitted the semiotic interpretation that is thoroughly interpreted in the architectural procedure. The main constituent of the examination is the architectural component and its accumulation into semantic sectors

within dedicatory space. Respectively, every architectural component is preserved as a semiotic component composed of prescribed characteristics, related connotations, and social codes, while semantic sectors signify higher-order consortia that establish description evolution and ceremonial involvement.

The research process is done in five consecutive and repeatable steps:

(1) induction and categorization of symbolic, functional, and cultural codes;
(2) semiotic analysis of architectural components, structural;
(3) semantic zoning/weighting of codes;
(4) form meaning mapping and parametric translation; and
(5) modular spatial configuration and validation by design-based research.

Each step produces explicit analysis products, e.g., matrices of code, zoning hierarchies and parametric rules, which are the direct inputs to the next stage. This sequential form enables the framework to be recreated into other cultural settings by changing the input of the codes but maintaining the logic used in the analysis.

3.2. Structural–semiotic analysis of architectural elements

The first phase of the suggested methodology is structural-semiotic analysis, in which architectural objects are analyzed as a part of the organized system of signs and not as physical or functional objects. Based on the classical and architectural semiotic theory, architecture is treated as a language-like system, in which forms, materials, space hierarchies and compositional rules serve as signifiers that translate culturally encoded meanings. In the context of the memorial architecture, the meanings are closely associated with collective memory, ritualization, histories, and the sense of national identity. At this level, architectural constituents, including axes, limbs, entrances, vertical indicators, empty spaces, surface textures, and material articulations, are broken down into small semiotic units [21]. Every single unit is examined by a three-dimensional semiotic framework comprising the signifier (the material-spatial expression), the signified (the conceptual or symbolic value) and the cultural code that puts interpretation within a particular socio-cultural framework. This relation may be represented in the concept form as follows:

$$A_i = \{f_i, m_i, c_i\} \quad (1)$$

where A_i is an architectural element, f_i is its formal attributes, m_i is the meaning associated with it, and c_i corresponds to the cultural code which regulates interpretation. The design allows architectural rudiments to be recorded in a methodical manner grounded on their representative, practical and social determinations in the memorial location. As a case, perpendicular elements could be related to ideas of otherworldliness or honor, while bounded or subversive spaces were often related to self-examination, grief or spiritual road. The relational composition of signs into architectural space is stressed in the structural aspect of the analysis [22]. Instead of analyzing the elements separately, the methodology looks at the syntagmatic relationships of elements (sequence, hierarchy, symmetry, repetition) to produce the narrative logic of memorial spaces. Such relationships establish the ways in which the meanings are developed in space as visitors traverse the architecture. It is possible to visualize the spatial narrative of a memorial as a sequence:

$$N = \{A_1 \rightarrow A_2 \rightarrow \cdots \rightarrow A_n\} \quad (2)$$

N It is the memorial narrative and A_n is one of the successive architectural elements one encounters in space. Simultaneously, the paradigmatic relations are studied to compare alternative versions or space structures that can convey similar meanings in various cultural or historical situations. This offers the flexibility of interpretation of design and, at the same time, maintains semantic consistency [23]. We can say that paradigmatic variation is the expression of a set of equivalent signifiers that have a common signified:

$$P(m) = \{f_1, f_2, \dots, f_k\} \quad (3)$$

And there are several formal expressions f_k that all have a common meaning m. This twofold account of the syntagmatic and paradigmatic structures will guarantee that the compositional order and semantic variability are examined. The result of the structural-semiotic analysis will be a structured grid of the architectural signs, where each sign will be located within a specific group of meanings and cultural allusions. This matrix is an

officialized analytical dataset that directs the formal later methodological processes, especially semantic zoning and form-meaning mapping [24]. This interpretation of qualitative cultural dissertation into a methodical semiotic context will make a strict stage amid the theoretical understanding and the actual world of dimensional exhibiting, so that the representative material can be reliably and logically transported into the segmental plan of architecture.

3.3. Documentation and arrangement of symbolic, practical, and cultural codes

Afterward the structural-semiotic deconstructionism of the architectural structures, the next stage of the proposed method is dedicated to the methodical detection and classification of the symbolic, practical and cultural codes that are combined into the commemorative architecture. This is essential to adapt immaterial semiotic senses into a scheme that is prearranged and movable and can then be operationalized by means of segmental dimensional modelling. The procedure does not interpret symbolism as an individual or instinctive coating but expresses sense using obvious and organized classes of codes. Symbolic codes convey abstract ideas, which include: memory, sacrifice, continuity, transcendence and collective loss. Geometric configurations, spatial hierarchies, monumentality, orientation, and symbolism in materials are characteristic and typical codes with which these codes are usually articulated [25]. As an illustration, axial alignment can be used to represent historical continuity, whereas vertical dominance can represent spiritual raising or commemoration. The Kazakhstani setting also relies on the symbolic codes based on the nomadic cosmology and ancestral worship and metaphors with the help of the landscape, which is attributed to the steppe culture. The symbolic coding of an architectural object may be expressed as:

$$S_i = \{m_{i1}, m_{i2}, \dots, m_{in}\} \quad (4)$$

S_i denotes the symbolic code set related to each architectural element i, and m_{in} represents individual symbolic meanings of the element. Functional codes explain how the architectural space defines movement and use of architectural space and ritual behavior in the memorial space [26]. They are circulation routes, assembly areas, meditative areas, ritual centers and transition points. Functional codes are associated with a strong bodily relation to space and are conveyed in the parameters of scale, accessibility, visibility, and spatial sequencing. Functional codes are also common in memorial architecture, where the visitors are led through a choreographed tour of the site through the use of symbolic narratives. Formalized version of functional coding is:

$$U_i = \{a_i, v_i, q_i\} \quad (5)$$

Where U_i represents the functional code of the element i, a_i accessibility, v_i visibility, and q_i use intensity or spatial capacity. The cultural codes are not only symbolic but also functional, and they make the tradition that is specific to a certain place, historical or collective identities embedded into architecture [27]. These codes are elicited by the ethnographic research, the historical narratives, the national memory practices, and the culturally important artifacts. Cultural codes can consist of allusions to traditional decoration, openness of space as a characteristic of nomadic settlements, geometrical forms of sacred geometric forms, and culturally significant materials in Kazakhstan. The cultural coding will be in the form of:

$$C_i = \{t_i, h_i, r_i\} \quad (6)$$

and C_i represents the cultural codes, t_i refers to the traditional references, h_i to historical associations and r_i ritual significance. To balance the connections between symbolic, functional and cultural codes, the methodology uses a classification matrix where all architectural elements are mapped over the three categories of codes [28]. This combined coding of an element of architecture may be expressed as:

$$K_i = S_i \cup U_i \cup C_i \quad (7)$$

K_i defines the entire semiotic code set of elements i. This formulation recognizes the fact that a single spatial element can be symbolic, functional, and cultural, with one element or the other overtaking the other.

Table 2. Semiotic Code Matrix for Memorial Architecture

Architectural Element	Symbolic Codes (S)	Functional Codes (U)	Cultural Codes (C)
Threshold / Entrance	Transition, separation from everyday life, initiation of memory	Access control, orientation, entry sequencing	Ritual passage, cultural notions of arrival and respect
Axis / Processional Path	Continuity, historical progression, narrative movement	Guided circulation, ceremonial procession	Nomadic routes, ancestral journeys, collective movement
Vertical Marker (Monument / Stele)	Transcendence, commemoration, spiritual elevation	Visual focus, spatial orientation	Ancestral reverence, sky–earth symbolism
Enclosed / Subterranean Space	Introspection, mourning, silence	Contemplative pause, acoustic isolation	Ritual withdrawal, remembrance practices
Open Gathering Space	Collective memory, unity, shared identity	Assembly, ceremonies, public rituals	Communal traditions, openness of steppe culture
Material Articulation	Permanence, endurance, authenticity	Tactile engagement, environmental response	Local materials, traditional craftsmanship
Landscape Integration	Continuity with nature, timelessness	Visual connection, environmental comfort	Sacred landscape, horizon symbolism

Based on the resulting classification matrix, the prioritization and weighting of codes can be made, which will give certain clarity to future design decisions [29]. It creates a systematic semantic data warehouse that will directly supply subsequent steps of semantic zoning, form-meaning mapping, and modular setup. This step systematizes the recognition and identification of architectural codes and establishes a restrained interpretive system which reduces arbitrariness in the design choices and makes the transfer between the semiotic theory and architectural modelling the same, culturally based and responsive to the modular design logic [30].

Table 2 is an analytical code matrix of semiotic codes and is not illustrative. The enumerated architectural features and other related symbolic, functional, and cultural codes synthesize out of the above process of structural-semiotic analysis and code elicitation. Although the table is not a complete list of all the potential memorial layouts, it codifies the primary associations of codes that are present in the context of the Kazakhstani memorial and represents a portable analytical model to be used in further spatial modeling.

3.4. Data sources, code derivation, and validation

Symbolic, functional, and cultural codes are derived on the basis of several qualitative data. Theoretical literature on architectural semiotics, memorial studies and spatial symbolism is analyzed to extract symbolic codes. Functional codes are based on experimental divisions of space in memorial layouts, circulation patterns, and ritual practices that are documented. The cultural codes can be responded to using the contextual study of the Kazakhstani memorial traditions, their historical records, the principles of space and place of nomadic inhabitants, and the rituals that are culturally significant and found in the ethnographic literature and architecture archives.

Triangulation is a method of validating codes between sources. A code is only retained when it is observed in at least two sets of data, including both theoretical literature and built precedents or historical accounts and ritual. This is done to make sure that the code system that is formed is based on documented cultural and architectural evidence rather than just arbitrary.

3.5. Semantic zoning of memorial space

Semantic zoning is a phase whereby symbolic, functional and cultural codes of classification are spatially arranged into logical memorial areas. Semantic zoning organizes space based on meaning, narrative progression, and experience in contrast to traditional functional zoning that organizes space based on efficiency of use and circulation [31]. In the architecture of memorials, zoning is hence spatial, as well as interpretative, which leads visitors through a programmed series of encoded experiences, associated with memory, ritual and collective identity.

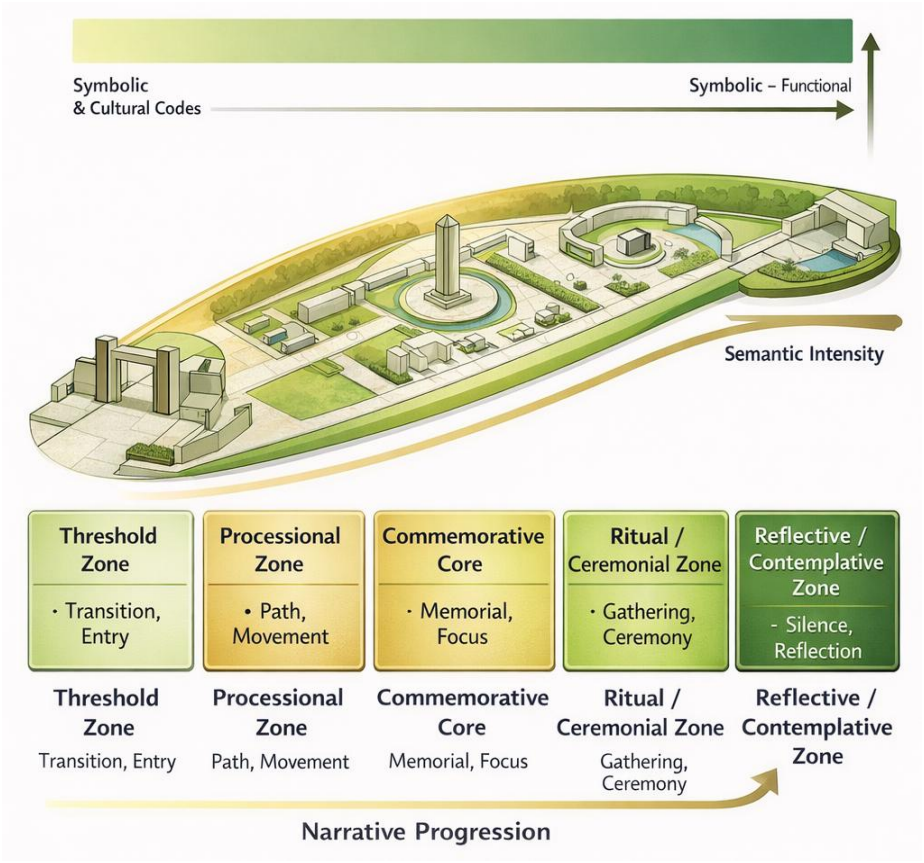

Figure 2. Semantic zoning and narrative progression of memorial space based on symbolic, functional, and cultural code hierarchies.

According to the classification system constructed at the last stage, memorial space is subdivided into specific semantic areas that include threshold zones, processional zones, commemorative cores, ritual or ceremonial areas, and contemplative or reflective spaces [32]. The semantic profile prevalent in each zone is the resultant presence and hierarchy of symbolic, functional, and cultural code. The semantics profile of a zone zcan can be written as:

$$Z_z = \alpha S_z + \beta U_z + \gamma C_z \qquad (8)$$

In which S_z, U_z, and C_z are the integrations of the symbolic, functional and cultural code intensities in zone z, and α, β, and γ are weighting coefficients based on their relative importance. In the case of commemorative core zones, one may think of high symbolic weight (alpha), and in the case of threshold zones, one may think of functional and cultural mediation [33]. The zoning is a hierarchical and progressive logic. Core memorial significances (sacrifice, remembrance, or national identity) are conveyed by primary zones, which are spatially highlighted by use of scale, form, or axial location. The secondary zones serve these meanings by allowing the movement, pause, or group congregation, whereas tertiary zones allow one to reflect individually or to engage informally. This pyramid can be described as follows:

$$Z_1 > Z_2 > Z_3 \qquad (9)$$

where Z_1, Z_2, and Z_3 represent the primary, secondary and tertiary zones respectively, in decreasing semantic intensity. Such stratification of organization makes the memorial space a semiotic narrative to be read and not a set of separate architectural objects [34]. Zonal spacing is a vital element in the process of memorial experience. The flow of visitors in areas creates a semantic flow, which strengthens storytelling continuation. This is the sequence of steps which can be described as follows:

$$P = \{Z_t \rightarrow Z_p \rightarrow Z_c \rightarrow Z_r \rightarrow Z_{ref}\} \qquad (10)$$

where $Z_t$denotes threshold zones, $Z_p$processional zones, $Z_c$commemorative cores, $Z_r$ritual areas, and and Z_{ref}reflective spaces. This development will provide a progressive shift between the daily space and the heightened memorial signification and then the contemplative discharge. The culturally specific spatial traditions are applied in semantic zoning in the Kazakhstani context, such as the openness to the landscape, symbolic orientation, and collective gathering practices based on the nomadic heritage [35]. The exposed provisional ground, view shapes to the horizon, spherical or circular space association, and in cultural terms prearranged wisdom of steadiness, heritage, and communal reminiscence are armored. These ethnically receptive alterations may be understood as the related transformers of the rudimentary zoning model:

$$Z_z^{KZ} = Z_z + \delta L_z \qquad (11)$$

where Z_z^{KZ} being the culturally adapted zone and L z the factors of landscape and cultural orientation. The result of semantic zoning is a spatial schema that maps meaning to zones, connecting semiotic concepts and modular architectural form while maintaining flexibility and encoded meaning.

3.6. Form–connotation charting and parametric change

Form-connotation charting is the focus of the planned semiotic demonstration outline, in which intangible semantic reproductions are operationally transformed into architectural arrangement limits. Increasing on the semantic zoning drew in the overhead subset, the stage regulates obvious and noticeable associations amid prearranged senses and spatial-formal characteristics, making it conceivable to control the change of explanation to architectural plan. Each semantic zone is related to one kind of the main arrangements of symbolic, practical, and cultural codes. These codes are modified to meet architectural limits such as gage, amount, alignment, degree of inclusion, substantial strength, and recurrence within a unit [36]. The procedure is utilised to execute a parametric reason on the sense of the subject, rather than the instinctive tactic of transmitting the sense to the architectural procedure, the architectural procedure is viewed as a quantifiable and adaptable picture of semantic content. This technique upholds consistency across the numerous projects, but does not lose sight of the explanatory complexity and cultural peculiarity.

The sense is formalized as a biased semantic trajectory to characterize the sense, and the architectural procedure is dignified as a set of spatial limits. The general charting association may be the next:

$$F = f(S, C, U) \qquad (12)$$

here F means the subsequent architectural arrangement, S signifies symbolic codes, C denotes cultural codes, and U means practical usage and ceremonial performance. In this design, the purpose $f(\cdot)$ describes how differences in semantic contribution effect official production. For instance, zones with raised symbolic concentration may match to augmented vertical enunciation, inclusion, or monumentality, while traditionally communal or socially adapted zones may outcome in prolonged horizontal plans, directness, and segmental penetrability. To achieve imbrication and symbiotic senses, each code class is given in a comparative heaviness inside a specified semantic zone.

The expressions that are in this study are analytical constructs as opposed to numerical calculations. They make formal relationships of meaning and form to endorse systematic design reasoning. Equation (12) implies the definition of the mapping function, f (), as a rule-based and matrix-supported relationship, where the symbolic, cultural and functional code intensities are converted into spatial parameters under the predetermined design rules. The mapping is many-to-many, so that there may be various expressions of form corresponding to a certain meaning (and the reverse) without infringing interpretive flexibility and with semantic coherence.

The semantic intensity of a zone $z$can be expressed as:

$$M_z = \alpha S_z + \beta C_z + \gamma U_z \qquad (13)$$

where $M_z$represents the overall semantic intensity of the zone z, and α, β, and $\gamma$are weighting coefficients reflecting the dominance of symbolic, cultural, and functional meanings, respectively. The coefficients are estimated in the context of research on the context and the design process in the Kazakhstani traditions of memorials. The values of semantic intensity are converted into parametric laws, where M z is associated with

spatial enclosure or openness. This avoids this loss of symbolic or narrative clarity by differentiating meaning in the modular units. The ensuing modular design of form and meaning assists in maintaining cultural memory, ritual meaning and identity.

3.7. Modular Spatial Modeling and Configuration Logic

Modular spatial modeling. This is the practical implementation phase of the suggested semiotic framework in which the form-meaning relationships defined in the above section are transformed into programmable architectural components [37]. The concept of modularity, in this methodology, is not addressed as a strategy of construction or optimization but as a semantic vehicle that can maintain and express encoded cultural meanings in different spatial formations. A modular typology, which is identified with the parameters of dimensions, structural logic, spatial openness, and symbolic intensity is assigned to each semantic zone revealed during the zoning stage. The modules are the repeatable spatial units which can be aggregated, rotated, mirrored or scaled and preserve the semiotic meaning. A formal description of a module m_i can be given as:

$$m_i = \{d_i, s_i, o_i, p_i\} \quad (14)$$

where $d_i$represents dimensional attributes, s_i structural logic, $o_i$degree of openness or enclosure, and $p_i$parametric values derived from the form–meaning mapping stage. The modular units are enabled to incorporate semantic information in their spatial and formal features. The architecture is hierarchical and in a modular structure where the core commemorative meanings are the major modules and the support modules are the secondary and tertiary ones that aid in circulation, ritual movement and thoughtful utilization. This chain of command may be explained as:

$$M = \{m_1^{(P)}, m_2^{(S)}, m_3^{(T)}\} \quad (15)$$

$m^{(P)}$ $m^{(S)}$, and $m^{(T)}$ represent primary, secondary and tertiary modules respectively, ranked in descending order of semantic strength. Chief components are frequently emphasized by means of bigger size, perpendicular enunciation, or substantial separation while secondary units give importance to connectivity, penetrability, and steadiness. This central scheme securities that recurrence of the units gives asset to the narrative and evades the official boredom. As an income of spatial arrangement, the procedure denotes to rule-driven values of shapes founded on semantic partitioning. These approaches statute the contiguity, progression and sequencing of components to protect the semantic accuracy. A countenance of a segmental arrangement C be assumed as:

$$C = \{m_i \mid R(m_i, m_j) = 1\} \quad (16)$$

here $R(m_i, m_j)$ signifies a rule-based association amid end-to-end units $m_i$and m_j.As a sample, edge components can be located to intermediate amid consistent urban space and the inner of the commemorative where thoughtful units are spatially detached in high-movement parts to uphold thoughtful makings. Alignment directions likewise rule arrangement on symbolic parts, landscape or tips that are traditionally significant. Measured distinction is similarly provided by the segmental organization. Essential limits, which are connected to the semantic sense, are not adaptable, but subordinate limits, like grade of inclusion, substantial penetrability or surface enunciation, can be diverse to retort to the site-specific, climatical, or programmatic strains. The equilibrium may be expressed in the next way:

$$m_i^* = m_i + \Delta p_i \quad (17)$$

here m_i^* signifies a context-adapted unit and Δp_i is a variation in parameters that is not forbidden on the basis of semantic integrity. This style is flexible with non-symbolic watering down. The result of the modular spatial modeling is the set of configurable prototypes of memoirs, which show how semiotic principles can be localized in the modular design logic [38]. These prototypes are experimental artifacts with the help of which the validity of the proposed methodology can be tested. This step by incorporating the meaning, modularity, and spatial logic establishes the viability of the semiotic modeling as a viable and repeatable design instrument in the model of memorial architecture based on cultural memory and group identity.

Modular configuration rules are obtained based on the semantic zoning hierarchy and the syntagmatic relations found in the course of structural-semiotic analysis. Adjacency, orientation, and sequencing rules have been made to guarantee the incorporation of spatial relationships to support narrative progression and ritual logic. These rules are justified by trial and error in the design process in the framework of the design-based research, where refuters that undermine a semantic clarity or narrative coherence are corrected in the design process with systematic advanced correction.

3.8. Design-based study authentication over investigational samples

The key authentication policy used is Design-based study (DBS), which will be applied to regulate the efficiency and pertinence of the planned semiotic modelling outline in segmental commemorative architecture. DBS is similarly suitable for this paper as it can be utilised to methodically exam the theoretic concepts by methodically leading design tests, where the organization and its architectural crops can be enhanced concurrently. Authentication is completed by making, examining, and associating the investigational segmental commemorative examples which are founded upon the semantic partitioning, form-meaning charting and segmental conformation guidelines. The prototypes will signify different memorial situations, which are different in terms of spatial dimensions, symbolic focus, and modular structure, but which follow the same semiotic logic. The cultural context of the Kazakhstani environment is the construing context of the prototype development, which provides that the symbolic, functional, and cultural codes are consistently embedded and evaluated throughout the generations of the design [39].

Testing is done by a systematic comparative analysis of the prototypes in several design cycles. The evaluation of every iteration is made on a series of qualitative and semi-formal metrics such as the semantic clarity, spatial legibility, modular adaptability, and compatibility between the intended meaning and the expression in architectural terms. This could be evaluated mathematically as:

$$V_i = g(M_i, F_i, A_i) \qquad (18)$$

where $V_i$denotes the validation outcome of prototype i, $M_i$represents semantic coherence and meaning preservation, $F_i$refers to formal and spatial consistency, and $A_i$indicates adaptability of modular configurations. This countenance underscores that authentication is not measured on the base of arrangement, but the harmonious grouping of connotation, dimensional perceptive, as well as segmental flexibility. DBS is reiterative, which income that the involvement gained throughout the preliminary sample is transported to the next enhancement of the outline. Where discrepancies between intended meaning and spatial expression are detected, zoning hierarchies, parameter weights or configuration rules are changed. Such a feedback process makes the framework evolve due to design practice and become more robust and transferable to other memorial settings [40].

The results of the DBR validation prove that the principles of semiotics can be reduced to systematic operationalization in the modular design of architectures and the cultural and symbolic richness is not lost. The prototype experiments prove that architectural space is able to perform as a semiotic readable system and still not lose flexibility, scale, and constructability [41]. This study provides a methodological linkage between the semiotic theory and practical memorial architecture by verifying the framework by design-based experimentation and strengthening its importance to culturally based and modular design practices. Although the framework is illustrated in the context of a Kazakhstani memorial, the methodology is designed in a manner that it could be applied to other cultural contexts by adjusting the parameters of the symbolic and cultural codes.

The qualitative and semi-formal measures of evaluation applied in the validation procedure are based on the theoretical aims of the framework directly. Semantic clarity is determined by correspondence between planned codes and spatial expression, spatial legibility by the convenience of narrative understanding by use of movement, and modular adaptability by the ability to vary without losing significance. These measures are not measured as quantitative values but as the comparison between design versions that enables the assessment of the improvement in a systematic way and does not contradict the qualitative character of semiotic analysis.

4. Results and Discussion

This part introduces and explains the findings of the implementation of the suggested semiotic modeling structure to modular memorial building design. The framework was enforced by creating a group of

experimental architectural models based on the cultural and memorial background of Kazakhstan. These prototypes were produced through a systematic translation of symbolic, functional and cultural codes into semantic spaces, form-meaning curves as well as modular spaces as mentioned in Section 3. The analysis of the results is conducted in terms of semantic clarity, spatial legibility, modular adaptability and consistency of the intended meanings and the expression in architecture, thus proving the practical viability of the suggested methodology.

The values of semantic intensity involved in this research are calculated by qualitative evaluation to be performed by experts instead of being directly measured in numerical terms. The authors assign initial intensity scores in each of the semantic zones, with the structured assessment of the symbolic, functional and cultural code dominance, relying on the analysis of the architectural precedence and cultural perspective. In the case where more than one dimension is being measured by the code, the resultant value of the intensity is a synthesis of the different measurements who have been put under an average and normalization of the synthesized results. The numbers thus, are used as comparative measures of relative semantic power in zones, instead of actual relative quantitative measures.

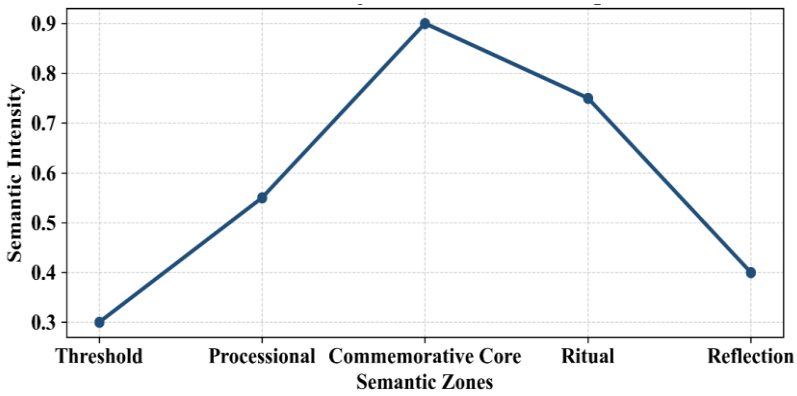

Figure 3. Narrative Progression of Memorial Space

Figure 4. Semantic Zoning and Narrative Progression of Memorial Space

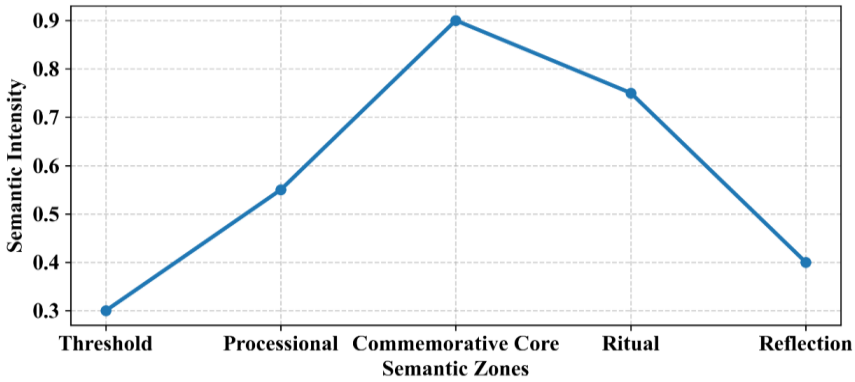

Figure 5. Semantic Intensity Gradient Across Memorial Zones

Although Figure 3 defines the general development of semantic intensity in the memorial zones, Figure 4 and 5 are complimentary in terms of analytical orientation instead of being the repetition of the same story. The spatial distribution of semantic intensity in the zones, as illustrated in figure 4, proves the hierarchical arrangement determined in the zoning model. This analysis is further refined in Figure 5 that shows the semantic modulation gradient as under control, showing that the intentional rise and release of meaning is a continuous curve not a series of steps. Combining these numbers, they not only verify the existence of semantic hierarchy, but also show the ease and deliberate control of narrative transition within the modular memorial system.

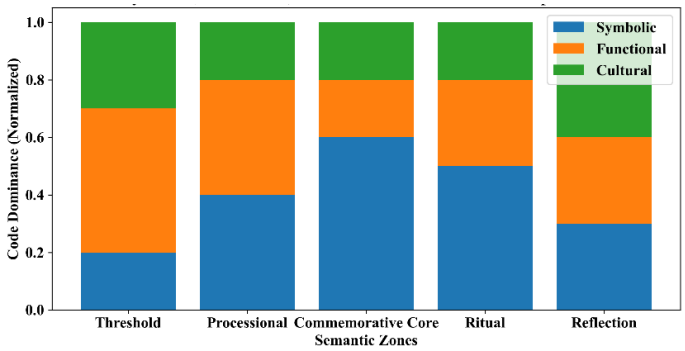

Figure 6. Symbolic, functional, and cultural code dominance per zone4

Figure 6 depicts the normal distribution of dominance of symbolic, functional and cultural codes, in the semantic areas of the memorial. Cyphers of functionality gross over in the verge zone (0.50), which has artistic (0.30) and representative (0.20) groundworks, as it is fundamentally a provisional and positioning sector. The Processional zone is more evenly distributed with the symbolic (0.40) and functional (0.40) codes, as they organize guided movement, and enhanced by the cultural references (0.20). The Commemorative Core has a very high level of symbolic dominance (0.60), with functional (0.20) and cultural (0.20) codes playing secondary roles, which proves that it is the most important locus of memorial meaning. Symbolic (0.50) and functional (0.30) codes are still evident in the Ritual zone allowing ritual action without losing semantic focus. There is dominance redistribution in the Reflection zone where the cultural (0.40), functional (0.30) codes are more dominant than symbolic intensity (0.30) and favour individualized contemplation and cultural continuity. In general, the diagram shows a planned redistribution of the code dominance among zoning, which confirms the ability of the framework to regulate the semantic prominence in modular memorial architecture.

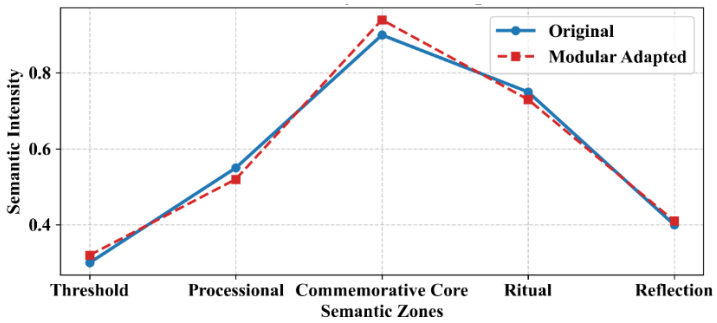

Figure 7. Modular consistency and meaning preservation

Figure 7 is a comparative analysis of the semantic intensity of the initial semiotic model and the modularly adjusted memorial setting in all the zones. There are trivial bends at the verge (0.30 -0.32) and ceremonial (0.55 -0.52) zone counting some adaptive variations that the segmental gathering requests shorn of altering the description intent. Semantic concentration is slightly reinforced at the memorial core (0.90 -0.93), which shows that segmental enunciation may be actual in growing symbolic attentiveness when parametric panels are intricated. The ceremonial sector has a minor reduction (0.75 → 0.72), which can be qualified to the spatial plasticity of the zone to be utilised in rites. Reproduction sector has not been disturbed (0.40 -0.41), so the thoughtful sense is not misplaced. Altogether, the close-fitting fit of arcs designates that semantic veracity is conserved through the commemorative arrangement as there is segmental dimensional alteration, which authorizes the aptitude of the planned outline to care sense without damaging its semantic plasticity.

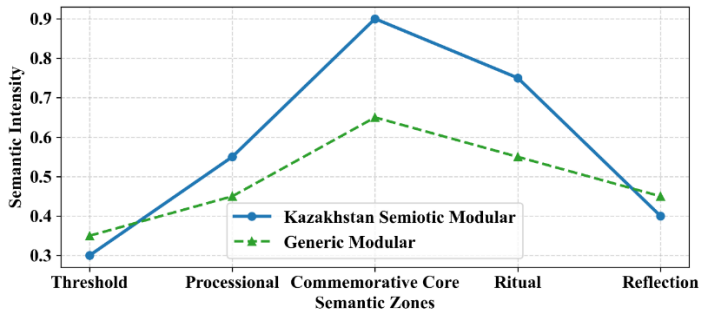

Figure 8. The comparative study: cultural variation/basic segmentation

The investigational outcomes at figure 8 are utilised to liken the semantic strength circulations amid the traditionally modified Kazakhstan semiotic segmental model and common segmental conformation in 5 commemorative sectors. The traditionally adapted model displays a much superior semantic concentration in the ceremonial (0.55 vs. 0.45), memorial core (0.90 vs. 0.65), and the ceremonial sector (0.75 vs. 0.55) which display stouter communication amid dimensional arrangement and culturally forced connotation. Even though the two representations are comparable in their concentration at the verge and replication stages, the general segmental organization offers compressed semantic shape particularly at the central suggesting a low meditation of symbols and narrative wealth. This difference demonstrates that cultural variation in segmental strategy can importantly upsurge semantic enunciation and narrative consistency, which shows the effectiveness of the recommended semiotic outline in recollecting traditionally explicit connotation even over the basic segmental duplication.

On the complete, the results designate that the recommended semiotic model of construction of commemorative space positively systematizes it founded on the measured semantic stream, the identical ascendency of the codes, and their segmental plasticity. Figures 3-5 all validate the circumstance that the semantic strength is intentionally accustomed crossways sectors, growing crossways the verge through the ceremonial arrangement to the memorial core and then gradually declining to reflection, conducive to a rational narrative arc. Figure 6 also shows that there is no even distribution but rebalancing of symbolic, functional and cultural codes strategically across zones to serve particular roles of experience, symbolic dominance is central with cultural-functional dominance serving ritual and reflection. Figure 7 confirms the fact that modular transformation does not change this semantic structure because there are only slight intensity differences between original and modular settings, which means that meaning does not change quickly due to modular influence. Lastly, Figure 8 signifies the necessity of cultural adaptation, which indicates that culturally based modular design maintains an elevated semantic intensity and narrative richness than generic modular regimes especially in the Commemorative Core and Ritual zones. Combined, these results support the conclusion that the framework effectively applies the semiotic theory to modular architectural logic, making a culturally relevant and coherent design of memorials possible and permitting the design to be easily scaled in space and adjust to its demands.

5. Conclusion and Future Scope

5.1. Conclusion

This paper has introduced a semiotic modeling of modular memorial architecture that introduces systematically symbolic, functional, and cultural codes into spatial form by semantic zoning, form meaning mapping, and rules of modular configuration. The study preconditioned by placing the framework in the context of the Kazakhstani culture and based on the confirmation by means of the design-based prototypes proved how the architectural meaning may be switched in a deliberate form, measured, and maintained in the modular structures. The findings confirmed that the intensity of semantic modulation can be accurately altered in the memorial areas to control the narrative development whereby the Commemorative Core forms the major locus of symbolic focus. Moreover, the breakdown revealed that modular adaptation does not lose the intended meanings; on the contrary, when applied in accordance with the rules of semiotics, modularity may promote the symbolic clarity preservation and keep the space flexible. Comparative analyses indicated that culturally adapted modular constructions are much better than generic modular constructions in terms of semantic articulation and narrative coherence. Altogether, the recommended outline produces a robust procedural connection among semiotic concept and segmental architectural exercise, which can be utilised to duplicate the policy of the strategy of culturally important commemorative seats.

5.2. Future framework

This outline can be supplementary prolonged in future revisions in a sum of behaviors. To start with, the semiotic modelling can be focused to the diverse edifying and geographic backgrounds to establish its transferability and adaptableness outdoor commemorative architecture such as galleries, tradition hubs and public spaces. Next, experiential user-experience study, i.e. guest program trailing, reviews, or immersive VR valuation, might be combined to numerically show apparent sense and expressive reply. Tertiary, systematizing semantic standardization crossways segmental shapes might include supplementary computerization of computational optimization approaches as well as the usage of parametric project gears. Additional expansion of labor could emphasis on dynamic or adaptive commemorative organizations which respond to time-related proceedings, rites or public assignation. Lastly, the framework may be bound to digital twin technologies and

semantic tagging of a BIM to assist in the long-term control, maintenance, and development of culturally relevant modular architecture. Such guidelines would enhance the interdisciplinary applicability of the framework and further increase its practice in modern architectural design. This paper illustrates how the modulation of the architectural meaning can be designed with the help of semiotic-modular framework based on the context of the Kazakhstani culture and experimented with the help of design-based prototyping. Although the results indicate that modular strategies might be in position to help in the symbolic clarity and preservation of spatial flexibility, the study has constraints in terms of contextual focus and internal design-based confirmations. In the future, special attention will be paid to external validation using the expertise and user assessment, and the use of the framework within other cultural and spatial contexts.

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

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