

县级城市居住街区空间形态地域特征的时空差异研究
——以庆城县、武安市、长兴县、连江县、金堂县为例

Research on the Spatial–Temporal Changes of Regional Morphology of
Residential Neighborhoods in County-Level Cities of China:
Cases Studies on Qingcheng County, Wu’an City, Changxing County, Lianjiang
County, and Jintang County

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摘要

城市粗放式开发促使城镇特色丢失，并促使人居环境愈发趋向“干城一面”。为此，本研究以位于中国不同气候区的县级城市为研究对象，以其居住街区空间形态为切入点，借助ArcGIS 10.2、SPSS 22与Origin 2021软件对60个代表性居住街区的空间形态以12个形态学指标进行主成分分析与相关性分析，借此判别、描述并解读了地域特征的时空差异。研究表明：1）60个样本街区的建设年代与中国住房制度改革的历史变迁存在一定协同性；2）不同气候区的县级城市居住街区空间形态存在差异，可借助街区形状、开发强度、街区规模、平面秩序和聚集程度5个表征因子进行描述；3）同一气候区的县级城市居住街区空间形态在不同时期存在差异，主要表现在建筑密度、街区面积和绿地率这三个形态学指标上，而不同气候区的县级城市居住街区空间形态在同一时期也存在显著差异，主要表现在绿地率、建筑角度紊乱度和建筑距离紊乱度这三个形态学指标上；4）县级城市居住街区空间形态地域特征的时空差异与住房政策制度、气候条件、居住建筑布局方式、城市自身发展进程等因素有关，为未来的政策、规划、建设等提供了尊重地域差异的参考依据。

关键词

空间形态；中国县级城市；居住街区；地域差异；主成分分析；相关性分析

ABSTRACT

The extensive growth in most Chinese cities at the expense of local identities of living settlement. Taking the 60 residential neighborhoods in county-level cities of varied climate zones in China as examples, this paper explores their spatial–temporal changes and differences in morphology, based on 12 morphological indicators through Principal Component Analysis and correlation analysis by ArcGIS 10.2, SPSS 22, and Origin 2021. The results show that 1) the construction dating of the 60 sample neighborhoods conforms to the development of China’s housing reform; 2) the spatial morphology of residential neighborhoods in county-level cities of different climate zones could be charaterized by 5 factors, i.e. neighborhood shape, development intensity, neighborhood size, layout order, and aggregation degree; 3) the disparities in the spatial morphology of residential neighborhoods in the same climate zone in different period of time are mostly indicated with 3 morphological indicators, i.e. Building Density, Neighborhood Area, and Green Space Ratio; rather, the morphology of residential neighborhoods built during a same period of time varies largely between climate zones, mainly indicated with Green Space Ratio, Degree of Building Angle Disorder, and Degree of Building Distance Disorder; and 4) China’s housing policies, climatic conditions, residential building patterns, and the urbanization of each city together influence the spatial–temporal changes in the spatial morphology, offering references to policy making, planning, and construction to protect the regional characteristics in the future.

KEYWORDS

Spatial Morphology; County-Level Cities in China; Residential Neighborhoods; Regional Differences; Principal Component Analysis; Correlation Analysis

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1 研究背景

随着中国经济的快速增长和城镇化的快速推进，城镇面貌已发生巨大改变。而大规模的城市扩张与粗放式的城市开发致使城镇特色丢失、城市面貌雷同等问题接踵而至^[1]。相较于大城市，县级城市相对滞后的发展阶段使它们在当前人居环境趋向“千城一面”的时代背景下保留了更多地方特征和自我个性^{[2][3]}。中国政府强调在提升城市人居环境质量的同时，应注重优化各地城乡人居环境的地域风貌特色^{[4]-[6]}。居住街区^①是人居环境建设和城市景观的重要组成部分^{[7]-[9]}，随着对地域环境的长期顺应和利用，居住街区的空间形态又成为反映地域特征的重要研究视角：有研究表明城市街区的空间形态因受地域气候^[10]、地形^[10]、历史^[11]、经济^[12]、政策^[12]等方面的综合影响，而易在时间维度上呈现出一定的连续性变化特征，在空间维度上则容易表现出相对稳定的地域差异——尤其是在那些保留着较多地域特色风貌的县级城市。因此，针对县级城市居住街区的空间形态的时空差异研究有助于推进城乡人居环境的地域特征的保持。

近年，陈飞等人通过建筑类型学分析进行了城市肌理研究^[13]，韩添从城市街区尺度出发分析了城市结构、街道系统等历史演变特征^[14]。也有学者通过康泽恩的城市形态学（Urban Morphology）进行实证定性研究：1）在街区层面，侧重于对街区内部建筑及其围合空间的形态特征、演变规律及内在机制的研究^{[15]-[17]}；2）在城市层面，以总结城市空间形态、结构、模式特征，探讨其空间演变动力为主^{[18]-[20]}；3）在区域层面，通过对宏观尺度的区域空间形态、空间结构的对比和分析，探讨地理、经济、历史对城市形态的影响^{[21]-[23]}。这些成果虽然从街区—城市—区域尺度逐渐丰富了城市街区空间形态的研究，但针对城市居住街区的空间形态，尤其是对不同地域的城市居住街区空间形态的时空差异与变化规律尚鲜有探讨。

因此，文章以中国县级城市居住街区的空间形态为研究对象，将甘肃省庆城县、河北省武安市、浙江省长兴县、福建省连江县、四川省金堂县这5个县级城市作为研究案例，从街区尺度出发，借助12个形态学指标定量分析了上述县级城市中60个居住街区的空间形态差异及表征因子，及其在城市发展过程中展现出的历时性变化，试图总结决定县级城市居住街区空间形态地域特征的主要影响因素，以为具有地域特色的人居环境保护与建设提供科学依据。

① 2018年发布的《城市居住区规划设计标准》规定，居住街区（街坊）是构成城市居住区的基本单元，一般由城市道路或用地边界线围合。

① According to the Standards for Urban Residential Areas Planning and Design issued in 2018, residential neighborhoods in China, usually enclosed by city roads or the boundaries of urban developments, are the basic units of residential communities of a city.

1 Research Background

With the rapid economic growth and aggressive urbanization process, the spatial construction of most Chinese cities has undergone profound changes losing their own identities^[1]. In contrast with large cities, such spatial homogenization has less witnessed in county-level cities, where locality and distinctiveness remain due to their relatively slow development^{[2][3]}. Chinese government stressed that in the current urbanization the improvement of living environment should be realized by protecting vernacular qualities^{[4]-[6]}. Residential neighborhoods^① are an important part of cities' living environment and urban landscapes^{[7]-[9]}. The spatial pattern of residential neighborhoods, as a result of long-term adaptive utilization of environmental resources, offers a perspective for the research on regional characteristics of climate^[10], topography^[10], history^[11], economy^[12], and policy^[12]. The spatial pattern of urban neighborhoods—particularly to the county-level cities where vernacular qualities are well preserved—often shows the persistence over a long period of time with an outstanding variety of physical environment. Thus the research on the spatial-temporal changes of the regional morphology of residential neighborhoods in county-level cities will help improve the regional persistence of living environmental construction in China.

Chen Fei et al. studied urban fabrics from the perspective of Architectural Typology^[13]. Han Tian analyzed the diachronic transformation of urban physical structures and street systems at the neighborhood scale^[14]. Existing empirical qualitative research under M. R. G. Conzen's Urban Morphology was conducted at varied scales: 1) at the community/neighborhood/block scale, the research studied the morphological characteristics, patterns, and evolution mechanism of the buildings within blocks as well as the enclosed spaces^{[15]-[17]}; 2) at the city scale, the research summarized the characteristics of urban spatial morphology, structures, and patterns, and discussed about the driving factors of city spatial evolution^{[18]-[20]}; and 3) at the regional scale, the research explored the impact of geography, economy, and history on urban morphology through comparative analysis of the regional spatial forms and structures^{[21]-[23]}. These findings improve the cross-scale research on the spatial forms of urban neighborhoods, but there is still a research gap in the spatial-temporal changes and patterns of the morphology of urban residential neighborhoods in different regions.

This paper studies the spatial morphology of 60 residential neighborhoods in 5 county-level cities of China, namely Qingcheng County in Gansu Province, Wu'an City in Hebei Province, Changxing County in Zhejiang Province, Lianjiang County in Fujian Province, and Jintang County in Sichuan Province. A total of 12 morphological indicators are introduced for a quantitative analysis of the differences in spatial morphology and the corresponding characterization factors, as well as the diachronic transformation of the 60 residential neighborhoods. This paper aims to explore the determining factors to the regional spatial morphology of residential neighborhoods in county-level cities and to provide suggestions for the protection and construction of living environment in China.

2 研究对象与方法

2.1 研究城市筛选

由于空间形态的形成是人类对地域环境的长期适应和利用的结果^[24]，地域环境中的气候^[25]、地形^[26]又是影响城市空间形态特征的重要因素。因此，为保障研究城市的气候、地形特征的多样性，本研究根据《建筑气候区划标准》（GB50176-93）中的中国建筑气候区划，从寒冷地区、夏热冬冷地区和夏热冬暖地区三个气候区（胡焕庸线以东人口主要分布区域^[27]，一定程度上能反映中国城镇的主要发展特征）中选择研究样本。而秦岭—淮河以南的夏热冬冷与夏热冬暖地区在属性上可以划分为湿热地区^[28]，其与寒冷地区存在较大气候差异。故结合两大气候区内主要的地形地貌类型和数据可获取性，最终选择了5个县级城市作为研究案例，分别为：寒冷地区中高原地形的甘肃省庆城县、平原地形的河北省武安市（后文简称“寒冷地区城市”）；湿热地区中平原地形的浙江省长兴县、盆地地形的四川省金堂县和丘陵地形的福建省连江县（后文简称“湿热地区城市”）。在后续研究中将主要分为这两种差异较为明显的地域进行比较分析。

2.2 研究方法

研究基于案例城市2017年中心城区地形图（各县自然资源局获取）、1993~2018年谷歌卫星影像图（“谷歌地球”官方网站获取）、航拍图（2020年9月由作者操作拍摄）、相关历史资料等数据，利用ArcGIS 10.2矢量化处理地理信息，计算了能反映县级居住街区空间形态地域特征的12个形态学指标，并借助SPSS 22与Origin 2021对主要影响因素进行提取与分析，以探究县级城市居住街区空间形态的空间差异与变化规律。

2.2.1 样本街区筛选与建设年代识别

本研究分别在5个案例城市的中心城区范围中，利用ArcGIS 10.2对以城市主要道路为边界的居住街区的空间属性进行识别，以挑选能够反映城镇整体居住街区空间特征的代表性街区。其中，空间属性旨在描述街区形状特征及位置特征。研究选择街区圆形率^[29]（高、中、低三个等级）、临水与否以及地处新城或老城这3个指标对中心城区居住街区进行计算，随后将居住街区的空间属性进行排列组合，获得12组街区^②，而后按各空间属性分组数量占各个县级城市总居住街区的比例，以各县占比最低的符合条件的居住街区分组抽取2个为基准进行计算，确定各组选择的街区数量，并在各组街区内按确定数量进行随机挑选，最终从5个县级城市共计481个居住街区中挑选出了60个居住街区样本：庆城县13个、武安市13个、长兴县10个、连江县12个、金堂县12个（图1）。这一样本数量与相关研究的样本数量比较符合^{[30][31]}，可用于统计学分析。

2 Sample Selection and Methodology

2.1 Selection of Sample County-level Cities

Spatial morphology is the result of human beings' long-term adaptive utilization of the regional resources^[24], wherein climate^[25] and topography^[26] factors are the major causalities. To cover as more climate zones and topographic types as possible, this research selected study samples from the cold zone, hot-summer and cold-winter zone, as well as hot-summer and warm-winter zone according to the Building Climate Zoning Standards (GB50176-93) released in 1993—all of which are populated areas east of the Hu's Line^[27] and representative in the development characteristics of contemporary Chinese cities and towns. The latter two climate zones, in contrast with the former one, can be further considered the hot and humid zone^[28] ("hot zone" hereafter). Taking the main landform types and data availability into account, 5 county-level cities were selected for case studies, namely Qingcheng County (plateau) and Wu'an City (plain) in cold zone; and Changxing County (plain), Jintang County (basin), and Lianjiang County (hilly area) in hot zone.

2.2 Methodology

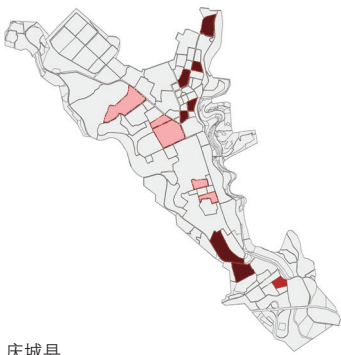
The research employed the maps of central town areas in 2017 sourced from the Natural Resources Bureau of each county, Google satellite images from 1993 to 2018 via Google Earth, aerial images taken by the authors in September 2020, and historical text materials about these sample cities. Processed with ArcGIS 10.2, 12 morphological indicators were selected to study the regional spatial morphology of residential neighborhoods, and determining factors were identified followed by the analysis with SPSS 22 and Origin 2021, thus to explore the morphological changes and diachronic transformation of the studied residential neighborhoods.

2.2.1 Selection of Sample Neighborhoods and Construction Dating

In order to select morphologically representative residential neighborhoods for each town, ArcGIS 10.2 was used to identify the spatial attributes of the residential neighborhoods bordered by main city roads in central town areas of the 5 cities. Three indicators, i.e. Circularity Ratio^[29] (at high-, medium-, and low-level) of the neighborhood, waterfront or not, and in the new or old downtown, were adopted to form 12 groups of the screening frame^②. The number of neighborhoods selected for each group was determined by the proportion of the neighborhoods in each spatial attribute group to the total residential neighborhoods of each city. Chosen randomly on the basis of two samples at least for the lowest-percentage residential neighborhoods of each city (excluding the non-available ones), a total of 60 residential neighborhoods samples out of 481 in the 5 cities were selected: 13 in Qingcheng, 13 in Wu'an, 10 in Changxing, 12 in Lianjiang, and 12 in Jintang (Fig. 1). The quantity is capable in statistics, corresponding to the sample size of previous studies^{[30][31]}.

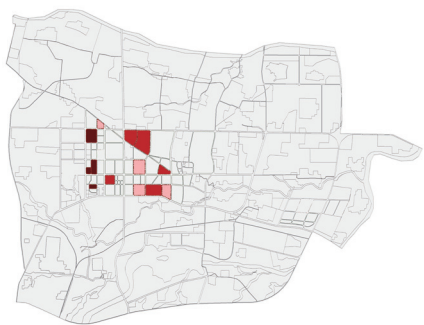
② 根据三个指标进行排列组合，形成包括高圆形率、临水、新城，高圆形率、临水、老城，高圆形率、未临水、新城，高圆形率、未临水、老城等在内的共计12组街区。

② There are 12 combinations among the three indicators. For example, group one: high Circularity Ratio, waterfront, and new downtown; group two: high Circularity Ratio, non-waterfront, and new downtown; group three: high Circularity Ratio, non-waterfront, and old downtown....



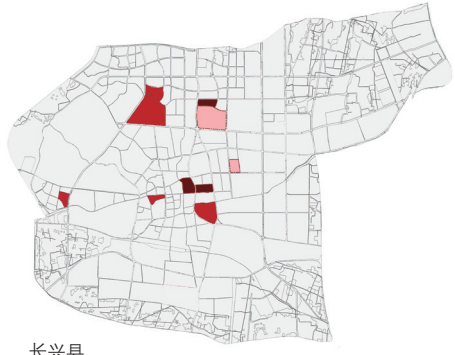
庆城县
Qingcheng County

0 1 2 4km



武安市
Wu'an City

0 1 2 4km



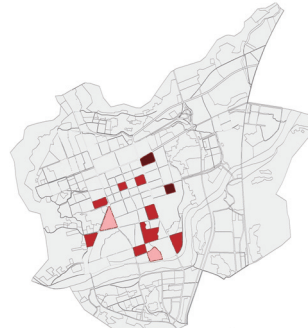
长兴县
Changxing County

0 2 4 8km



金堂县
Jintang County

0 2 4 8km



连江县
Lianjiang County

0 1 2 4km

样本街区建设年代分期
Construction dating of the
sample neighborhoods

时段一 Period 1
时段二 Period 2
时段三 Period 3

1. 研究所选的样本街区及其建设年代分期

1. The sample neighborhoods and the corresponding construction dating

其次，研究通过对比1993~2018年期间谷歌卫星地图及查阅相关文献^{[32][33]}，对样本街区建设年代进行了分期，以分析样本街区形态演变背后的历史、经济、政策等因素。

接着，基于既往文献形态量化与表征研究^{[34]-[40]}，选取了能够反映城市居住街区的空间形态特征的12项形态学指标（表1），以便初步计算具体数值，用以量化表征居住街区空间形态特征。

2.2.2 统计分析

研究基于60个样本街区的形态学指标的计算结果，借助SPSS 22、Excel表格和Origin 2021来检验指标之间的相关性，并实现对主要影响因素的提取与分析，以从统计学角度探究县级城市居住街区空间形态的时空差异与变化规律。

3 研究结果与分析

3.1 样本街区建设年代分期与分析

在本研究中，60个样本街区的建设年代可分为3个时期（图1）：

时段一：1994年前，包括庆城县5个，武安市4个，金堂县、连江县、长兴县各2个。

By comparing the satellite maps of Google Earth from 1993 to 2020 and document review^{[32][33]}, the sample neighborhoods were grouped by their construction years to analyze the historical, economic, and policy factors during the time span.

Referring from existing quantitative morphological tools and characterization research on urban morphology^{[34]-[40]}, 12 morphological indicators (Table 1) were selected to quantitatively study the spatial morphology of residential neighborhoods.

2.2.2 Statistical Analysis

SPSS 22, Excel, and Origin 2021 were employed to test the correlations among the morphological indicators of 60 sample neighborhoods. Statistically, determining factors are identified and analyzed to explore the spatial-temporal changes and diachronic transformation of the morphology of residential neighborhoods in the cities.

3 Research Results and Analysis

3.1 Construction Dating of the Sample Neighborhoods

The 60 sample neighborhoods can be grouped by their construction years (Fig. 1):

1) Before 1994 (Period 1): 5 in Qingcheng, 4 in Wu'an, and 2 in Jintang, Lianjiang, and Changxing each;

表1：城市居住街区空间形态学指标的定义与计算公式
Table 1: Definition and formula of each morphological indicator for the urban residential neighborhoods

编号 No.	指标名称 Indicator	指标定义 Definition	计算公式 Formula
1	街区面积 Neighborhood Area	街区所占空间的大小，反映居民的活动范围与规模（来源：参考文献[34]） The area occupied by the neighborhood, indicating the scope and scale of the residents' activities [Source: Ref. [34]]	—
2	周长 Perimeter	街区边缘的长度，即所有边长的总和，反映街区边缘复杂程度（来源：参考文献[35]） The total length of the neighborhood boundary, indicating the complexity of the neighborhood edges [Source: Ref. [35]]	—
3	建筑密度 Building Density (BD)	街区内建筑物基底面积与街区面积的比率，反映街区范围内的空地率和建筑密集程度（来源：参考文献[36]） Ratio of building area within the neighborhood, indicating the vacant ratio and building density within the neighborhood [Source: Ref. [36]]	$BD=A_{\text{建筑}}/A_{\text{街区}}$ 式中， $A_{\text{建筑}}$ 表示街区建筑基底面积， $A_{\text{街区}}$ 表示街区面积 $BD=A_{\text{building}}/A_{\text{neighborhood}}$ A_{building} is the building area and $A_{\text{neighborhood}}$ is the neighborhood area
4	绿地率 Green Space Ratio (GR)	街区内各类绿地面积总和与街区面积的比率，是街区空间对环境的调节能力的反映（来源：参考文献[34]） The ratio of the total area of all types of green spaces in the neighborhood, indicating the environmental regulation capacity of the neighborhood [Source: Ref. [34]]	$GR=A_{\text{绿地}}/A_{\text{街区}}$ 式中， $A_{\text{绿地}}$ 表示街区绿地面积， $A_{\text{街区}}$ 表示街区面积 $GR=A_{\text{green}}/A_{\text{neighborhood}}$ A_{green} is area of the green spaces and $A_{\text{neighborhood}}$ is the neighborhood area
5	庭院空间率 Courtyard Space Ratio (CSR)	街区铺装、绿地、水体所占的比例，是对建筑单体外部空间形态布局疏密的重要反映（来源：参考文献[35]） The ratio of paving, green spaces, and water bodies, indicating the density of the neighborhood's spatial layout [Source: Ref. [35]]	$CSR=A_{\text{庭院}}/A_{\text{街区}}$ 式中， $A_{\text{庭院}}$ 表示街区庭院空间面积， $A_{\text{街区}}$ 表示街区面积 $CSR=A_{\text{courtyard}}/A_{\text{neighborhood}}$ $A_{\text{courtyard}}$ is the area of the paving, green spaces, and water bodies, and $A_{\text{neighborhood}}$ is the neighborhood area
6	紧凑度 Compactness Ratio (COR)	街区形状特征的测度，反映了街区饱满程度，一般将圆形视为最紧凑的特征形状（来源：参考文献[37][39]） A measurement of the typological characteristics of the neighborhood, where a circular shape is considered the most compact [Source: Ref. [37][39]]	$COR=2\frac{\sqrt{\pi A}}{P}$ 式中， P 表示街区周长， A 表示街区面积 P is the neighborhood perimeter and A is the neighborhood area
7	景观形状指数 Landscape Shape Index (LSI)	街区形状与相同面积的圆或正方形之间的偏离程度，反映街区轮廓的方正程度（来源：参考文献[38]） The degree of deviation between the shape of the neighborhood and a circle or square of the same size, indicating the squareness of the neighborhood's typology [Source: Ref. [38]]	$LSI=0.25P/\sqrt{A}$ 式中， P 表示街区周长， A 表示街区面积 P is the neighborhood perimeter and A is the neighborhood area
8	分维数 Fractal Dimension (FD)	街区斑块或景观镶嵌体几何形状复杂程度，反映街区内外环境及自然地理条件对街区边界的干扰程度（来源：参考文献[39]） The geometry complexity of the patches or landscape mosaics in the neighborhood, indicating the interference degree of the neighborhood boundary by environmental or geographical factors inside or outside the neighborhood [Source: Ref. [39]]	$FD=\frac{2\ln(\frac{P}{A})}{\ln A}$ 式中， P 表示街区周长， A 表示街区面积 P is the neighborhood perimeter and A is the neighborhood area
9	建筑角度紊乱度 Degree of Building Angle Disorder (DAD)	建筑单体的朝向角度差均值，反映建筑单体的方向特征（来源：参考文献[35]） The mean value of angle difference of building orientation between the building units, indicating the building's orientation characteristic [Source: Ref. [35]]	$DAD=AVERAGE\sum_{i=1}^n A_i-A_a $ 式中， A_i 表示第 <i>i</i> 栋建筑朝向角度， A_a 表示与 <i>i</i> 栋相邻建筑朝向角度 A_i is the orientation angle of the <i>i</i> -th building and A_a is the angle difference from its adjacent building
10	建筑面积紊乱度 Degree of Building Area Disorder (DBA)	建筑单体间面积差值均值，反映建筑单体平面轮廓大小的变异程度（来源：参考文献[35]） The mean difference of the area between building units, indicating the variation degree of the building's layout [Source: Ref. [35]]	$DBA=AVERAGE\sum_{i=1}^n A_i-A_a $ 式中， A_i 表示第 <i>i</i> 栋建筑面积， A_a 表示与 <i>i</i> 栋相邻建筑的面积 A_i is the building area of the <i>i</i> -th building and A_a is the area of its adjacent building
11	建筑距离紊乱度 Degree of Building Distance Disorder (DBD)	建筑单体间最小距离标准差，反映街区建筑单体外部空间的大小（来源：参考文献[35]） The standard deviation of the minimum distance between building units, indicating the area of the building's external space [Source: Ref. [35]]	$DBD=\sqrt{1/n\sum_{i=1}^n(D_i-\mu)^2}$ 式中， D_i 表示相邻建筑几何中心直线距离， μ 表示距离的算术平均值 D_i is the straight-line distance between the geometric centers of adjacent buildings, and μ is the arithmetic mean distance
12	混合功能 Functional Mixture (MIX)	街区面积中各类功能的建筑面积在总建筑面积中的比率，是街区空间活力及利用率的重要反映（来源：参考文献[40]） The ratio of the floor area of "mixed-uses" and "buildings of varied age and condition" within the total gross floor area of a neighborhood, indicating the vitality and utilization rate of the neighborhood spaces [Source: Ref. [40]]	$MIX=-\sum_{i=1}^n P_i * \ln P_i$ 式中， P_i 是第 <i>i</i> 个功能类型的比例 P_i is the proportion of the <i>i</i> -th functional type

时段二：1994~2010年，包括庆城县1个，武安市5个，金堂县5个，连江县8个，长兴县5个。

时段三：2011~2018年，包括庆城县7个，武安市4个，金堂县5个，连江县2个，长兴县3个。

另外，可以发现同一时期不同县级城市的建设进度与更新速度存在差异。庆城县与武安市在时段一建设的居住街区多于其他三个县级城市；庆城县时段二期间建设的街区数量较少，2010~2018年期间较多；连江县、长兴县的时段二期间建设的街区在3个时期中数量最多。研究进一步发现，这3个时期与中国的住房制度改革的历史变迁具有一定协同性。1978~1993年，是以“出售公房”为主的住房商品化探索阶段，1994~2010年，为中国住房商品化推进与建设阶段，2011~2018年，则是中国房地产市场规范阶段。^{[32][33][41]}

3.2 形态学指标计算与地域差异表征因子分析

样本街区形态学指标的计算结果显示（表2），不同样本街区的空间形态存在不同程度的差异，很难判定居住街区空间形态时空差异的主要影响因素，不利于客观评价样本街区空间形态的时空差异；且鉴于各指标之间可能存在强相关性（如绿地率与建筑密度、景观形状指数与分维数），因此并不适合直接利用这12项指标展开后续地域差异的表征因子分析，需要借助主成分分析（PCA）进行影响因素降维。

2) From 1994 to 2010 (Period 2): 1 in Qingcheng, 8 in Lianjiang, and 5 in Wu’an, Jintang, and Changxing each;

3) From 2011 to 2018 (Period 3): 7 in Qingcheng, 4 in Wu’an, 5 in Jintang, 2 in Lianjiang, and 3 in Changxing.

The construction dating shows that the studied cities differed in construction and renewal speed during a same period of time. Qingcheng and Wu’an built more residential neighborhoods in Period 1 than the other three cities. In Qingcheng, a small number of residential neighborhoods were constructed in Period 2, but a larger in Period 3. It also sees most construction of residential neighborhoods in Lianjiang and Changxing took place in Period 2. Moreover, the findings suggest that the three periods of time conform to the stages of China’s housing reform: China’s housing marketization had started its exploration during 1978 to 1993 in form of public housing development, witnessed a boost in construction from 1994 to 2010, and grown into a mature real estate market since 2011.^{[32][33][41]}

3.2 Calculation of the Morphological Indicators and Analysis of the Characterization Factors of Regional Morphology

The calculation results of the indicators of the sample neighborhoods (Table 2) reveal a significant disparity and complexity in spatial morphology, which little inform the identification of the causalities. In addition, seeing the strong correlations between the indicators (such as GR–BD and LSI–FD), this paper applied the Principal Component Analysis (PCA) to reduce the dimensionality of the data set consisting of a large number of interrelated variables to facilitate follow-up analysis.

表2：部分样本街区的形态学指标计算结果
Table 2: Calculations of morphological indicators for parts of sample neighborhoods

编号 No.	指标名称 Indicator											
	街区面积 Neighborhood Area	周长 Perimeter	建筑密度 BD	绿地率 GR	庭院空间率 CSR	紧凑度 COR	景观形状指数 LSI	分维数 FD	建筑角度紊乱度 DAD	建筑面积紊乱度 DBA	建筑距离紊乱度 DBD	混合功能 MIX
街区1 Neighborhood 1	-0.759	-1.127	-0.499	-1.023	0.497	0.587	-0.541	-0.480	-2.633	4.122	-0.597	1.397
街区2 Neighborhood 2	-0.411	-0.385	-1.511	1.642	1.510	0.105	-0.077	0.120	-0.191	-0.462	-0.139	1.397
街区3 Neighborhood 3	-0.627	-0.805	-0.667	-0.947	0.666	0.265	-0.309	-0.480	-3.029	3.247	-0.587	-0.066
街区4 Neighborhood 4	-0.776	-1.114	-0.246	0.119	0.244	-0.217	0.039	0.120	-0.064	-0.233	-0.471	-2.168
街区5 Neighborhood 5	-0.790	-1.207	0.681	-0.947	-0.685	0.587	-0.541	-0.480	-0.103	-0.271	-0.796	-0.216
街区6 Neighborhood 6	0.402	0.445	0.007	0.043	-0.010	1.069	-0.889	-0.480	0.037	-0.188	-0.318	1.172

首先，基于斯皮尔曼相关性分析得出的相关性矩阵数据，借助 Excel生成相关性分析热力图（图2）。结果表明，在相关关系上，街区面积与周长呈**强正相关**（ $\rho=0.977$ ），与建筑距离紊乱度呈**中度正相关**（ $\rho=0.494$ ）；景观形状指数与分维数（ $\rho=0.949$ ）呈**强正相关**，与建筑角度紊乱度（ $\rho=-0.444$ ）呈**中度负相关**；周长与建筑距离紊乱度呈**中度正相关**（ $\rho=0.486$ ）；紧凑度与建筑角度紊乱度（ $\rho=0.425$ ）呈**中度正相关**；绿地率与建筑距离紊乱度（ $\rho=0.517$ ）、庭院空间率（ $\rho=0.551$ ）呈**中度正相关**；建筑密度与绿地率（ $\rho=-0.550$ ）、建筑距离紊乱度（ $\rho=-0.414$ ）呈**中度负相关**；建筑密度与庭院空间率（ $\rho=-1.000$ ），以及紧凑度与景观形状指数（ $\rho=-0.995$ ）、分维数（ $\rho=-0.943$ ）呈**强负相关**；分维数与建筑角度紊乱度呈**中度负相关**（ $\rho=-0.428$ ）；建筑距离紊乱度与庭院空间率呈**中度正相关**（ $\rho=0.414$ ）；建筑面积紊乱度与建筑距离紊乱度呈**弱正相关**（ $\rho=0.297$ ）。以上结果验证了上述变量之间存在高度共线性，不具备统计学意义。其他指标之间则不存在显著的相关性，意味着这些指标之间相互独立，可独自反映某一方面的形态特征。

接着，利用SPSS 22对12项形态学指标进行主成分分析，研究将选取特征根大于等于1的成分；运用KMO和Bartlett球形检验进行因子分析的实用性检验，经检验，KMO检测系数为0.618，大于0.6，符合统计学要求；Bartlett球形检验的 p 值为0.00（满足 $p<0.01$ ），说明这些指标具有强相关性且相互独立，符合因子分析条件。

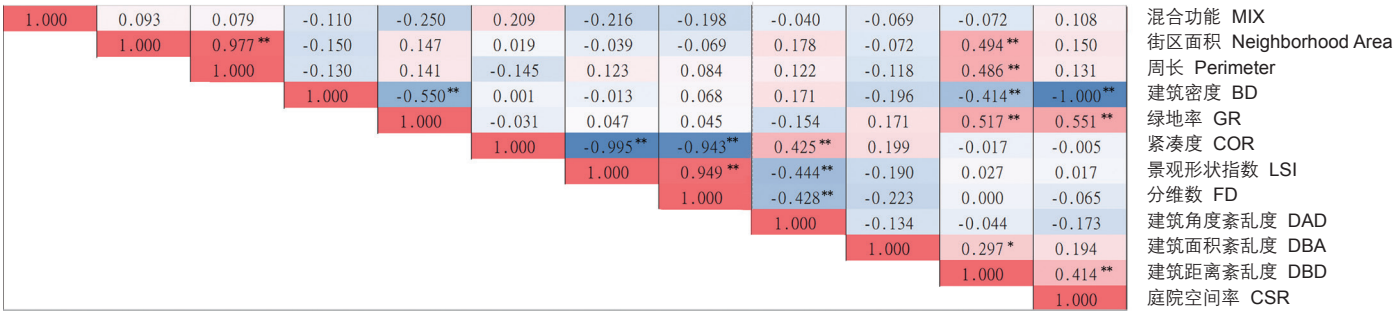
根据总方差解释表（表3），发现特征根大于1、影响样本街区空间形态差异性的主成分有5个，累积方差贡献率为87.42%；对5个主成分进行旋转成分分析（表4），结合其与形态学指标的相关系数，研究将同时期背景中，影响县级城市居住街区空间形态地域差异的主要因素整合 / 解释为：

A Correlation Heat Map (Fig. 2) was generated based on the matrix data obtained from Spearman’s correlation analysis. The results show that Neighborhood Area is in a strong positive correlation with Perimeter ($\rho=0.977$) and a moderate positive correlation with DBD ($\rho=0.494$); LSI is in a strong positive correlation with FD ($\rho=0.949$) and a moderate negative correlation with DAD ($\rho=-0.444$); Perimeter and DBD are in a moderate positive correlation ($\rho=0.486$); COR is in a moderate positive correlation with DAD ($\rho=0.425$); GR is in a moderate positive correlation with DBD ($\rho=0.517$) and CSR ($\rho=0.551$); BD is in a moderate negative correlation with GR ($\rho=-0.550$) and DBD ($\rho=-0.414$); COR is in a strong negative correlation with LSI ($\rho=-0.995$) and FD ($\rho=-0.943$), just like BD with CSR ($\rho=-1.000$); FD is moderately negatively correlated with DAD ($\rho=-0.428$); DBD is moderately positively correlated with CSR ($\rho=0.414$); and DBA and DBD are slightly positively correlated ($\rho=0.297$). The results have no statistical significance as the obvious collinearity among the variables mentioned above. There is, however, no significant correlation between the remaining indicators. In other words, these indicators are independent of each other and capable to represent a certain morphological characteristics alone.

SPSS 22 was then used to perform PCA on the 12 morphological indicators. Components with eigenvalue greater than or equal to 1 were chosen. KMO test and Bartlett’s test were employed to verify the practicability of factor analysis. According to the results, the KMO value, being 0.618 (> 0.6), is valid in statistics. The p value of Bartlett’s test is 0.00 ($p < 0.01$), verifying that the indicators are strongly correlated and independent of each other, in accordance with the conditions for factor analysis.

According to the total variance interpretation table (Table 3), 5 principal components with an eigenvalue greater than 1 were identified as the determining factors to the spatial morphology of the sample neighborhoods. The cumulative variance contribution is 87.42%. The rotated component matrix was obtained (Table 4). Together with their correlation coefficients with the morphological indicators, the matrix was used to integrate/interpret the determining factors to the regional

2. 样本街区形态学指标相关性分析热力图
2. Correlation Heat Map of the morphological indicators of sample neighborhoods



注
**代表 $p<0.01$ ；*代表 $p<0.05$ 。
NOTE
** means $p < 0.01$, * means $p < 0.05$.

表3：总方差解释表 Table 3: Total variance explained						
成分 Component	初始特征值 Initial eigenvalue			旋转载荷平方和 Extraction sums of squared loadings		
	总计 Total	方差百分比 % of variance	累积 (%) Cumulative (%)	总计 Total	方差百分比 % of variance	累积 (%) Cumulative (%)
1	3.242	27.019	27.019	2.956	24.633	24.633
2	2.907	24.222	51.242	2.457	20.475	45.108
3	1.802	15.019	66.261	1.110	17.580	62.688
4	1.307	10.892	77.153	1.628	13.563	76.251
5	1.233	10.275	87.428	1.341	11.178	87.428
6	0.678	5.654	93.082			
7	0.350	2.916	95.998			
8	0.337	2.811	98.809			
9	0.114	0.950	99.758			
10	0.024	0.203	99.962			
11	0.004	0.037	99.999			
12	0.000	0.001	100.000			

1) 街区形状（载荷量27.02%），包括紧凑度、景观形状指数和分维数；

2) 开发强度（载荷量24.22%），包括庭院空间率、建筑密度和绿地率；

3) 街区规模（载荷量15.02%），包括街区面积和周长；

4) 平面秩序（载荷量10.90%），包括建筑角度紊乱度和建筑面积紊乱度；

5) 聚集程度（载荷量10.28%），包括混合功能和建筑距离紊乱度。

因此，这5个主成分基本可以反映全部的空间形态指标的信息，可以代替原来的12个指标，作为反映居住街区空间形态地域差异的表征因子（表5）。

指标名词 Indicators	主成分 Principal Components				
	街区形状 Neighborhood shape	开发强度 Development intensity	街区规模 Neighborhood size	平面秩序 Layout order	聚集程度 Aggregation degree
街区面积 Neighborhood Area	-0.026	0.200	0.941	0.095	0.008
周长 Perimeter	0.142	0.171	0.939	0.151	-0.019
建筑密度 BD	0.072	-0.969	-0.140	0.028	0.061
绿地率 GR	-0.009	0.702	0.169	0.074	0.496
庭院空间率 CSR	-0.068	0.969	0.141	-0.027	-0.062
紧凑度 COR	-0.985	0.049	-0.051	0.008	0.010
景观形状指数 LSI	0.982	-0.051	0.041	-0.003	-0.009
分维数 FD	0.954	-0.048	-0.026	-0.047	0.061
建筑角度紊乱度 DAD	-0.182	-0.073	0.082	0.888	0.015
建筑面积紊乱度 DBA	-0.121	-0.058	-0.106	-0.887	-0.043
建筑距离紊乱度 DBD	-0.140	0.027	0.476	-0.070	0.596
混合功能 MIX	-0.115	0.013	0.154	-0.082	-0.852

注
加粗的数值为该指标所隶属的主成分位置。

NOTE
Bold-type number refers to which principal component the indicator belongs to.

morphology of residential neighborhoods of county-level cities in a same period of time:

1) neighborhood shape (loading=27.02%), including COR, LSI, and FD;

2) development intensity (loading=24.22%), including CSR, BD, and GR;

3) neighborhood size (loading=15.02%), including Neighborhood Area and Perimeter;

4) layout order (loading=10.90%), including DAD and DBA;

and 5) aggregation degree (loading=10.28%), including MIX and DBD.

Since these 5 principal components cover all the aspects presenting by the 12 indicators, they were used as the characterization factors of the regional spatial morphology of residential neighborhoods (Table 5).

表5：各城市及寒冷地区、湿热地区城市主成分因子得分表
Table 5: PCA scores for the five county-level cities and the two climate zones

城市 City	主成分 Principal components				
	街区形状 Neighborhood shape	开发强度 Development intensity	街区规模 Neighborhood size	平面秩序 Layout order	聚集程度 Aggregation degree
庆城县 Qingcheng County	-0.053	0.149	-0.062	-0.324	-0.159
武安市 Wu'an City	-0.579	-0.390	0.089	0.612	-0.610
寒冷地区城市 Cities in cold zone	-0.316	-0.121	0.014	0.144	-0.385
长兴县 Changxing County	0.127	0.344	0.488	0.301	0.373
连江县 Lianjiang County	-0.010	-0.256	-0.487	0.227	0.536
金堂县 Jintang County	0.012	0.143	0.399	-0.342	0.251
湿热地区城市 Cities in hot zone	0.065	0.116	0.200	0.093	0.580

具体而言，武安市得分较高的主成分为街区形状（-0.579）、开发强度（-0.390）、平面秩序（0.612）和聚集程度（-0.610），表明该县级市居住街区空间形态的地域差异主要由这4个表征因子决定，尤其是后面两个因子；长兴县和连江县在街区规模上得分较高，分别为0.488和-0.487，可见这两个城市的居住街区空间形态的地域差异主要由街区规模决定，另外连江县的聚集程度（0.536）也发挥了重要作用，其他因子影响较小；庆城县则主要由平面秩序（-0.324）决定，金堂县主要由街区规模（0.399）决定。总体上，寒冷地区城市在街区形状（-0.316）与聚集程度（-0.385）上得分较高，湿热地区城市在聚集程度（0.580）上得分较高，可见不同气候区的县级城市之间存在地域差异。另外，同一气候区中的县级城市的地域差异与总体差异并不完全一致，如寒冷地区城市在街区形状（-0.316）与聚集程度上得分较高，但其中，庆城县的街区形状得分较低（-0.053）；湿热地区城市在聚集程度（0.580）上得分较高，但其内部的长兴县却在街区规模（0.488）上得分最高。

3.3 空间形态时空差异的影响因素分析

为了进一步探索样本街区空间形态的时空差异，研究基于历史时期的卫星影像地图，根据12个形态学指标计算公式，分别计算了3个时段的数据，并运用SPSS 22和Origin 2021来检验指标之间相关性，以寻找不同时期影响各个样本街区空间形态时空差异的具体因素。根据前文的

Specifically, Wu'an scores higher in neighborhood shape (-0.579), development intensity (-0.390), layout order (0.612), and aggregation degree (-0.610), suggesting its regional morphology is largely determined by those four, especially the latter two. Changxing and Lianjiang are seeing higher scores in neighborhood size, 0.488 and -0.487 respectively, and aggregation degree (0.536) is the other characterization factor to Lianjiang. The spatial morphology of Qingcheng and Jintang are mainly depended on layout order (-0.324) and neighborhood size (0.399) respectively. In general, cities in cold zone score higher in neighborhood size (-0.316) and aggregation degree (-0.385), wherein Qingcheng has a lower score in neighborhood shape (-0.053), while cities in hot zone score in aggregation degree (0.580), wherein Changxing, however, has the highest score in neighborhood size (0.488). In other words, the regional morphology of the cities in a same climate zone does not exactly conform to the individual ones belonging to it.

3.3 Analysis on the Factors Influencing the Spatial–Temporal Changes in Morphology

To further explore the spatial–temporal changes in morphology of the sample neighborhoods, data in each period of time were calculated with the formulas of 12 indicators based on the satellite images. Using SPSS 22 and Origin 2021 to test the correlations among the indicators, this research attempts to identify the factors influencing the spatial–temporal changes in morphology. According to the

针对12个形态学指标的相关性检验情况，剔除强相关指标，即庭院空间率、分维数、紧凑度和周长。并对剩下的8个指标进行正态分布检验，发现只有建筑密度符合正态分布的指标，其余指标均不符合正态分布。故在相关性分析中采用上述独立样本T检验与曼-惠特尼U检验结合的方式，并借助Origin 2021可视化检验结果，以研究不同气候区的县级城市在不同发展阶段存在的具有显著差异的形态学指标。

分析结果表明样本街区的部分形态学指标在不同时期存在明显差异（图3）：

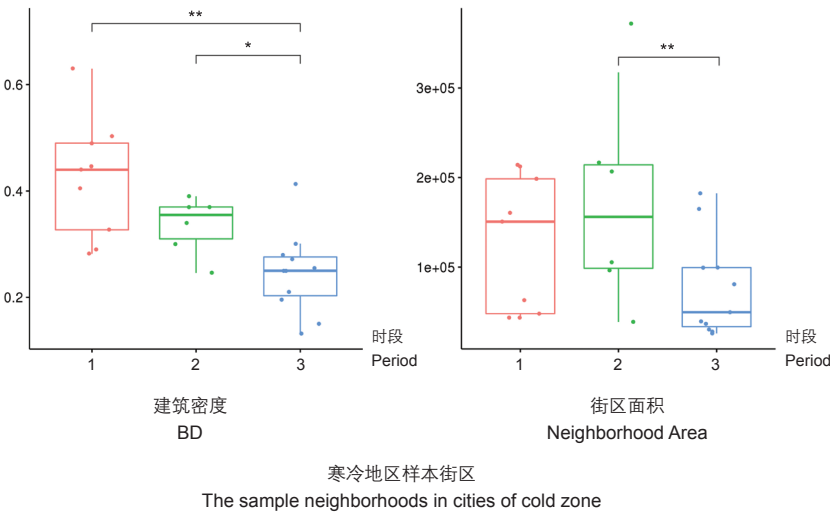
1）针对寒冷地区城市的样本街区，时段三的建筑密度分别与时段一、二存在显著差异，总体呈现为不断下降趋势；对于街区面积差异，时段三相较时段二呈显著下降趋势。

2）针对湿热地区的样本街区，时段一的建筑密度分别与时段二、三存在显著差异，总体呈现为不断下降趋势；对于绿地率，时段三相较时段一持续上升且差异显著。

另外，对于相同气候区的县级城市，分析结果显示（图4）：1）在1994年住房改革前，绿地率存在显著差异，其他指标无显著差异；2）时段二期间建设的街区，建筑角度紊乱度呈现出显著差异，其他指标无显著差异；3）时段三建设的街区，绿地率和建筑距离紊乱度呈现出较为显著差异，其他指标无显著差异。

具体表现为时段一与时段三两个阶段中，湿热地区城市的样本街区绿地率显著高于寒冷地区城市的；时段二中，寒冷地区城市的样本街区建筑角度紊乱度显著小于湿热地区城市的样本街区；时段三中，湿热地

3. 两个气候区的样本街区自身在不同发展时期的空间形态演变的相关性分析
3. Correlation analysis of the diachronic transformation in spatial morphology of the sample neighborhoods in two climate zones in each period of time



时段一 Period 1 时段二 Period 2 时段三 Period 3

correlation test results, strongly correlated indicators, namely CSR, FD, COR, and Perimeter, were excluded. A test of normality performed to the rest 8 indicators suggest that only BD shows a normal distribution. Therefore, the Student's T-test of independent samples and Mann-Whitney U test were used for the correlation analysis. Visualizing the analyses with Origin 2021, the study examines the morphological indicators of significant differences among county-level cities in two climate zones in different periods of time.

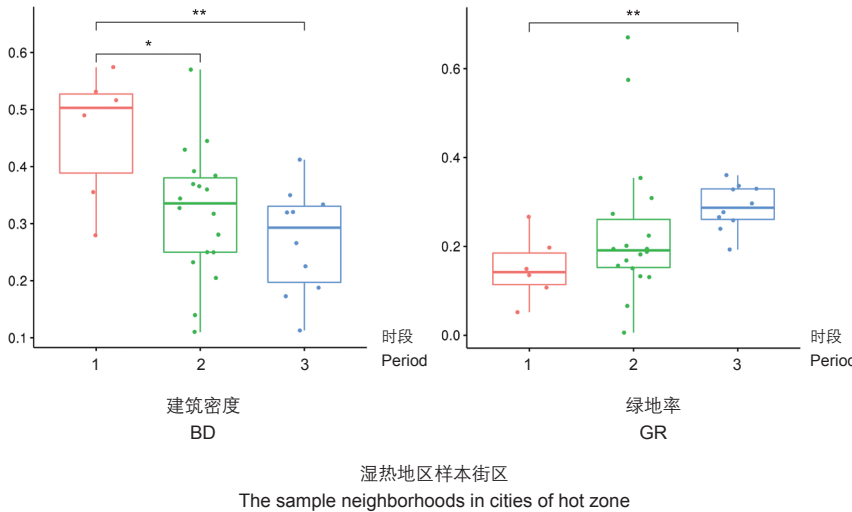
The results reveal that some morphological indicators show significant differences in different periods of time (Fig. 3).

1) To the sample neighborhoods of the cities in cold zone, BD decreased continuously from 1994 to 2018, and that in Period 3 varied significantly from Period 1 and Period 2, respectively; Compared with the years in Period 2, Neighborhood Area decreases dramatically in Period 3.

2) To the sample neighborhoods of the cities in hot zone, BD in Period 1 is significantly different from that in Period 2 and Period 3, with an overall decline since 1994; in contrast, GR keeps growing since 1994, showing a significant difference between Period 1 and Period 3.

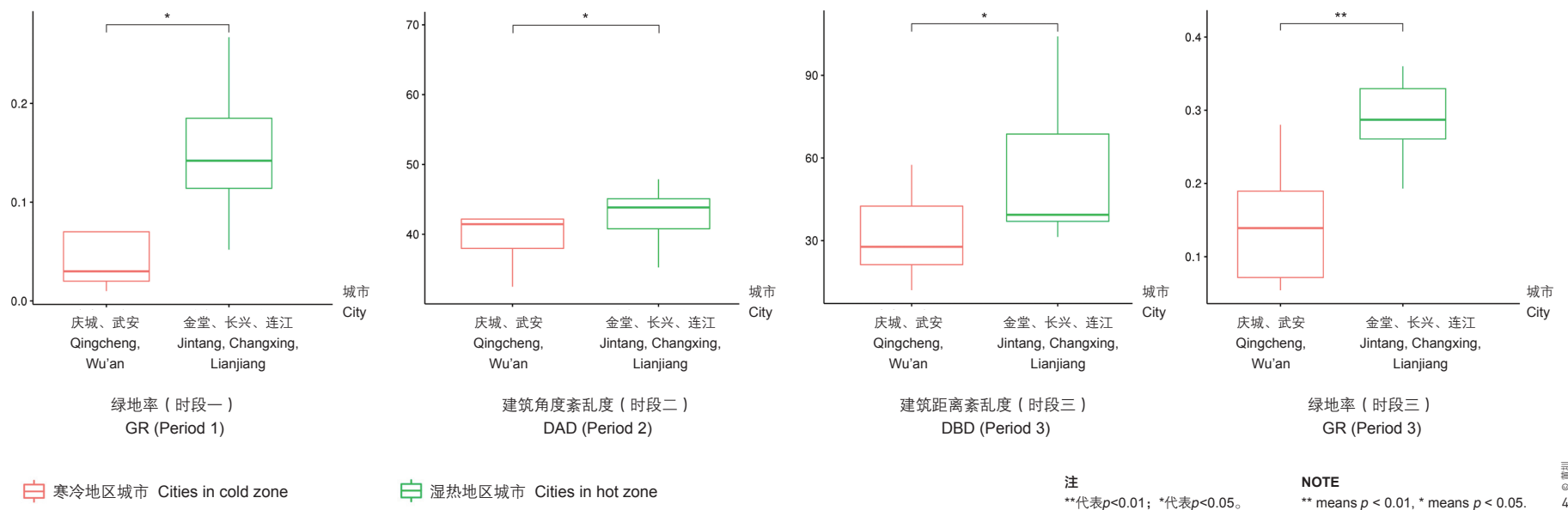
Comparative analyses between the cities in a same climate zone (Fig. 4) indicate that before the housing reform in 1994, GR is the only one indicator that shows a significant disparity; the neighborhoods built in Period 2 demonstrate a significant disparity only in DAD; and the neighborhoods built in Period 3 show significant disparities in GR and DBD.

To be specific, in Period 1 and Period 3, GR of the sample neighborhoods in cities of hot zone is significantly higher than that in cities of cold zone. DBD in cities of cold zone is significantly lower than that in cities of hot zone in Period 2. DBD in cities of hot zone is significantly higher than that in cities of cold zone in Period 3. These results prove that regional differences can be found in certain



注
**代表 $p < 0.01$; *代表 $p < 0.05$ 。

NOTE
** means $p < 0.01$, * means $p < 0.05$.



区城市的样本街区建筑距离紊乱度显著大于寒冷地区城市的。可以发现不同气候区的居住街区在同一时期中某些指标存在地域差异，其中绿地率在两个时期内都表现出显著的差异性。

4 讨论

4.1 县级城市居住街区空间形态地域差异的表征因子

研究结果显示（表5）：

1）武安市的居住街区空间形态的地域差异主要由平面秩序和聚集程度决定，庆城县主要由平面秩序决定。其中，平面秩序可能与寒冷地区的建筑布局方式有关。在寒冷地区，为了获得更多光照会更加重视建筑方向选择^[42]，从而影响建筑角度紊乱度，最终显现于平面秩序因子上。而武安市的聚集程度可能与其城内占据主导地位的三类居住用地（主要由城中村用地和部分单门独院住宅构成）有关，这些用地多由早期单位住宅用地改造而成，楼层低、密度大，并且随着各种配套商业设施的不断增加，形成了较多功能混乱的居住街区^{[43][44]}，从而使其混合功能指标偏高。

2）长兴县、连江县和金堂县的居住街区空间形态的地域差异主要由街区规模决定，其中，连江县的聚集程度也对其地域差异的形成发挥了重要作用。造成这一现象的原因可能是这三个城市均位于湿热地区，该地区的城市在自身发展阶段中形成了较大面积的自建房与老旧片区，

indicators (especially GR) among the residential neighborhoods in different climate zones built in a same period of time.

4 Discussions

4.1 Characterization Factors of Regional Spatial Morphology of Residential Neighborhoods in County-Level Cities

The research findings include (Table 5):

1) The regional differences in spatial morphology of residential neighborhoods in Wu'an are mainly characterized by layout order and aggregation degree, while Qingcheng by layout order only. The layout order might be closely related to the regional building pattern that adapts the best direction upon the insolation standard in cold zone^[42], indicated by DAD in this research. In addition, the dominant land occupancy mostly consisting of urban villages and some single-door courtyard houses may affect the aggregation degree of Wu'an. The multifunctional and cluttered residential neighborhoods, low-rise buildings and high density, transformed from the early residential buildings built by local industry enterprises, have been formed with the continuous increase of various commercial facilities^{[43][44]}—This could somehow explain why Wu'an witnesses a higher MIX.

2) The regional differences among Changxing, Lianjiang, and Jintang are mostly characterized by neighborhood size. The reason might be that unplanned housing once dominated throughout the cities in hot zone, which now has resulted in that a large proportion of city road network is poorly defined, indicated by the higher Neighborhood Area and Perimeter^[45]. The finding also suggests that aggregation degree is another characterization factor to Lianjiang, which may be due to the heavy disorder of spatial morphology in the old downtowns^[46].

And 3) on the whole, the cities in cold zone are mainly characterized by

4. 两个气候区的样本街区在三个发展时期中的空间形态的显著差异指标

4. Indicators of the significant differences in spatial morphology of the sample neighborhoods in two climate zones in each period of time

街区规划与局部路网均未获得进一步细化，因此街区面积与周长数值较大^[45]。而在留存了较多老城区的连江县，内部城市空间形态失序问题比较严重^[46]，这可能影响建筑距离紊乱度指标。

3) 总体上，寒冷地区城市在街区形状与聚集程度上得分较高，而湿热地区城市则在聚集程度上得分较高；这些表征因子与各个地区的县级城市本身的地域差异表征因子存在一定差异，可能与同一地区的县级城市自身的气候条件对建筑的影响、建设发展阶段等方面的差异有关。

4.2 县级城市居住街区空间形态时空差异的驱动因素

4.2.1 各个气候区的样本街区不同时期的形态差异驱动因素

根据研究结果，在城市自身空间形态演变上（图3）：

1) 寒冷地区城市的样本街区呈现出了建筑密度、街区面积的时期差异，可能与这些县级城市均属于发展起步较早的工矿城市有关，他们在1994年前便已完成大量相对规范且密集的职工住宅建设^[47]；并且1998年后，其中的庆城县由于油田机关南迁，导致了“人去楼空、百业凋敝”^[48]。故总体上，寒冷地区城市建设进展相对滞后。直到2010年，转型发展才成为寒冷地区城市发展的重点^[48]，此时的城市居住街区开始大力开发建筑密度更小的商品房，并且由于城内本身便少有大规模的自建房等，对于2016年引入的、在全国范围推进的“小街区，密路网”规划模式的街区制政策落实也便更为顺畅^{[45][49]}，最终，使其街区建筑密度和街区面积均在时段三得到极大降低，进而与时段二的指标形成显著差异。

2) 湿热地区城市的样本街区呈现出了建筑密度和绿地率的时期差异。其中，建筑密度差异可能与这些城市的传统居住模式有关——以自下而上的自建房为主的模式，这促使其得以在1994年住房政策改革后，统一向商品房建设推进，致使建筑密度在时段一与时段二之间呈现出显著差异；另一方面，湿热地区城市的降水及温度有利于植被生长^[50]，因此，中国规划指标中的绿地率要求容易在这些地区实现增量，该结果也与李彤杉等人针对不同气候区划下的中国建成区绿地率区域差异研究相符^[51]。

4.2.2 不同气候区的样本街区同一时期的形态差异驱动因素

根据研究结果，不同城市的空间形态演变上（图4）：

1) 绿地率在时段一、时段三均呈现出显著差异，这可能与不同气候区的城市自然条件有关，湿热气候区具有良好种植环境，为绿地规划设计提供了更多的物种选择与更好的种植条件^[50]，使其绿地率保持在较高水平。而在时段二期间，两个气候区的绿地率并未呈现显著差异，这可能是由于该时期寒冷地区城市正处于商品房建设初期，拥有基数较大的绿地率较高的职工住房，这与湿热地区城市以非规范的自建房为主的商品房发展初期相比，具备了比较接近的绿地率。

neighborhood shape and aggregation degree, while the ones in hot zone by aggregation degree only. The highest factor to the cities of two climate zones differs from that to the individual cities in the same zone—This may be down to the residential building patterns adapted to the local climate and the urbanization of each city.

4.2 Causalities to the Spatial–Temporal Changes in Morphology of Residential Neighborhoods in County-Level Cities

4.2.1 Causalities to the Morphological Differences Among the Sample Neighborhoods in a Same Climate Zone in Different Periods of Time

The findings of this research lead to the following conclusions (Fig. 3):

1) BD and Neighborhood Area of the samples in the cities of cold zone change dramatically in different periods of time, probably because in earlier years these cities had been shaped by the extensive industrial development—many staff houses were built in a standard and intensive way before 1994^[47]. After 1998, the relocation of the oilfield authorities in Qingcheng resulted in a sluggish economy^[48]. Overall, the urbanization in the cities of cold zone started relatively late, and housing marketization had not been locally promoted until 2010^[48]. Other reasons might be there are less unplanned areas in the cities of cold zone, and the policy of “smaller block size, higher street density” introduced in 2016 was well implemented in these cities^{[45][49]}, which together have resulted in the sharp decrease of BD and Neighborhood Area in Period 3, compared with Period 2.

2) BD and GR of the studied neighborhoods in the cities of hot zone change dramatically in different periods of time. The significant disparity of BD can be probably explained with that the housing commercialization policy introduced in 1994 was implemented based on the vast informally built housing, just like the results of significant differences in BD between Period 1 and 2. In addition, in the cities of hot zone where precipitation and temperature conditions are more favorable to leafy plants^[50], GR is easy to increase as the construction standard requires. This conclusion confirms the findings by Li Tongshan et. al, who studied the regional differences in GR of built districts in China based on climate division^[51].

4.2.2 Causalities to the Morphological Changes Among the Sample Neighborhoods of Different Climate Zones in a Same Period of Time

The findings of this research lead to the following conclusions (Fig. 4):

1) GR of the two zones vary in both Periods 1 and 2, which could be resulted from the varied natural conditions of the cities in different climate zones. In the hot zone, green space planning and design is allowed to use a wider range of plant species due to the favorable climate conditions^[50]. Interestingly, GR between the two climate zones does not vary significantly in Period 2. A possible reason might be that at that time housing marketization in the cities of cold zone was still in its early stage, and most staff housing enjoyed a higher GR, which narrowed down the difference with the hot zone where more informal housing dominated in that period of time.

2) 在时段二呈现出的建筑角度紊乱度的显著差异可能与两类城市的发展进程情况有关, 湿热地区城市的样本街区在时段二期间存在较多人自建房, 这造就了这些城区整体表现为杂乱无章的居住形态。而寒冷地区城市的样本街区属于矿产开采城市, 城市发展较早^[47], 产生了较多考虑采光等规范的单位自建房和集体住房, 整体表现为规整的建筑布置。

3) 在时段三呈现出的建筑距离紊乱度的显著差异, 则可能与两个气候区的居住建筑布局方式有关, 寒冷地区的居住建筑为抵御寒风而较多采用围合形式^[52], 使其两侧相邻建筑间距较小, 从而减少了相邻建筑的平均距离。而湿热地区城市多为独栋住宅, 少有围合的建筑形式。

4.3 研究不足

研究所使用的街区样本量还比较少, 分析所得结果可能存在偏差, 后续需要在更多样本的情况下进行验证; 另外, 虽然通过上述分析可只是对特定的三个时期的样本街区的空间形态进行的比较, 使得针对形态学指标的相关性分析不免受到住房政策的较大影响, 无法全面客观地反映产生这些地域差异的综合原因, 分析方法有待进一步完善。

5 结论

不同的县级城市居住街区空间形态存在显著的时空差异, 这对探讨地域差异具有重要意义。本研究选取中国不同气候区的60个样本街区作为研究对象, 定量计算并分析了影响县级城市居住街区空间形态地域差异的表征因子, 并从具体指标对县级城市居住街区的空间形态时空差异及变化规律进行分析, 得出如下结论:

1) 不同气候区的县级居住街区在空间形态上存在差异, 并主要表现为街区形状、开发强度、街区规模、平面秩序和聚集程度5个方面, 可作为描述不同县级城市居住街区空间形态的地域差异的表征因子;

2) 同一气候区居住街区的空间形态本身存在时间差异, 主要表现在建筑密度、街区面积、绿地率这三个形态学指标上; 不同气候区的居住街区的空间形态在同一时期也存在显著差异, 主要体现在绿地率、建筑角度紊乱度和建筑距离紊乱度这三个形态学指标上。

3) 县级城市居住街区空间形态的时空差异与住房政策的发展历史存在协同性, 同时也与气候条件、居住建筑布局方式、城市自身的发展进程等存在关联, 未来的住房政策制定应基于决定不同城市居住街区的地域差异的表征因子, 考虑如何尊重地域差异。LAF

2) The significant differences in DAD may attribute to the disparity of urbanization in each studied city. In the sample neighborhoods of the cities in hot zone, informal housing construction dominated in Period 2, leading to the overall disorder of building pattern in these cities. In contrast, most collective-owned housing was built in a planned manner along with the development of mining industry in the cities of cold zone^[47].

And 3) the significant differences in DBD could be resulted from the disparity of residential building patterns in each climate zone. The cities of cold zone see a larger but more enclosed layout pattern adapted to withstand cold wind^[52], leaving a smaller distance between adjacent buildings. In contrast, most houses in hot zone are single-family homes with more open spaces.

4.3 Research Limitations

The findings of this research need to be further verified because of the sample size for the county-level cities is inadequate. Due to the focus of this research, as well as the studied time span that might witness a great influence by China's housing policies, scientific efforts are expected to further explore more suitable analysis methods to comprehensively reveal the causalities to the regional morphological differences and changes.

5 Conclusions

This research studies the spatial-temporal differences in the morphology of residential neighborhoods across county-level cities, offering evidences for further studies on regional spatial variety. This research examines 60 sample neighborhoods of county-level cities from different climate zones in China, quantitatively analyzes the characterization factors of the regional spatial morphology, and discusses the spatial-temporal changes and the diachronic transformation by scrutinizing 12 morphological indicators. The main research findings include:

1) There are differences in spatial morphology of residential neighborhoods in county-level cities of different climate zones, and the characterization factors include neighborhood shape, development intensity, neighborhood size, layout order, and aggregation degree.

2) There are disparities in the spatial morphology of residential neighborhoods in the same climate zone but in different period of time, mostly indicated with BD, Neighborhood Area, and GR. The spatial morphology of residential neighborhoods built in a same period of time varies largely between climate zones, mainly indicated with GR, DAD, and DBD.

And 3) the spatial-temporal changes in the morphology of residential neighborhoods in county-level cities are related to not only China's housing policies in different periods of time, but also to regional climatic conditions, residential building patterns, and the urbanization of each city. Future housing policy-making should take regional characterization factors into account, for a greater protection of regional qualities. LAF

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