Quantifying the Spatial Evolution of Bai People’s Courtyard Houses

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Abstract. Bai People’s courtyard houses in the rural parts of China’s Dali area are a particular type of Chinese courtyard house, adapted to local culture and conditions. These dwellings were constructed in vernacular tradition up until the 1980s but underwent significant changes in the following decades. The goal of this study is to examine the evolution of the spatial structure using quantitative data, and relate it to changes in the social culture of the inhabitants. Three vernacular and three contemporary cases in the village Gushengcun are compared. To enhance understanding and examine the idea of evolutionary change in architecture, the concept of a Spatial DNA is applied, building on a metaphor of the biological DNA. It uses Space Syntax techniques and links numerical values of integration and space type to functional information. Findings show that the integration of the courtyard and bedrooms is decreasing, and space types indicate a change from rings to sequences. In contrast, the kitchen space integration is increasing. These results reveal parallels to changes in the means of subsistence, social structure of the family and conceptions of privacy: Decreasing spatial centrality of the courtyard - once a key space in the processing of agricultural produce - coincides with a shift from work in the primary sector to secondary and tertiary industries. Modern conceptions of privacy and individualism replacing the family as a unit of privacy are related to the segregation of bedrooms. The change in the spatial location of the kitchen is interpreted in the context of abolished gender separation and the changing role of women. This study hence provides measurable evidence to the links between space and culture in an intertemporal comparison of dwelling types.

1. Introduction
The Bai people in China’s southwestern Yunnan province have a unique vernacular housing culture, influenced by Han Chinese courtyard dwellings [1]. In recent decades, a process of modernization brought about a new generation of houses, adapted to modern needs. Although there have been efforts to inherit traditional architectural elements, the spatial structure has changed noticeably. The objective of this study is the examination of these changes and the mechanisms behind them. Six dwellings from the village Gushengcun are examined, which were recorded in a 2019 field study. In order to develop quantitative measures, which allow a structured comparison between the two stages of dwelling and at the same time facilitate inferences about the relation between space and culture, Space Syntax techniques are applied. Hillier and Hanson [2] put forward a theory which provides tools to quantitively describe and represent spatial configurations of urban structures and houses, and claims that spatial properties of the built environment are closely linked to sociological meaning. This is because patterns of behaviour and human activity are thought to be recorded in the spatial structure.
[3]. Analyzing the spatial structure of a dwelling can therefore offer insights into the social culture of inhabitants, even when dealing with historical cultures which elude ethnographic observations [4]. Furthermore, specific cultural concepts imprinted in the spatial configuration, such as Confucianism, can be understood with the help of syntactic theory [5]. The temporal nature of reality, which is key to the evaluation of a dwelling’s evolution as attempted in this study, also plays an important role in space syntax theory, although this aspect has often been subordinated in the quest for a morphological grammar of social organization [6]. The quantitative approach of the theory allows objective readings and enables analytic comparison of buildings across space as well as time [7]. Such comparisons of buildings of different eras, as an assessment of the temporal dimension of dwelling typologies, answer the call to regard dwelling typologies as materializations of a dynamic process [8]. The vernacular and the modern, two terms often juxtaposed but seldomly compared in terms of their spatial structure, can furthermore offer insights into what can be labelled spatial cultural heritage and its situation today.

To illustrate the idea of heredity in architecture, as well as to provide an easily comprehensible framework for the structuring of data, the concept of a Spatial DNA is used. It incorporates the syntactical measures and links them to qualitative information of activity and sectors of space-use. It uses the biological DNA as a metaphor, which contains encoded genetic information and governs heredity in living organisms [9]. The illustration of the DNA with the duality of the base pairs are adapted to structure and display spatial metrics and non-spatial data, in order to visualize the inner workings of a dwelling underlying floorplans as geometric structures. By comparing two stages of a dwelling typology using empirical data in the concept of a Spatial DNA, this study contributes to a better understanding of dwelling culture, its socio-spatial characteristics and evolution.

2. Methodology
In order to comprehensively illustrate the socio-spatial dimension of the dwellings, they are evaluated using a multitude of empirical data in an approach juxtaposing spatial and functional information. The purpose is to diminish and minimize the impact of the limitations of each technique and mode of investigation, to arrive at a comprehensive analysis of the examined cases. This data is displayed in the Spatial DNA as a tool to link spatial to sociocultural information and deduce connotations in a clearly structured and visually coherent way. This is also to react to critics who have lamented that the Space Syntax method is often presented using complex mathematical tables which are difficult to comprehend [10]. The data which was necessary for applying the Spatial DNA and conducting the comparative study was acquired in field research and literature review. The data for the floor plans was collected in 2019, on a field study in the Dali Autonomous Prefecture in Yunnan.

2.1. The Spatial DNA
Spatial and a-spatial metrics are the basic components of the Spatial DNA, displayed as what would be the base pairs in biological terms. Spatial metrics are the syntactical measures derived from the spatial configuration and comprise the Space Syntax measures integration value and space-type. A-Spatial metrics are functions, sectors of space-use as well as activity types (figure 1).

Figure 1. Metrics of the Spatial DNA.

2.1.1. Spatial Metrics. An important tool in Space Syntax theory is the Justified Permeability Graph (abbreviated as J-Graph) which abstracts the spatial configuration to nodes and edges [10]. The term
‘justified’ here means the arrangement of a graph by defining one point as the root and assigning the other spaces stepwise by relative depth. Depth can be understood as the steps necessary to go from one space to another. This can be applied to distinct rooms as well convex spaces, meaning spaces in which any one point is visible from everywhere else in that space. The graph is the starting point of calculating the integration value and defining the space types.

The integration value describes the depth of a space in relation to all others in the system. It “has emerged in empirical studies as one of the fundamental ways in which houses convey culture through their configurations” [3]. The integration value is calculated according to Hanson and Hillier’s [2] theory as the reciprocal of the RRA value [11]. The integration value of the spaces is the deciding factor in the ranking order of the Spatial DNA, placing the most integrated space at the top, while the most segregated is at the bottom. To calculate integration values, a convex map of the layout was utilized. The multi-platform and open-source spatial network analysis software ‘depthmapX’ [12] is used to calculate the integration value according to Hanson and Hillier’s [2] theory.

Hillier [13] identifies four space types in a J-Graph which each have specific properties. An a-space is a terminal space which does not allow through-movement and is usually used as a room. B-spaces have more than one link and lead to one or more dead ends, and as such are thoroughfares. C-spaces have more than one link and are part of a ring, providing choice through an alternative way back. D-spaces are part of at least two rings and are commonly transitions.

2.1.2. A-Spatial Metrics. The first step in the definition of a-spatial metrics is the identification of functions for each space. To facilitate inferences of cultural connotations and a detailed understanding of what the usage of a space encompasses, information regarding general space-use sectors and activity types are used to elaborate each function. The use of activity types is building on the idea that culture can be broken down into activities, to obtain a more tangible concept of a culture’s substance [14]. The sectors of space use and activities therefore serve as a vehicle to understand sociocultural processes in the dwelling and relate them to their cultural context.

The sectors of space-use entail private, social and service sectors. Spaces of the private sector offer seclusion and intimacy for individuals or subgroups of the household; social sector spaces accommodate interaction among inhabitants and inhabitants and visitors; the service sector groups activities regarding the continuation and maintenance of the dwelling’s life. Functions and sectors are then refined by linking them to activities occurring in each space. The five activity types are covering all major activities occurring in the domestic setting and are religious, family, hosting, work and personal activities. This multilayered classification enables a substantial representation of what a specific function implies.

2.2. The Cases
The vernacular houses investigated in this paper are samples of typical traditional courtyard houses around Erhai lake in the Dali Bai Autonomous Prefecture. Although this is only representing one extract of the various typologies which developed in different regions in the Bai minority region, it is the most commonly found and most prominent example of Bai housing culture [15]. These dwellings were constructed in vernacular tradition up until the 1980s but underwent significant changes in the following decades. All vernacular (table 1) and modern cases (table 2) are located in the village Gushengcun.
Table 1. Floor plans of the vernacular cases.

| C1 | C2 | C3 |
|----|----|----|

Ground floor

* A (Attic), An (Animals), B (Bedroom), C (Corridor), CY (Courtyard), E- (Elders-), K (Kitchen), L (Living Room), S (Study), Sr (Storeroom).

Table 2. Floor plans of the modern cases.

| C4 | C5 | C6 |
|----|----|----|

Upper floor

Ground floor

* B (Bedroom), Ba (Bathroom), C (Corridor), CY (Courtyard), E- (Elders-), Gr (Guestroom), K (Kitchen), L (Living Room), S (Study), Sr (Storeroom).

In order to make meaningful comparison, only eight spaces per group were chosen to be examined. These include the attic, the bathroom, the bedroom, the corridor, the courtyard, the elders’ bedroom and living room, the kitchen and the living room. These spaces include all the rooms in which the main inhabitants are dwelling and the main activities are taking place.

3. Analysis and Results
After calculating and identifying the spatial and a-spatial metrics of the two groups of dwelling cases the data is implemented into the framework of the Spatial DNA. The integration is firstly calculated in depthmapX as seen in the convex maps in table 3 and table 4, in which red denotes a high and blue a low integration.
Table 3. Convex analysis of the vernacular cases.

| C1 | C2 | C3 |
|----|----|----|
| ![Diagram C1] | ![Diagram C2] | ![Diagram C3] |

* A (Attic), An (Animals), B (Bedroom), C (Corridor), CY (Courtyard), E- (Elders-), K (Kitchen), L (Living Room), S (Study), Sr (Storeroom).

Table 4. Convex analysis of the modern cases.

| C4 | C5 | C6 |
|----|----|----|
| ![Diagram C4] | ![Diagram C5] | ![Diagram C6] |

* B (Bedroom), Ba (Bathroom), C (Corridor), CY (Courtyard), E- (Elders-), K (Kitchen), L (Living Room).

The numerical integration values underlying the colours are subsequently exported and listed in table 5 and table 6 in order to create an integration ranking. The ranking order of the key functions - bedroom, elders’ bedroom and living room, kitchen, living room - displays strong similarities across all of the samples for each group of cases.

Table 5. Integration rank order vernacular cases.

| Rank Order Key Functions | Max   | Min   |
|--------------------------|-------|-------|
| C1 Elders L > Elders B > Living R > Bedroom = Kitchen | Courtyard 2.1507 | Attic 0.5197 |
| 1.2229 1.1340 1.0059 0.9900 | | |
| C2 Elders L > Elders B > Living R > Bedroom > Kitchen > Corridor | Attic 2.7248 | 0.6553 |
| 1.3275 1.2943 1.2627 1.2327 1.1766 | | |
| C3 Elders L > Elders B > Living R > Bedroom > Kitchen > Corridor | Attic 1.5212 | 0.4131 |
| 1.0942 1.0225 0.8663 0.8544 0.7606 | | |

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Table 6. Integration rank order modern cases.

| Rank | Key Functions | Max   | Min   |
|------|---------------|-------|-------|
| C4   | Elders L > Elders B > Living R > Kitchen > Bedroom Corridor > Bedroom | 0.7727 | 0.5177 |
| C5   | Elders L > Elders B > Living R > Kitchen > Bedroom Corridor > Laundry | 0.6812 | 0.3922 |
| C6   | Elders L > Elders B > Living R > Kitchen > Bedroom Corridor > WC | 0.7505 | 0.4181 |

The key differences in the spatial structure and implications are discussed according to the differences between the vernacular and modern cases as seen in the Spatial DNA (Table 7).

Table 7. The Spatial DNA of vernacular and modern Bai dwellings.

3.1. Courtyard
The courtyard, although in the second position in both the vernacular and the modern cases, changed in regard to work activities, which are not conducted there anymore. Its integration relative to the corridor also decreased and is in the modern Bai dwellings closer to the elders’ living room, as opposed to the integration-wise proximity to the corridor in vernacular Bai courtyard houses. As there is only one living room remaining which is facing the courtyard, it is now a ‘b’ space, meaning a thoroughfare which is not located on a ring anymore, and its social function decreased. It is nevertheless a space that connects the dwelling with itself and to the outside.
3.2. Bedrooms
The changes regarding the spatial location of the bedrooms are the most striking. Apart from the elders’ bedrooms on the ground floor of the Bai dwellings – in the cases where they were still in use and not replaced by a guestroom as in C5 – all other bedrooms significantly decreased in integration value and are now at the bottom of the integration ranking. The bedrooms used to be connected to the adjacent living room and the courtyard, resulting in relatively high integration values and well-connected space types. Now being on the upper floor, the prevalent space type changed from ‘c’ into ‘a’, as all the upper floor bedrooms are dead ends. At the same, although still adjacent to the living room, the two functions became separated integration-wise.

3.3. Kitchen
The kitchen, which was the most segregated key function space in the vernacular Bai dwellings, is less segregated in the contemporary dwellings. Although still in the lower third regarding the overall ranking, the change is relevant because of the bedroom position, which it overtook in terms of integration. It is especially interesting when thinking about the floor plans, in which the kitchen stayed in a very similar position adjacent to the courtyard, yet due to the changed surroundings, it underwent a change in the spatial integration. On the other hand, family and personal activities are removed from the kitchen space, leaving it as a space purely for cooking as a type of housework. While it was a social space in the vernacular dwellings, it is now categorized as a service space. Spaces for work activities also decreased leaving the kitchen and corridor as spaces which still accommodate certain types of work or housework.

4. Discussion
The results of the analysis are discussed in regard to sociocultural meaning and inferences are corroborated by findings in literature. The following three aspects serve to illustrate the sociocultural mechanisms governing the shaping of spatial configurations and as such the differences between the groups of cases as highlighted in the Spatial DNA.

4.1. Means of Subsistence
Vernacular dwellings were optimized to meet the needs of people, including, for a large part, work activities. Now, work and private life become more and more separated. The transition from work in the primary industries, such as farm work or fishing, to working in the secondary and tertiary sector [16] also had an impact on the usage of space in the dwellings. It is not necessary anymore for the spatial structure to revolve around farm produce. Due to the decreased importance of farming, large, well-integrated courtyard spaces become less necessary, which is reflected in the decreased integration value as seen in the Spatial DNA. The attic which was used to store goods, is not built anymore, the courtyard is starting to be used more as a garden for recreational activities. In the vernacular dwellings, remnants of agricultural life can still be found, while the contemporary dwellings lay a greater focus on the aesthetics and comfort of the courtyard.

4.2. Social Structure
Regarding the kitchen spaces, it is tempting to assess the role of women in relation to the spatial structure beyond practical reasons of climate and construction. In premodern China, as in most traditional societies, the kitchen was seen as the women’s domain [17, 18]. Women were furthermore often excluded from the public sphere [19]. Confucian values embedded in the configuration of Chinese courtyard dwellings appear to place great emphasize on the separation of genders, which can be clearly seen in the larger complexes in northern China [20]. The extent to which gender separation was regarded as a cultural core value in traditional China is underpinned by early Chinese historians who used examples of other cultures lacking such features to distinguish their own identity [21]. If we continue the thought process of the kitchen as a representation of the gender separation in traditional Chinese society, the abandonment of it could be paralleled with the increased integration of the
kitchen space. Other studies seem to validate this assumption as they have also found correlations between the improvement of the women’s status in the dwelling and the rising integration value of the kitchen space, concluding that the occupation of the kitchen by both men and women in contemporary society is directly reflected in the spatial structure [22].

4.3. Conceptions of Privacy
In traditional societies the unit of privacy is commonly the entire family or subgroups within it rather than the individual [23] as in these cultural groups “privacy is very often a shared experience” [19]. Separation of different subgroups in this study is most obvious regarding the living rooms and bedrooms of different generations, mirrored by different levels of integration. The space of the patriarch as the head of the family is reflected in the high integration of the elders living room and bedroom, showing that privacy of the bedroom, created through spatial segregation, was subordinate to the centrality of the main living room. The private sectors of the vernacular dwellings are located in either ‘c’ or ‘a’ spaces. The predominance of ‘c’ spaces is coherent with the smaller emphasis on personal privacy.

The rising demand for privacy and seclusion, while in China still not as important as in western Cultures [24], seems to have an impact on the preferred location of the younger generations’ bedrooms. Regarding the low integration values with the bottom position in the ranking and the ‘a’ space type in contemporary Bai dwellings, it would be suitable to speak of strong privacy, although the adjacency to the upper floor living room still limits the actual perceived privacy. Noticeable is also the generational difference in that the elder’s bedroom still has somewhat well integrated bedrooms, clearly showing the trend towards more individual privacy is more pronounced in the second generation.

5. Conclusions
Space syntax techniques are applied within the concept of a Spatial DNA to quantify the evolution of Bai people’s courtyard houses. The measurable differences between the two stages reveal parallels to sociocultural changes:

(1) Decreasing integration and change of space type from rings to sequences of the courtyard, which in vernacular dwellings was a key space in the processing of agricultural produce, coincides with a shift from agricultural work to secondary and tertiary sector jobs.

(2) The segregation of bedrooms and change of space types from c-spaces to dead ends in modern dwellings appear to be related to modern conceptions of privacy and individualism which are replacing the family as a unit of privacy.

(3) Increasing integration of the kitchen is interpreted in the context of abolished gender separation which was an important cultural characteristic of pre-modern China.

While this study focused on the differences in the two stages of Bai people’s dwellings, an additional focus on the continuities could facilitate a discussion about spatial heritage. The findings could serve as a rational basis for the preservation of vernacular dwellings beyond the often solely considered architectural form and decoration, in terms of their spatial structure and the connotations it carries. It furthermore serves to illustrate the cultural and spatial heritage these vernacular dwellings passed on, and to what extent they can be found in contemporary houses. Such a comparison of the past and the present enables us to reevaluate the aspects we consciously strive to preserve and pass on to future generations.
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