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Component-Scale Relationships and Morphological Types of Traditional Mongolian Yurts in Inner Mongolia

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Abstract

Traditional Mongolian yurts in Inner Mongolia vary in wall height, roof inclination, and top profile, but whether these differences arise from stable component-scale relationships remains unclear. This study analyzes measured data from 41 traditional yurts, examines how component dimensions vary with yurt diameter, and classifies overall morphology using the relative heights of the wall, roof, and top. The results show that yurts do not enlarge isometrically: the toono and uni accommodate most horizontal expansion, khana height remains comparatively constrained, and the number of khana sections cannot independently indicate yurt size. Hierarchical clustering identifies four recurring types: moderate-wall–gentle-roof, high-wall–high-roof, high-neck–convex-top, and low-wall–high-roof. These findings explain how differentiated component scaling produces recurring whole-form configurations and provide a reproducible typological basis for measured documentation, digital reconstruction, conservation, and the selection of representative cases for building-performance research.

Keywords: traditional Mongolian yurt; component scale; morphology; cluster analysis; typology

1. Introduction

Traditional Mongolian yurts, also known as gers, constitute living heritage embodied in a construction system rather than a single fixed architectural image. The Mongol ger integrates a demountable wooden frame, felt covering, ropes, household labour, and transmitted assembly knowledge [1]. Its cultural representation has also changed with urbanisation, tourism, and debates over nomadic identity [2]. The yurts surveyed across Inner Mongolia nevertheless differ visibly in wall height, roof inclination, and top profile. These differences affect measured documentation, digital reconstruction, conservation, and the selection of representative cases for environmental-performance analysis. A single standardised model may therefore preserve the general image of the yurt while obscuring the morphological diversity of the surviving building tradition.

The overall profile of a yurt arises from relationships among its constituent components. The khana (lattice walls) establishes the wall and body diameter, the uni (roof poles and rafters) connects the wall to the toono (the upper frame, also referred to as the crown wheel), and the dimensions and elevation of the toono define the upper termination of the roof [3]. The felt covering produces the visible surface, but its principal geometry

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follows the underlying frame. Research on mid-century Ger canons further indicates that component dimensions follow calculable proportional rules rather than arbitrary assembly decisions [4]. When body diameter increases, builders can accommodate the additional span through a larger toono, longer uni poles, a different number of khana sections, greater vertical dimensions, or a combination of these adjustments. Each solution redistributes the height and span of the wall, roof, and top. Overall morphology therefore cannot be inferred from body diameter or any single component alone.

Existing yurt research establishes the individual parts of this problem but does not connect component dimensions to recurring whole-form variation. Architectural surveys have documented the basic components, spatial organisation, materials, and assembly of Mongolian yurts [3]. Studies of contemporary residential use have examined how the yurt accommodates household activities and changing urban lifestyles [5]. Environmental research has evaluated heating demand and energy performance using specified experimental or simulated yurt configurations [6]. Other studies have examined how contemporary buildings reproduce recognisable elements of yurt morphology [7]. These studies explain construction, use, performance, and cultural representation, but they generally treat yurt form as an established type. They do not determine whether measured differences among traditional yurts follow repeated component-scale relationships or form recurrent morphological configurations.

Quantitative architectural typology provides a way to connect measured dimensions with recurring form. Recent studies of traditional settlements have constructed typological systems from measurable morphological factors and their geometric relationships [8]. Clustering research has also shown that representative architectural archetypes can be extracted when the selected variables describe interpretable aspects of form [9]. Research on residential building classification further demonstrates that the resulting clusters depend strongly on the architectural meaning and redundancy of the input variables [10]. These approaches cannot be transferred mechanically to traditional yurts. Clustering absolute dimensions would primarily reproduce differences in size, whereas entering numerous correlated measurements would repeatedly weight the same geometry. Yurt morphology instead requires a representation that separates absolute scale from the proportional organisation of the wall, roof, and top.

This study asks if the apparent morphological differences between traditional Mongolian yurts in Inner Mongolia are the result of stable relationships at the component scale within a common construction system. It responds to three research questions:

(1) What dimensions are continuously adjusted as the yurt diameter is changed, which dimensions are constrained, and what differences in apparent size reflect the subdivision into modules?
(2) Do combinations of wall, roof, and top proportions form stable and recurring morphological types?
(3) To what extent do the data-derived types correspond to constructional distinctions and regional patterns documented in the field?

2. Materials and Methods

2.1. Sample Sources and Study Objects

This study employed purposive sampling. Priority was given to yurts preserved by practitioners of traditional yurt-building techniques or constructed according to traditional methods; those long retained by herding families with clear dating or information on their transmission; and those held in museum collections that retain traditional wooden structural components. Provided that the components were identifiable, site access was permitted, and field measurements could be conducted, the survey ensured spatial coverage

across different leagues and cities in Inner Mongolia, ultimately yielding 41 valid samples. The samples are distributed across Alxa League, Ulanqab, Xilingol League, Chifeng, Tongliao, Hinggan League, Hulunbuir and Ordos (Table 1). All survey subjects retained identifiable khana, uni, and toono components; modern steel-frame settled yurts were excluded from the study (Figure 1).

Table 1. Regional composition of the sample.

League/Prefecture-Level City	Sample Size	Percentage
Ulanqab	1	2.4%
Hinggan League	3	7.3%
Hulunbuir	8	19.5%
Chifeng	9	22.0%
Tongliao	1	2.4%
Ordos	6	14.6%
Xilingol League	11	26.8%
Alxa League	2	4.9%
Total	41	100.0%

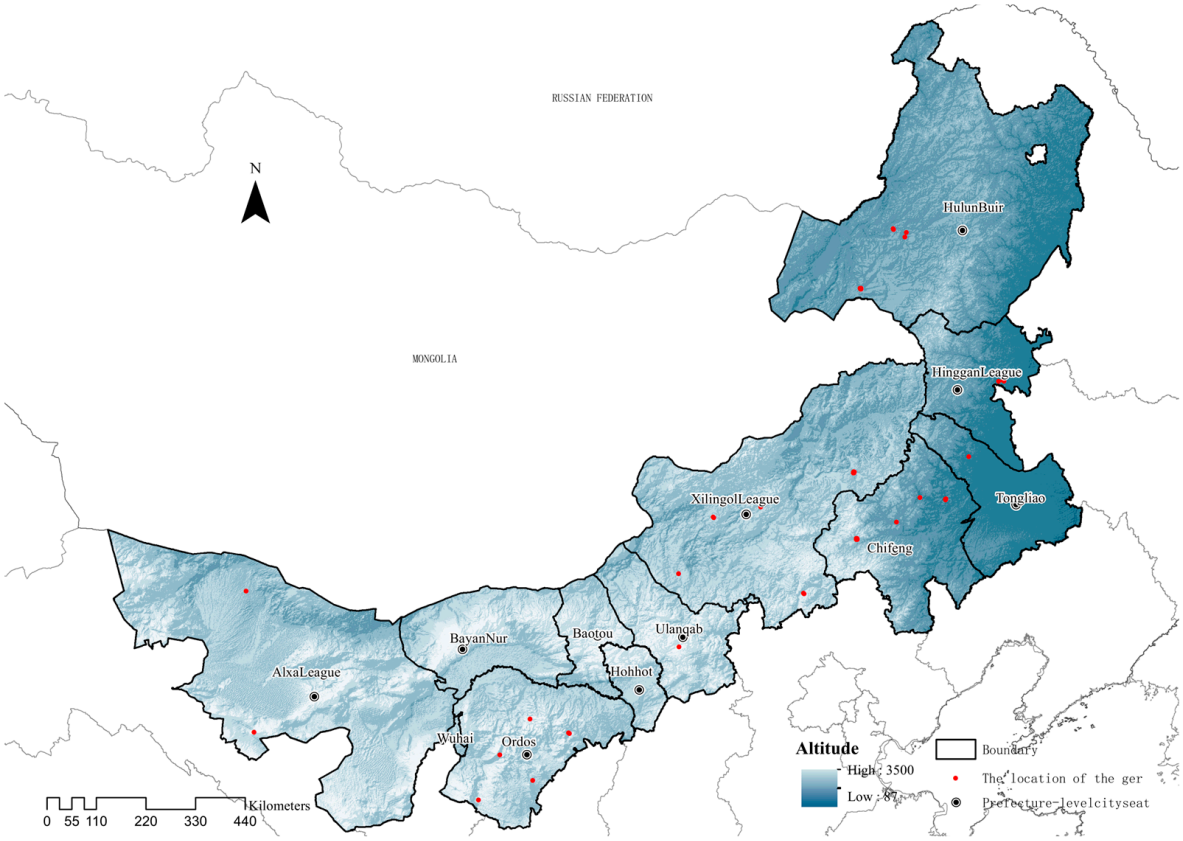


Figure 1. Study area and sample distribution.

2.2. Measurement Variables and Morphological Representation

Only variables directly relevant to the research question were retained. Yurt diameter was defined as the reference diameter of the enclosed main body, excluding the projection of the door frame. For slightly elliptical cases, the mean of two mutually perpendicular diameters was used. The felt covering and ropes and straps were treated as supporting elements of the overall morphology (Table 2, Figure 2).

Table 2. Measurement variables and definitions.

Symbol	Variable	Definition	Unit
D	Yurt diameter	Reference diameter of the enclosed main body	mm
H	Overall yurt height	Ground to the highest point of the top	mm
H_k	Expanded khana height	Ground to the upper edge of the khana	mm
H_r	Roof rise	Vertical height from the upper edge of the khana to the lower edge of the toono	mm
H_t	Top rise	Lower edge of the toono to the highest point of the top	mm
D_t	Outer diameter of the toono	Outer-edge diameter of the toono	mm
L_u	Uni length	Eave connection point to toono connection point	mm
N_k	Number of khana sections	Total number of expanded khana sections	section
N_u	Total number of uni poles	Total count of all uni poles	pole
W_d	Clear door width	Clear width of the door frame	mm
H_k/D	Wall height/diameter	Wall height relative to yurt diameter	-
H_r/D	Roof rise/diameter	Main roof height relative to yurt diameter	-
H_t/D	Top rise/diameter	Additional top height relative to yurt diameter	-

Note: Subscripts are derived from the initial letters of the English component names: k = khana, r = roof, t = top/toono, u = uni, and d = door. Each symbol is used consistently after its first definition.

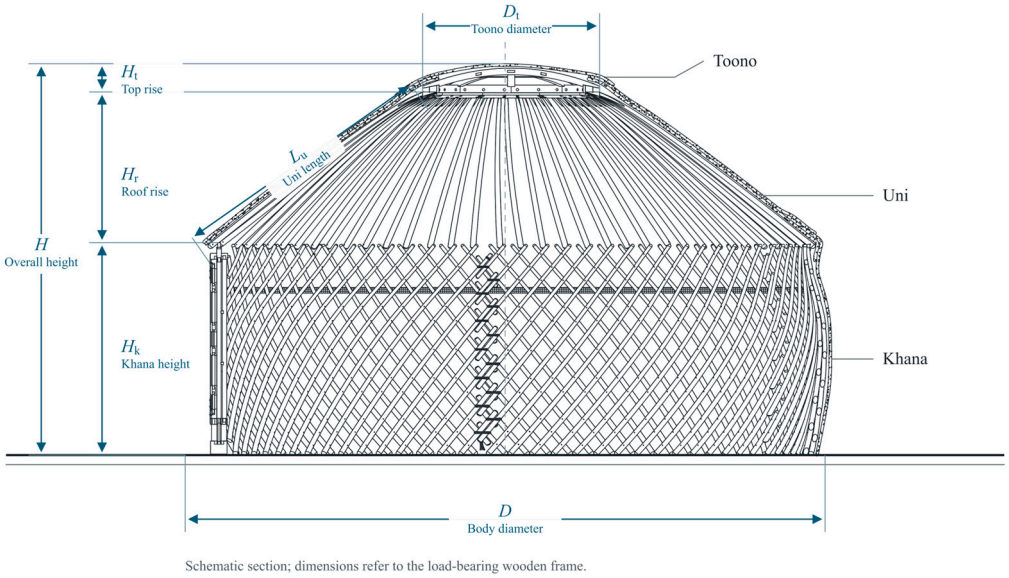


Figure 2. Sectional measurement variables of a traditional Mongolian yurt.

Roof rise was calculated by subtracting expanded khana height and top rise from overall height:

$$H_r = H - H_k - H_t \quad (1)$$

Khana height alone cannot characterize overall morphology because the same wall height may occur with different diameters, roof rises, and top profiles. The wall-height-to-diameter, roof-rise-to-diameter, and top-rise-to-diameter ratios were therefore used jointly to represent the wall–roof–top vertical composition. Absolute diameter was not entered into the clustering with these three ratios, thereby preventing yurt size from dominating the resulting types.

2.3. Analysis Procedure

The analysis proceeded through data preparation, component-scale relationship analysis, morphological clustering, validation, and field interpretation (Figure 3). Measurement protocols were first harmonized across the 41 samples, after which relationships between the principal components and yurt diameter were analyzed. The three wall, roof, and top

height-to-diameter ratios were then clustered, and both the number and stability of the resulting clusters were evaluated. Finally, field records and geographical distributions were used to interpret the morphology of each type.

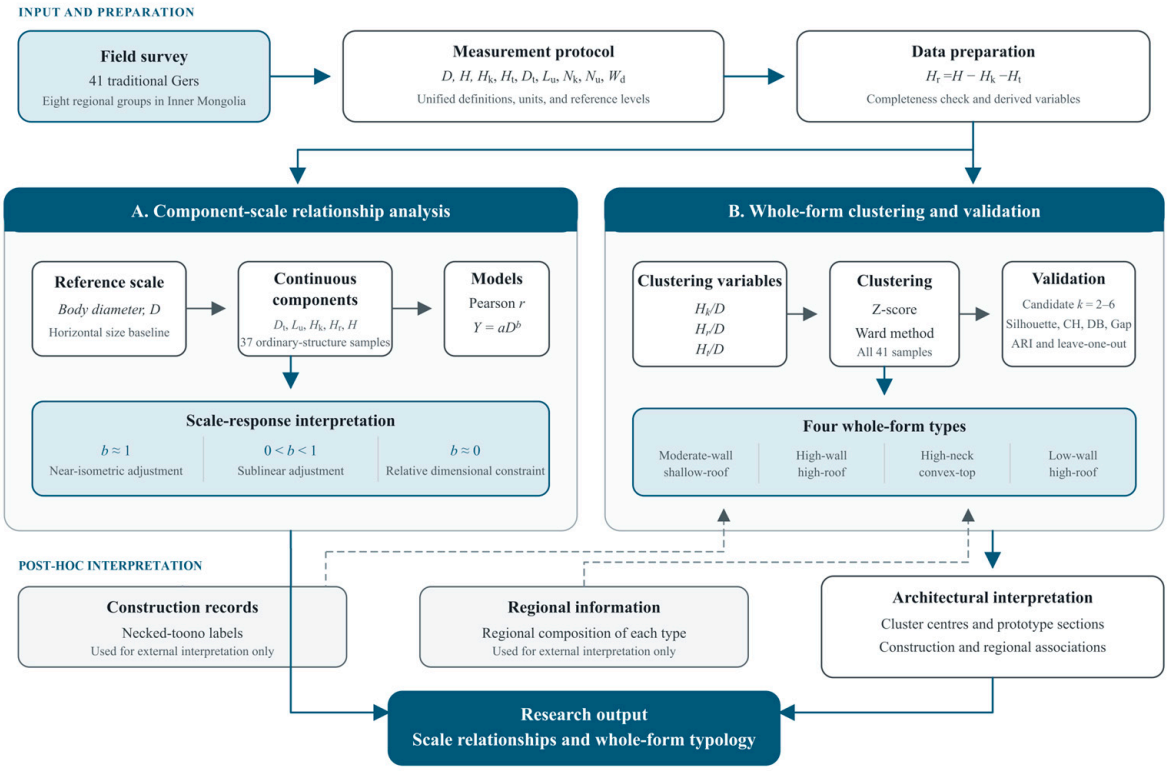


Figure 3. Analytical workflow.

2.4. Component-Scale Relationships

For continuous components, scatterplots and correlation analysis were first used to identify the direction of change, after which a power function tested whether component dimensions increased in step with yurt diameter. Power functions are commonly used in building geometry to distinguish isometric from allometric scaling [11]. The model was specified as:

$$Y = aD^b \tag{2}$$

where Y is the component dimension, D is the yurt diameter, a is a constant, and b is the scaling exponent. The model was estimated after natural-log transformation:

$$\ln(Y) = \ln(a) + b\ln(D) + \varepsilon \tag{3}$$

A scaling exponent close to 1 indicates that the component and yurt diameter increase approximately in step; a value below 1 indicates slower component growth; and a value close to 0 indicates a relatively stable component dimension. Research on the proportions of traditional timber buildings shows that modular control and non-isometric adjustment may coexist across components [12]. Building-mass studies likewise indicate that constructional constraints can produce different scaling responses among geometric variables [13]. Bootstrap estimates were used to quantify uncertainty in the scaling exponent, while the number of khana sections was evaluated separately through grouped distributions and sensitivity analysis.

2.5. Clustering and Validation of Overall Morphology

The clustering input comprised only the wall-height-to-diameter, roof-rise-to-diameter, and top-rise-to-diameter ratios. Each variable was first converted to a z-score:

$$z_{ij} = \frac{x_{ij} - \overline{x_j}}{s_j} \quad (4)$$

The standardized variables were analyzed using Ward's minimum-variance hierarchical clustering. Ward's method merges observations by minimizing the increase in within-cluster dispersion [14]. Murtagh and Legendre clarified differences among algorithmic implementations of Ward's criterion [15]. Candidate cluster numbers ranged from two to six and were compared in terms of within-cluster compactness, between-cluster separation, minimum cluster size, and stability under sample perturbation.

The number of clusters was not determined from a single metric. The silhouette coefficient compares the proximity of each observation to its own and neighboring clusters [16]. The Calinski–Harabasz index contrasts between- and within-cluster dispersion [17]. The Davies–Bouldin index evaluates a partition from within-cluster scatter and between-cluster distance [18]. The gap statistic compares observed within-cluster dispersion with a reference distribution [19]. Cluster selection must also avoid treating a single anomalous case as a distinct type [20].

Agreement between algorithms was evaluated using the adjusted Rand index for the K-means and Ward partitions. The adjusted Rand index quantifies agreement between two partitions [21]. In the leave-one-out analysis, one sample was removed at a time and the clustering was repeated to assess sensitivity to sample perturbation. Principal component analysis was used only for two-dimensional visualization [22].

3. Results

3.1. The Samples Exhibit Continuous Rather than Discrete Morphological Variation

The 41 yurts spanned broad ranges of diameter and overall height, while all three vertical ratios also varied continuously (Table 3). Top rise showed the greatest variation, primarily because of the necked-toono samples. The wall, roof, and top ratios did not form a single sequence along the diameter range, providing a basis for identifying recurrent configurations.

Table 3. Descriptive statistics for the 41 samples.

Variable	Unit	Mean	SD	Median	Minimum	Maximum
D	mm	4671	737	4520	3131	6851
H	mm	2639	524	2493	2003	4894
H_k	mm	1341	184	1300	1072	1847
H_r	mm	1071	272	1030	672	1898
H_t	mm	227	201	163	78	1149
D_t	mm	1293	216	1249	915	1752
L_u	mm	2079	315	2031	1510	3007
H_k/D	-	0.291	0.046	0.279	0.184	0.418
H_r/D	-	0.229	0.042	0.233	0.147	0.341
H_t/D	-	0.048	0.035	0.039	0.017	0.177

3.2. Components Respond Differently to Increasing Yurt Diameter

The outer diameter of the toono increased approximately in step with yurt diameter, and uni length also increased consistently. Together, these two components accommodated most of the increase in horizontal span. The relationship between the height and diameter of the khana is relatively weak, indicating that the expansion of the yurt does not require the

side walls to rise in the same proportion. Overall height and roof rise occupied intermediate positions, showing that vertical form is produced by the combination of several components rather than controlled by any single dimension (Table 4, Figure 4).

Table 4. Component-diameter relationships for samples with conventional construction.

Component Y	n	Pearson r	p	Scaling Exponent b	95% CI for b	R^2
D_t	37	0.833	<0.001	1.002	[0.826, 1.211]	0.707
L_u	37	0.915	<0.001	0.886	[0.737, 1.024]	0.836
H_k	37	0.256	0.129	0.234	[−0.085, 0.487]	0.075
H_r	37	0.602	<0.001	0.848	[0.425, 1.197]	0.307
H	37	0.616	<0.001	0.516	[0.263, 0.713]	0.377
W_d	37	0.704	<0.001	1.270	[0.990, 1.547]	0.477
N_u	37	0.335	0.041	0.296	[−0.074, 0.649]	0.078

Note: The four known necked-toono samples were excluded from these fits.

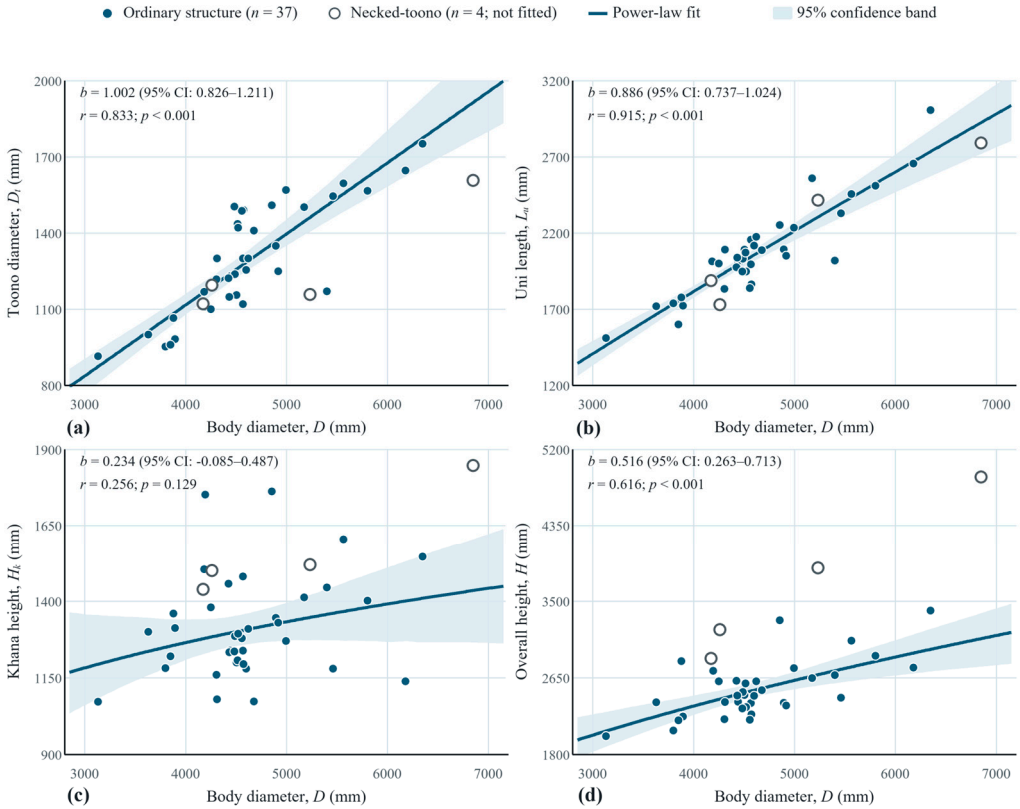


Figure 4. Power-law relationships between body diameter and key component dimensions. (**a**) Toono outer diameter, D_t; (**b**) uni length, L_u; (**c**) khana height, H_k; and (**d**) overall height, H. Filled circles represent the 37 conventional-construction samples used for model fitting, whereas open circles represent the four necked-toono samples shown for comparison but excluded from the fitted models. Solid lines indicate the fitted power-law relationships, and shaded bands represent the 95% confidence intervals. Each panel reports the scaling exponent b with its 95% confidence interval, Pearson's r, and the corresponding p value.

3.3. The Number of Khana Sections Does Not Directly Indicate Yurt Size

The diameter ranges of yurts with four, five, and six khana sections overlapped substantially (Table 5, Figure 5). Although the six-section group had a larger mean diameter, the number of sections did not exhibit a stable linear relationship with diameter. Excluding samples with a different connection system did not change the direction of the association.

The number of khana sections is therefore a discrete constructional attribute influenced by the connection system and cannot substitute for a direct measure of overall size.

Table 5. Yurt diameter by common numbers of khana sections.

Number of Khana Sections	*n*	Mean Diameter (mm)	Median Diameter (mm)	Diameter Range (mm)
4	11	4468	4516	3850–4894
5	13	4444	4442	3131–5565
6	14	4876	4622	3880–6349

Note: Samples E-04, E-05, and E-08, which use a different connection system, were excluded from this analysis.

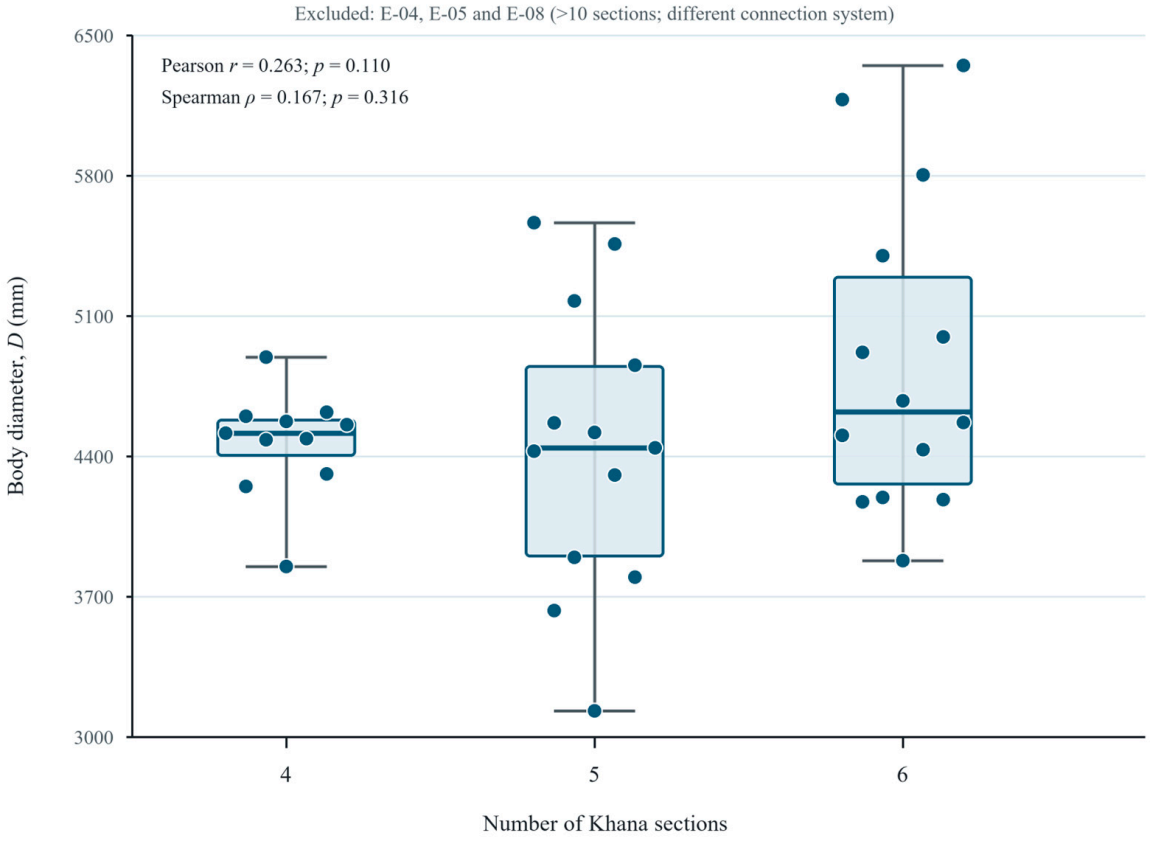


Figure 5. Distribution of yurt diameter by number of khana sections. Boxes indicate the interquartile range, horizontal lines indicate the median, whiskers span the observed minimum and maximum values, and points represent individual yurts. Samples E-04, E-05, and E-08 were excluded because their khana systems contain more than ten sections and employ a different subdivision and connection method. Pearson's *r* and Spearman's *p* describe the associations between khana-section number and body diameter.

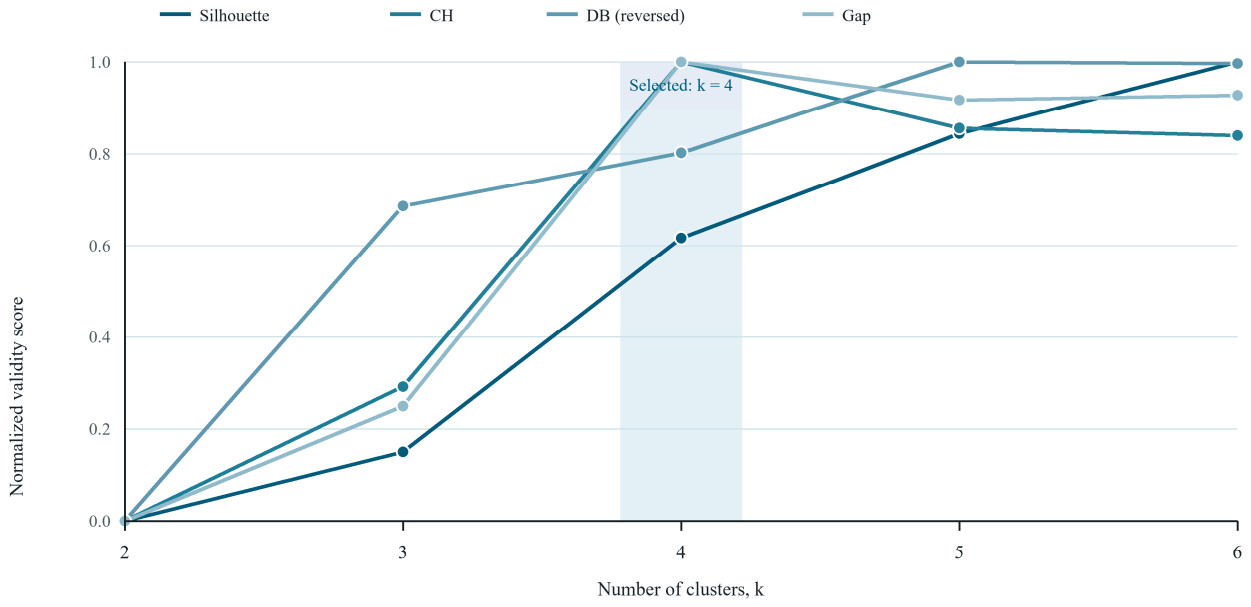
3.4. The Four-Cluster Solution Balances Separation and Stability

As the number of clusters increased from two to six, the silhouette coefficient rose only gradually. Both the five- and six-cluster solutions produced a singleton cluster, indicating overpartitioning of individual variation. Although the high-neck–convex-top cluster contains only four samples, it was retained because it represents a repeated constructional configuration rather than a singleton or an isolated outlier. All four members show elevated H_t/D values and were independently recorded during fieldwork as necked-toono yurts, whereas no ordinary-toono sample entered this cluster. The three-cluster solution left variation among conventional yurts unresolved, while the five- and six-cluster solutions generated singleton clusters. The four-cluster solution was therefore selected on the com-

bined basis of statistical stability, minimum cluster size, architectural interpretability, and agreement with independent field records (Table 6, Figure 6).

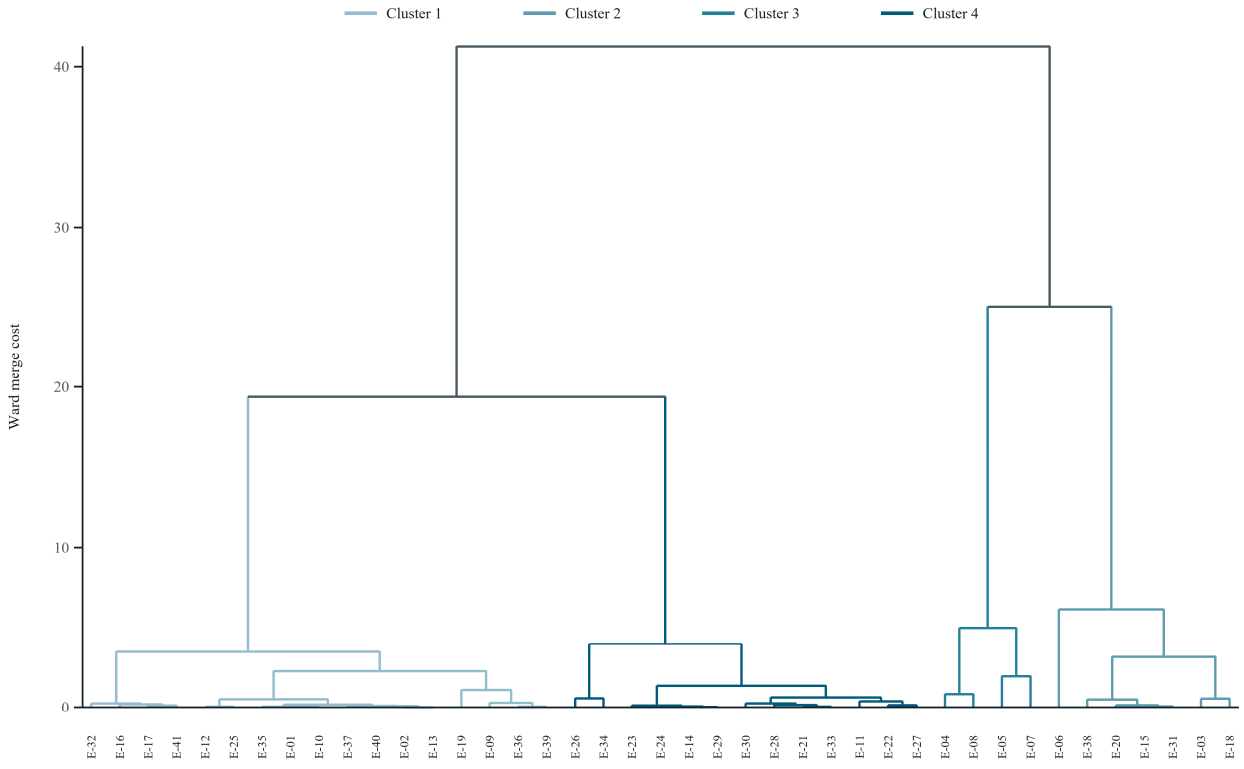
Table 6. Comparison of candidate numbers of clusters.

k	Silhouette	CH	DB	Gap	Algorithm Agreement	Leave-One-Out Stability	Minimum Cluster *n*	Assessment
2	0.418	20.420	1.252	0.637	0.898	0.861	11	Too coarse: variation among conventional yurts remains unresolved
3	0.421	23.447	0.855	0.697	0.829	0.892	4	Too coarse: variation among conventional yurts remains unresolved
4	0.430	30.799	0.788	0.880	0.932	0.969	4	Selected: highest CH and Gap; stable, with no singleton cluster
5	0.434	29.297	0.674	0.859	0.715	0.957	1	Overpartitioned: one singleton cluster
6	0.437	29.135	0.676	0.862	0.711	0.948	1	Overpartitioned: one singleton cluster

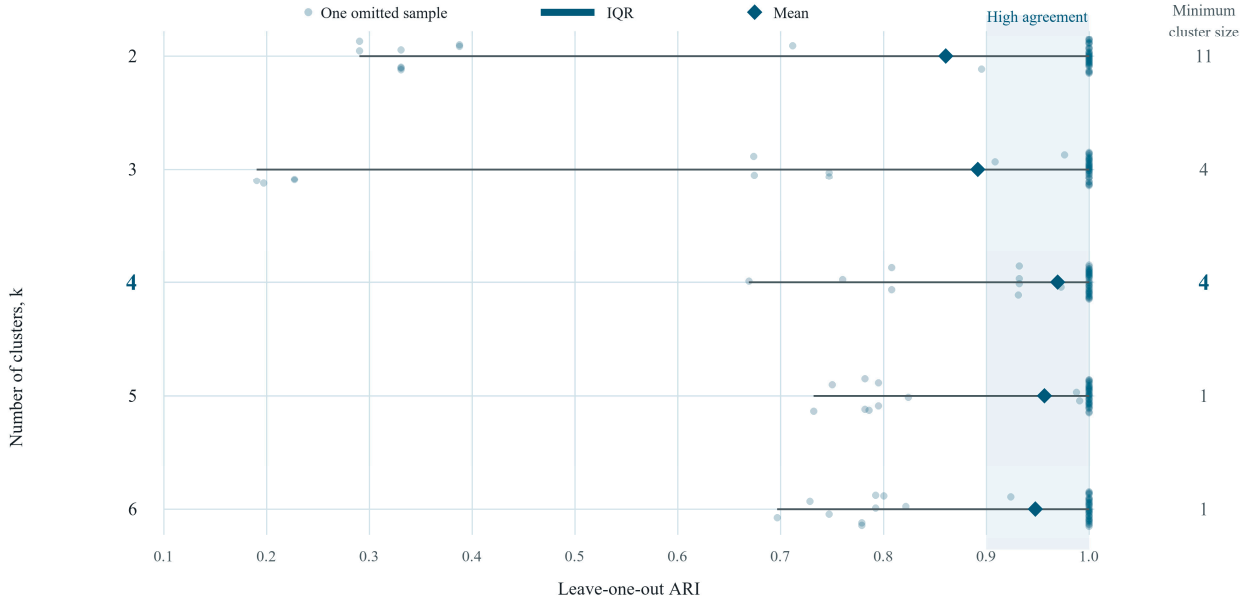


(**a**)

Figure 6. *Cont.*



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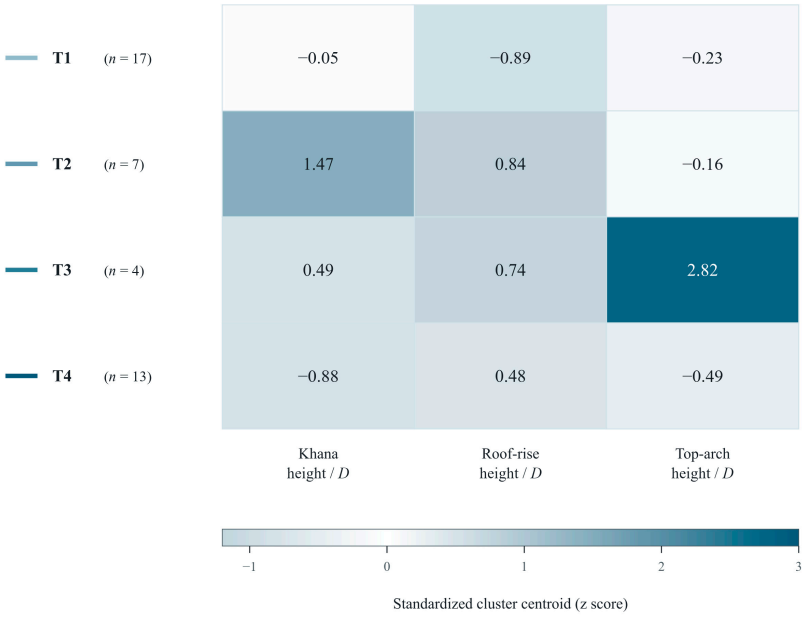


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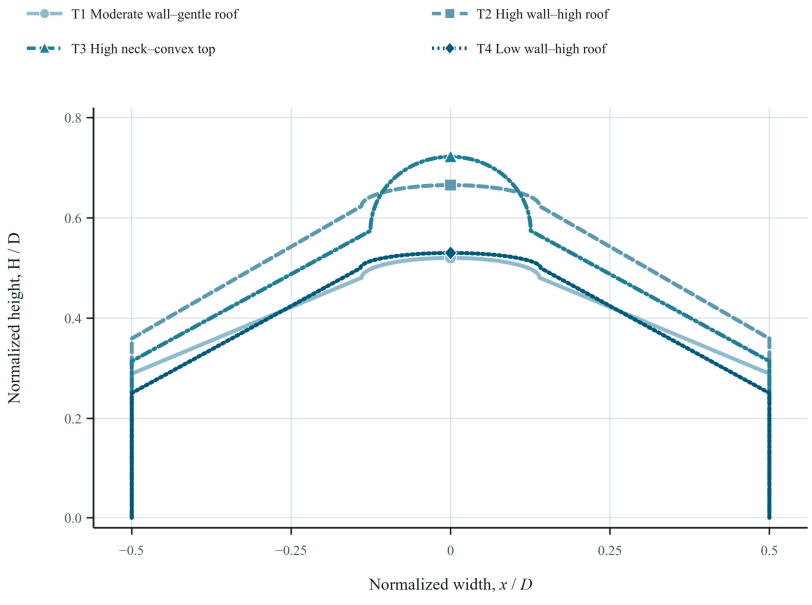
Figure 6. Selection and validation of the four-cluster solution. (**a**) Normalized silhouette, Calinski–Harabasz, reversed Davies–Bouldin, and gap-statistic values for candidate cluster numbers from $k = 2$ to 6; the shaded band indicates the selected solution at $k = 4$. (**b**) Ward hierarchical-clustering dendrogram for the 41 samples; branch colors and the lower color strip indicate membership in the four clusters, and the vertical axis represents Ward merge cost. (**c**) Leave-one-out adjusted Rand index values for each candidate k. Points represent individual sample omissions, horizontal bars indicate the interquartile range, diamonds indicate the mean, the shaded area denotes high agreement, and the values on the right indicate the minimum cluster size.

3.5. The Four Types Represent Different Wall–Roof–Top Configurations

The moderate-wall–gentle-roof type contained 17 yurts and combined an intermediate wall ratio with a relatively low roof rise. The high-wall–high-roof type contained seven yurts and had high wall and roof proportions despite having the smallest mean diameter of the four types. The high-neck–convex-top type contained four yurts and was the most readily identifiable because of its pronounced additional top height. The low-wall–high-roof type contained 13 yurts and combined a relatively low wall with a high roof rise to produce a steep profile. These proportional differences are summarized in Table 7 and visualized through the standardized cluster centroids, archetypal profiles, and representative cases in Figures 7 and 8.

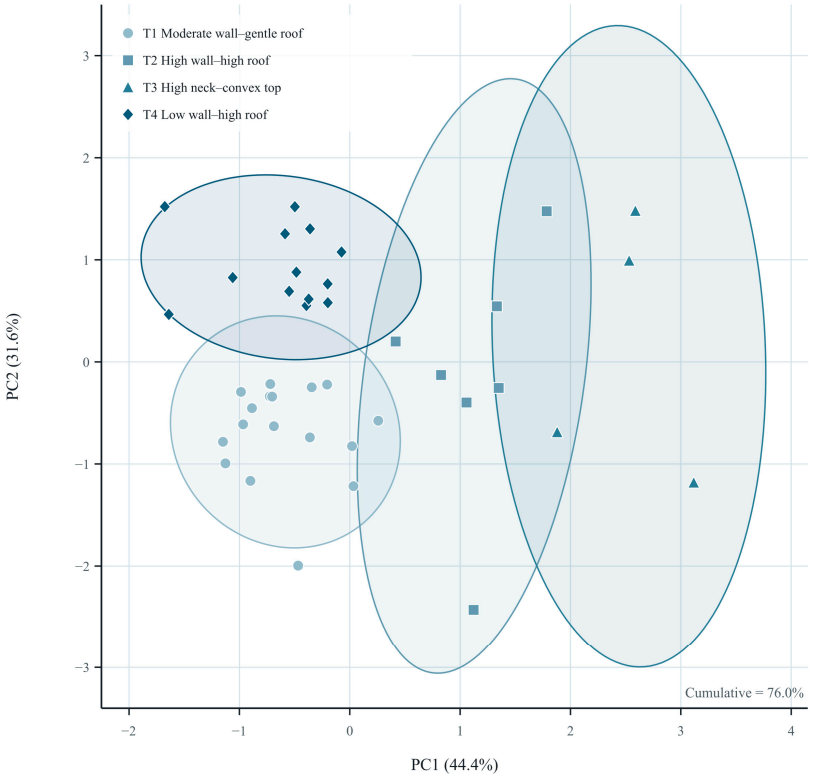


(**a**)



(**b**)

Figure 7. *Cont.*



(**c**)

Figure 7. Proportional characteristics of the four morphological types. (**a**) Heatmap of standardized cluster centroids for H_k/D, H_r/D, and H_t/D; cell values are expressed as z scores. (**b**) Mean sectional profiles of the four types normalized to an equal body diameter of D = 1.0, showing the proportional allocation of height among the wall, roof, and top. Mean D_t/D is used only to draw the toono width and was not included as a clustering variable. (**c**) Principal component score plot of the 41 samples based on the three standardized clustering variables. Symbols indicate type membership. The shaded ellipses are covariance-based 95% data ellipses centered on each type's mean PCA score, and PC1 and PC2 explain 44.4% and 31.6% of the total variance, respectively, with a cumulative contribution of 76.0%.



Figure 8. Representative photographs and normalized sections of the four traditional Mongolian yurt types.

Table 7. Centroid characteristics of the four morphological types.

Type	*n*	Mean *D* (mm)	H_k/D	H_r/D	H_t/D	*H*/*D*	Roof Pitch (°)
Moderate-wall–gentle-roof	17	4585	0.289	0.192	0.040	0.520	28.0
High-wall–high-roof	7	4018	0.359	0.264	0.042	0.666	36.0
High-neck–convex-top	4	5129	0.314	0.260	0.148	0.722	34.6
Low-wall–high-roof	13	4995	0.251	0.249	0.030	0.530	34.8

Cluster membership and regional composition are presented in Table 8 and Figure 9. All four samples recorded in the field as having a necked toono were assigned to the high-neck–convex-top type, and no samples without this field-recorded feature entered the cluster. The type was also concentrated in Ordos, although the sample size is insufficient to equate one region directly with one morphological type. The low-wall–high-roof type was dominated by Chifeng samples, whereas the remaining types extended across several leagues and prefecture-level cities. Regional building traditions may therefore be associated with overall morphology, but the relationship is not one-to-one.

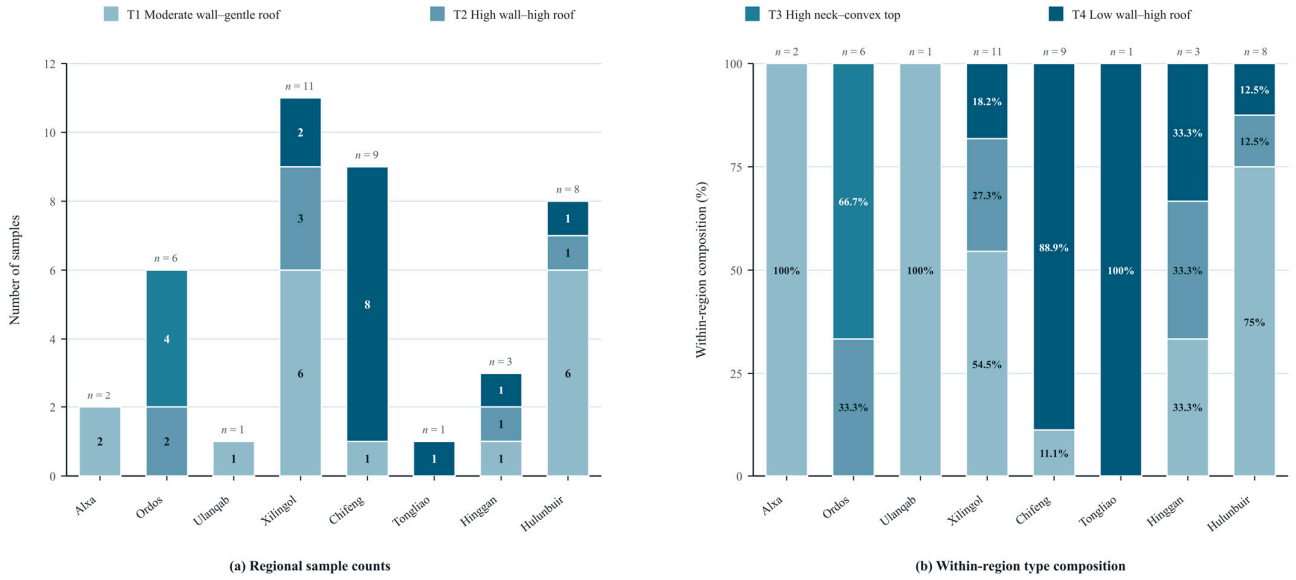


Figure 9. Regional composition of the four morphological types. (**a**) Number of samples belonging to each morphological type in the eight surveyed regions; labels above the bars indicate the total regional sample size. (**b**) Within-region composition of the four types after each regional total was standardized to 100%. Colors correspond to T1–T4. Because regional sample sizes are unequal, the distributions are presented descriptively and should not be interpreted as population-level proportions.

Table 8. Regional composition, field-recorded labels, and sample membership of the four types.

Type	*n*	Regional Composition	Necked Toono (*n*)	Sample ID
Moderate-wall–gentle-roof	17	Ulanqab 1; Hinggan League 1; Hulunbuir 6; Chifeng 1; Xilingol League 6; Alxa League 2	0	E-01, E-02, E-09, E-10, E-12, E-13, E-16, E-17, E-19, E-25, E-32, E-35, E-36, E-37, E-39, E-40, E-41
High-wall–high-roof	7	Hinggan League 1; Hulunbuir 1; Ordos 2; Xilingol League 3	0	E-03, E-06, E-15, E-18, E-20, E-31, E-38
High-neck–convex-top	4	Ordos 4	4	E-04, E-05, E-07, E-08
Low-wall–high-roof	13	Hinggan League 1; Hulunbuir 1; Chifeng 8; Tongliao 1; Xilingol League 2	0	E-11, E-14, E-21, E-22, E-23, E-24, E-26, E-27, E-28, E-29, E-30, E-33, E-34

4. Discussion

4.1. Comparison with Previous Studies

This study shifts the representation of the Mongolian yurt from a single standardized archetype to a set of measured types that share a construction system but differ in proportion. Byambajav extracted recurring dimensions from historical yurt-component parameters, providing a direct precedent for quantifying component relationships [4]. The present results further show that the same component system does not generate a single set of proportions but produces recurring wall–roof–top configurations. Previous environmental studies of Mongolian yurts have generally selected one or a few cases for analysis [23]. The four identified types indicate that thermal-environment, wind-load, and retrofit simulations based on a single "standard yurt" may overlook differences associated with profile proportions.

Compared with proportional studies of other traditional buildings, the Mongolian yurt exhibits a particularly clear division of dimensional roles among components. Research on Korean traditional timber buildings has shown that proportional rules vary across component hierarchies [24]. A study of the Yingxian Wooden Pagoda likewise identified morphological control relationships through component proportions [25]. In the present study, the outer diameter of the toono and the length of the uni adjust with yurt diameter, whereas khana height remains relatively constrained, demonstrating that the yurt does not scale as a single isometric form. This finding locates morphological variation in component-scale relationships rather than leaving it as a visual description of tall, low, steep, or gentle forms.

Compared with building-clustering studies, this study uses fewer variables with more direct architectural meanings. Building-stock models often derive representative archetypes from numerous attributes [26]. Research using national spatial datasets likewise identifies building groups from multidimensional morphological indicators [27]. Because the present dataset contains only 41 yurts, it does not pursue high-dimensional characterization; instead, three nonredundant ratios cover the complete vertical composition. Comparable small-sample studies of architectural types show that cluster labels must be interpreted through architectural features rather than reported only as algorithmic identifiers [28]. The exact correspondence between the field-recorded necked-toono label and the high-neck–convex-top type provides an independent field validation of this interpretation.

4.2. Possible Environmental and Cultural Associations with Regional Variation

Field observations and sample distributions indicate possible associations between regional environmental conditions and yurt profiles. Lower and gentler profiles occurred more frequently among the surveyed western cases, whereas steeper roofs occurred more frequently among the surveyed eastern cases. The concentration of the low-wall–high-roof type in Chifeng is compatible with a drainage-related interpretation, but the unequal regional sample sizes and absence of site-specific climatic variables preclude causal inference. Previous studies have identified relationships between precipitation, snow conditions, and roof form [29–31]. The pattern observed in this study should therefore be treated as a hypothesis for future testing rather than as evidence that climate determined type formation.

The high-neck–convex-top type more clearly demonstrates the role of cultural and tectonic traditions. The four necked-toono samples span different diameters but entered the same cluster because of their shared top construction, indicating that a construction tradition can outweigh the effect of overall yurt size. Cross-ethnic research on traditional dwellings shows that morphological types can simultaneously record cultural interaction and local building knowledge [32]. Archaeological typology likewise emphasizes that type interpretation must incorporate chronology and building context [33]. Distinguishing environmental adaptation from cultural transmission will require future samples to

include coordinates, long-term climate records, construction dates, craftsperson origins, and migration pathways.

4.3. Limitations and Future Research

Based on a sample of 41 traditional yurts, the four categories identified in this study primarily reflect the morphological patterns observed in the existing sample and do not yet represent the typological distribution across the entire region of Inner Mongolia. Furthermore, the climatic explanation currently provides only directional evidence at the regional level. Future research could expand the regional sample to further elucidate the influence of environmental conditions and construction traditions on the formation of yurt morphology.

5. Conclusions

This study quantified the relationships between component dimensions and overall morphology using 41 traditional Mongolian yurts surveyed across Inner Mongolia. The results show that their visible morphological differences follow repeatable relationships among yurt diameter and the relative dimensions of the wall, roof, and top. Three main conclusions emerge from the analysis:

(1) Yurt enlargement follows a component-specific scaling pattern. Among the 37 conventional-construction samples, the outer diameter of the toono increased almost proportionally with yurt diameter (b = 1.002), while uni length showed a similar response (b = 0.886). Overall height increased more slowly (b = 0.516), and khana height showed no statistically significant association with diameter (p = 0.129). Traditional builders therefore enlarged the yurt mainly by extending the horizontal span of the toono–uni roof system while maintaining a comparatively stable wall height. Khana-section count cannot directly indicate yurt size because it also reflects subdivision and connection practices.

(2) The standardized wall, roof, and top ratios produced a stable four-cluster solution that remained consistent under leave-one-out perturbation and avoided singleton classes. The moderate-wall–gentle-roof type (n = 17) combines an intermediate wall proportion with a relatively shallow roof. The high-wall–high-roof type (n = 7) increases both wall and roof proportions, despite having the smallest mean diameter. The high-neck–convex-top type (n = 4) concentrates additional height above the main roof, whereas the low-wall–high-roof type (n = 13) combines a relatively low wall with a steep roof. Proportional configuration therefore defines the types independently of absolute size. All four field-recorded necked-toono yurts fall within the high-neck–convex-top cluster, providing independent field validation of the statistical classification.

(3) The data-derived types correspond to field evidence to different degrees. The strongest correspondence occurs in the high-neck–convex-top type: all four yurts recorded in the field as having a necked toono entered this cluster, whereas no ordinary-toono sample did. Regional concentration was weaker and non-exclusive, indicating that constructional distinctions provide clearer support for type interpretation than geographical provenance alone.

These findings replace qualitative descriptions such as tall, low, steep, and gentle with measurable component relationships and reproducible morphological types. The resulting framework supports comparative survey and documentation, parametric reconstruction, conservation design, and the selection of representative cases for environmental-performance analysis. Future research should expand the geographically balanced sample and examine how climate, construction chronology, craft lineage, materials, and local building practices contribute to the formation of each type.

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