The relationship between urban form and land-use regulation in China: the case of Nanjing

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Abstract. *Urban form is shaped by numerous factors interacting across various social strata, notably influenced by the dynamics of economic development and urban policy. Urban planning policies related to land use play a vital role in the change and management of urban form. In this context, this study examines the influence of land use regulations on urban form in China, using Nanjing as a case study. We investigate relevant urban planning policies at national, provincial, and local city planning administration levels. Depending on their impact on urban form, these policies can be classified as having a direct impact, an indirect influence or no effect, predominantly encompassing mandatory land use conditions, building layout and guiding principles for urban landscape organization. Focusing on land use regulations at the street-block and plot scale, we established a morphological model adhering to these regulations and a correlation evaluation chart. This correlation was validated using 142 plots and 5 street blocks in Nanjing's historical city centre. Our findings reveal the implications of these policies on the specific physical structure of the urban form through theoretical and empirical analysis. This research significantly contributes to the method of morphological modelling and the revision of relevant urban policy and design specifications.*

Keywords: land use regulation, plot indicators, urban form, street-block, plot, Nanjing

Urban form might be described as the product of numerous factors shaping processes in varying social layers, including social, economic, political and environmental, during a particular stage of historical development at a given geographical location, particularly resulting from the influences of internal and external economic development and urban policy control (Rangwala, 2012). In the formation and development of urban form, economic dynamics, social behavior, historical culture, geographical environment and other factors affecting the city are spontaneous and do not depend on people's will; while the policy proposals and regulatory provisions in relevant legislation, urban planning policies, planning regulations, technical provisions and design codes are the primary means to dictate the progress of urban construction and significantly affect urban form and environmental quality (Ding, 2007). In particular, land regulations are essential to regulate land use, plot allocation and the location and layout of buildings, as public and private benefits are involved. Following rapid urbanization in many countries since the 1980s, the pressing challenge in urban development lies in creating a distinct and livable urban environment

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(Guaralda, 2014). This increasingly involves discussing critical issues related to the poor quality of urban form and social environment, such as insufficient public spaces, the absence of people-friendly movement, lack of meaningful places, traffic congestion and suburban sprawl (Ben-Joseph, 2005). China, for instance, grapples with controlling urban form effectively and generating urban public spaces to enhance the sustainability of the urban environment (Zheng and Lin, 2002). It is crucial to foster a people-oriented urban quality (Tibbalds, 1992), which could be achieved by establishing a set of urban planning and design methods based on morphological design criteria (McGlynn and Samuels, 2000; Samuels, 2008; Form Based Codes Institute, 2014; Oliveira, 2021). Concerns around this approach have been emphasized based on the relationship between morphological research and planning and design practice (examples in this journal include Larkham, 2005; Whitehand, 2007; Ding, 2013; Hall, 2013; McCormack, 2013).

In China, urban planning policies related to land use, including key indicators such as land-use proportions, floor area ratio (FAR), building density (BD) and the distance between buildings for fire control, daylight access, and transportation, have effectively addressed health and safety concerns and balancing the relationship between serving public interests and delivering private benefits. These land-use regulations manage the land use, plot development intensity and building locations by establishing upper and lower limits of land indicators, using detailed regulatory planning as a tool. However, they have also influenced the morphological characteristics of urban areas via the layout and types of blocks, the form of plot divisions and the morphological order of combinations of buildings (Gao and Ding, 2017). Thus, examining the relationship between urban form and land use regulations is critical to shaping urban spatial quality effectively, and this study does so by using a method of creating morphological models following the land-use regulations and empirical analysis of the relationship in the historical context, and based on a review of the key literature, investigation of relevant planning regulations and of sample street blocks and plots.

The key concepts

Street, street-blocks, plots and buildings are the principal physical components of urban form (Figure 1). Moreover, on a cognitive scale, they compose the basic units of urban form and shape the perception and experience of cities: most morphological studies focus on these patterns or typologies (Kropf, 1993). As Conzen (1960) proposed, a town plan is a complex system encompassing these components, presenting the urban landscape's nature and intensity through the town plan, building forms and land use. The urban designer Lynch (1960) argued that edges, paths, districts, nodes and landmarks shape perceptions of a city. Urban form is not only a physical expression but also mirrors societal characteristics, and Jacobs (1961) noted that shaping these elements is essential for reflecting urban diversity. In recent years, the relevant regulations of urban planning policies and design codes have emerged as essential operating tools for shaping urban form, enhancing the quality of public spaces and producing meaningful places (Moudon, 1992; Whitehand, 2005; Cuthbert, 2007; Marshall, 2011). In contrast, the morphological characteristics of the historical evolution of street blocks, plots and buildings allow greater precision in judging whether new development proposals will enhance an area. These factors serve as design tools used to understand the city and to guide planning and design practice (Nasser, 2013).

The critical operational elements, relevant urban form regulations and correlation attributes of street-blocks and plots

The critical operational tool to optimize urban form mainly relies on the provisions of controlling physical elements (see Figure 1): building control lines, height limits, setback distances and distances between buildings; together with a management system for

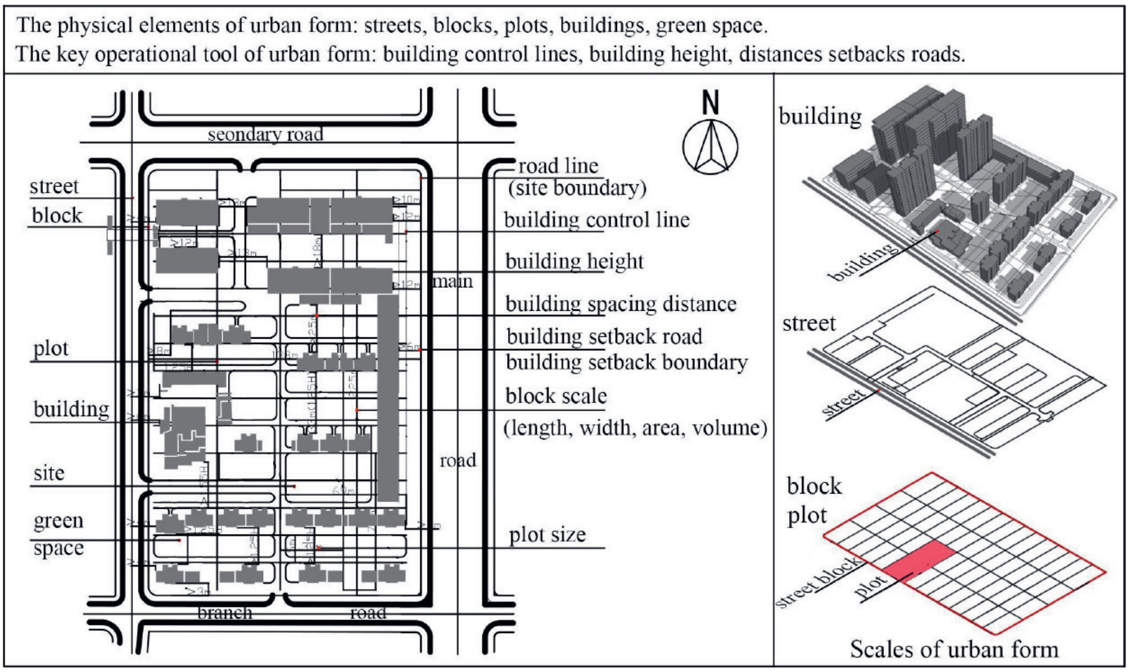


Figure 1. The physical elements, scales and critical operational tools of urban form.

approving planning permits (Ding and Liu, 2007; Kropf, 2011; Talen, 2012). These collectively deal with urban health, safety and social problems, ideally forming an orderly and harmonious environment (Marshall, 2011). Shirvani (1985) identified eight primary components for optimal urban design, including the relationship between buildings, the nature of land use, form and plot intensity, to enhance public space quality. The New Urbanism movement proposed an alternative to traditional zoning, emphasizing community scale, development density, walkability, mixed use and sustainability, and suggested an urban design approach based on morphological codes in shaping the urban environment (Parolek *et al*., 2008).

Relevant urban planning and design regulations affecting urban form primarily include two aspects: the first involves the provisions of direct influence such as traditional zoning, form-based design codes and implicit codes based on the social structural order; the second is the indirect influences such as legislation or policy, fire codes, financing rules, and provisions governing the process of building and design review (Parolek *et al*., 2008; Talen, 2012). Among these, traditional zoning emerged in the early-twentieth century, aimed at protecting public health and safety, controlling urban development and preventing harmful land use through the land subdivision, street width and layout, and spatial arrangement provisions. However, its continued usage influenced urban form and brought problems such as urban sprawl, lack of public spaces, and traffic congestion (Ben-Joseph, 2005; Talen, 2009). Form-based codes were proposed by the New Urbanism movement since the 1980s, controlling the components through sets of design rules, thereby influencing the form and appearance of the urban environment (Parolek *et al*., 2008; Zukin, 2009). Beyond defining ratios and quantities, these codes provide a design tool for balancing the order and diversity of the city to enhance a better sense of place and quality of form (Guaralda, 2014). Furthermore, legislation and policy can significantly affect the urban layout on a broader scale, such as in establishing urban growth boundaries (Talen, 2012).

The correlation point between the urban form and relevant urban planning and design regulations is the attributes of street-blocks and plots. The shared values of optimizing urban physical form yield the corresponding morphological attributes in different environments, guided by provisions for urban planning policy and design codes. These attributes encompass settlement pattern, land-use functions, plot divisions and shapes, relationship between plot boundaries and streets, open spaces, and architectural responses such as building height and width and mass (Nasser, 2013; Gao and Ding, 2017). The management and controlling of relevant provisions lead to changes in block and plot attributes, thereby influencing the morphological characteristics of urban form and the quality of urban space and built form (Ding, 2007; Nasser, 2013).

Control methods and the effectiveness of planning and design provisions on street-block and plot form

The majority of the relevant literature is from Europe and the United States, and experience elsewhere is scarcely covered. These studies discuss the relationship between urban morphological research and urban planning policy and design practices, principally from three perspectives: historical and geographical, scale, and implicit social norms – each perspective analyzes control methods and effects of planning and design policies on urban form.

The first perspective is historical and geographical. Urban form is influenced by planning and design policies deeply rooted in history. Understanding the historical change and existing realities of urban form is critical for practical planning and design strategies, and this includes their transition from the often little-understood 'planning and zoning' of traditional urban development, to those regulations shaping the city – space, mixed-use, public environment and walkability (classic examples of such studies include Conzen, 1960; Benevolo, 1980; Mumford, 1989; Krier, 2003; Whitehand, 2007; Form-Based Codes Institute, 2014). The impact of planning policies and design codes on the urban form of ten cities across varied geographic and historical contexts have been analyzed, exploring the role of regulation as a design tool to balance urban diversity and order (Marshall, 2011). Kropf's (2011) study of French coding identified three core elements – zoning plan, regulations and a mechanism for administering building permits – for examining the system incorporating typomorphological analysis to make the coding more responsive to the local and regional character. In the US, Barnett (2011) showed that zoning codes guide almost all development but go far beyond establishing land-use zones to determine construction parameters, significantly shaping urban form, including building height, total floor area, the ratio of open space and building density. In China, Guo (2011) explored the historical links between architecture and planning in Beijing, demonstrating that planning codes control building size, patterns of streets and city plans. Ding's research team showed that the control indicators could directly or indirectly influence urban form in Nanjing (Ding, 2007; Gao and Ding, 2017).

The second perspective is scale, primarily focusing on three levels: the street block, plot and buildings. At the level of street-block pattern and land use, Talen (2012), from morphological assessment in urban planning and design practice, pointed out that the control methods are achieved mainly by applying pattern regulations such as land subdivisions, street width and zoning code. These methods, developing from simple zoning to intricate plot subdivision and building layout, guide the layout of land use, housing and public plazas within blocks, affect the block pattern changing from logical to complex, and yield orderly or disordered, disjointed or coordinated morphological results. However, the zoning code did not seem to provide control of urban form, and good intentions do not guarantee that a better city will result: Talen (2012) suggested an urban planning approach based on flexibility, livability and predictability, guided by morphological guidelines. At the street block and plot level, Berghauser Pont and Haupt (2007) developed their 'spacematrix' method, combining four indicators – floor area ratio, building coverage, open space ratio, and height – to analyze the morphological types associated with different building densities. This method demonstrated the effectiveness of these indicators in affecting morphological characteristics.

The final perspective concerns implicit social norms, which foster a bottom-up urban form guided by doctrinal and social behavior, striving to harmonize complex heterogeneous forms with social structure and order. African shantytowns, for example, exemplify this influence of implicit social codes on urban form. In some suburbs south of the Sahara, the morphological unit of the village is partly reproduced during the urbanization process and rural-urban migration. Communities often tend to replicate traditional dwelling practices and spaces, especially courtyards. Such settlement patterns reflect a social structure in which humans are closely linked to spatial production (Steyn, 2011). Similarly, in Islamic cities, the implicit norms derived from Qur'anic teachings have shaped the formation of street forms with a sense of respect and orderly arrangement (Hakim, 2013).

Research area, examples of blocks and plots, and morphological attribute classification

Nanjing has a long history as a capital city of China's Six Dynasties and, particularly in the city centre, the morphological attributes of street-blocks and plots have grown increasingly complex and diverse since the Ming dynasty. Its urban development has been largely influenced by governmental policies and urban regulations, as well as by economic dynamics, culture, geography and other factors. Urban planning and design regulations have played a significant role in shaping its urban form. Therefore, this study takes Nanjing as an exemplar of Chinese large historical cities. Five historical street blocks and 142 sample plots along the main and secondary roads in Nanjing's historical city centre were selected for empirical analysis (Figure 2). The selection was based on the local regulations operating since 1928, the planning approval maps of the corresponding years, and the annual maps of plot auctions, to analyze the correlative effects of regulations on the urban form in a historical context.

First, the five historical street blocks were defined based on their encircling roads at the date of the local plan approving relevant site boundaries, as shown in Figure 2. These range from block SB–2 (approved in 1956) in the planned economy stage with local land layout provisions, block SB–4 (1987) in the transition period between planned and market economy periods corresponding to the detailed regulatory planning regime, to blocks SB–5 (1990), SB–3 (1997) and SB–1 (2004) during the market economy and modern stage with the technical planning provisions and urban design guidance. Due to various changes in population and land functions, some blocks were later gradually subdivided into multiple blocks by new roads. Each block consists of multiple plots or one larger plot. The characteristics of the morphological attributes of these five blocks were identified by comparing planning approval maps, 2007 topographical maps and the most recent aerial photographs. Observations show a transition in land use from sole functions of residential or public buildings or a few mixed uses, to diverse activities and complex mixed uses including residential, commercial and industrial and others. The block sizes range from an expansive 55 ha to a more modest 1.9 ha. These five street blocks reflect the varying morphological characteristics of Nanjing's historical city centre.

Secondly, the 142 plots were examined and classified according to their varied morphological attributes relating to land-use function, plot size, plot shape and building layout, to analyze the correlation between plot indicators and the morphological characteristics of building combinations. As Figure 3 shows, these plot samples comprise 74 residential-oriented and 68 public building-oriented plots: first, based on the land-use function attribute, they were classified into four types of plots of single residential, residential dominance mixed with other functions, single public building plots, and public building dominance mixed with other functions; secondly, they were further classified for each functional type of plot

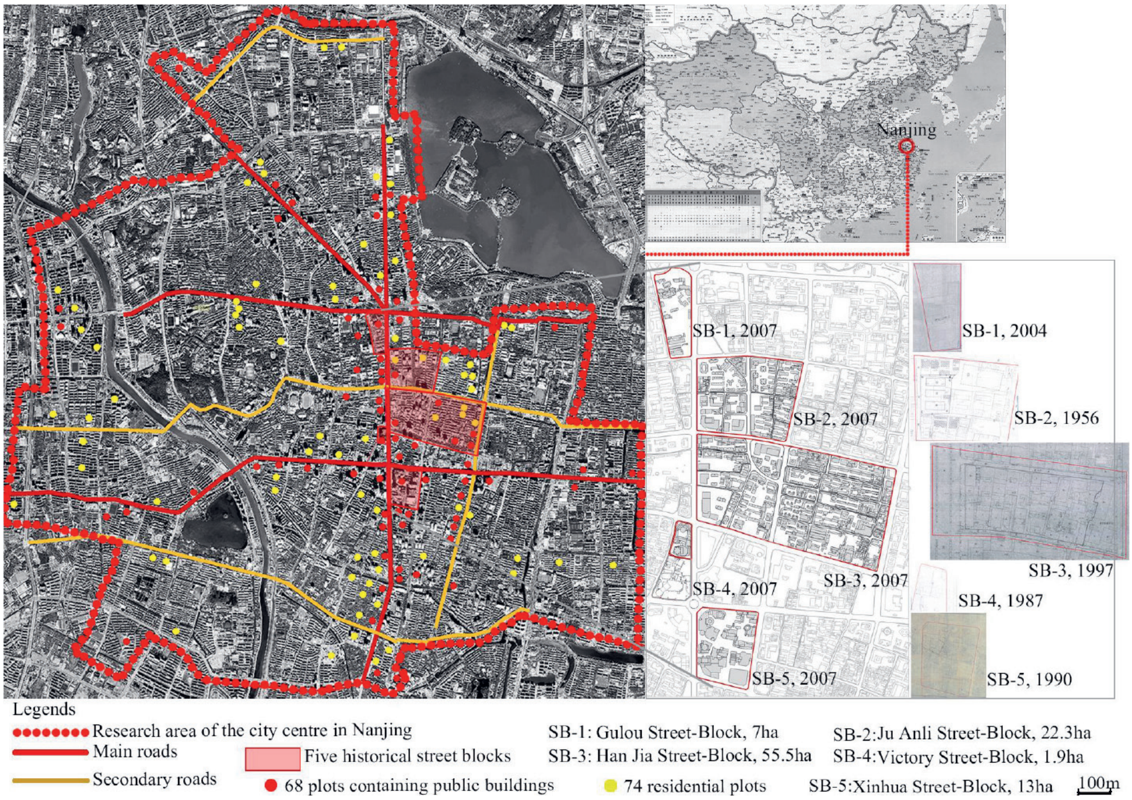


Figure 2. Example of five historical street blocks and 142 plots in Nanjing city centre.

according to plot size and shape; for instance, plot type of single residential use and regular and large size, and so on. This therefore shows the characteristics of morphological attributes of these plots: the land uses of these plots range from single residential or public buildings such as commercial, schools, hospitals and military areas to mixed uses. Plot shapes changed from regular quadrangular to irregular; the building heights varied from low-rise, mid-rise and high-rise to super-high-rise, and the building layouts transitioned from dense to sparse with open space.

Land-use regulations related to street-block and plot forms

Historical development, and original purpose, of relevant urban planning policies

In China, the regulations relating to urban form are mainly found in urban planning policies and design codes at the national and local levels, ranging from planning laws, regulations such as land use and urban landscape, architecture codes and urban design guidance. Specific morphological policy documents have not yet been produced. Urban planning policy has developed significantly in response to the shift from a planned economy to an open market economy. This change shifted urban construction from the initial purpose of addressing urban functional health and safety problems, such as lighting, fire protection and traffic congestion, to concern about the quality of urban form and the sustainable environment. Using Nanjing as an example, urban construction regulations have developed through four stages.

From 1928 to 1978, during the planned economy era, land use and building layout were controlled by local regulations for dealing with the urban functional issues (Public Affairs Bureau of Nanjing Municipal Government (PABNMG), 1928; Nanjing Municipal Government (NMG), 1935, 1948;

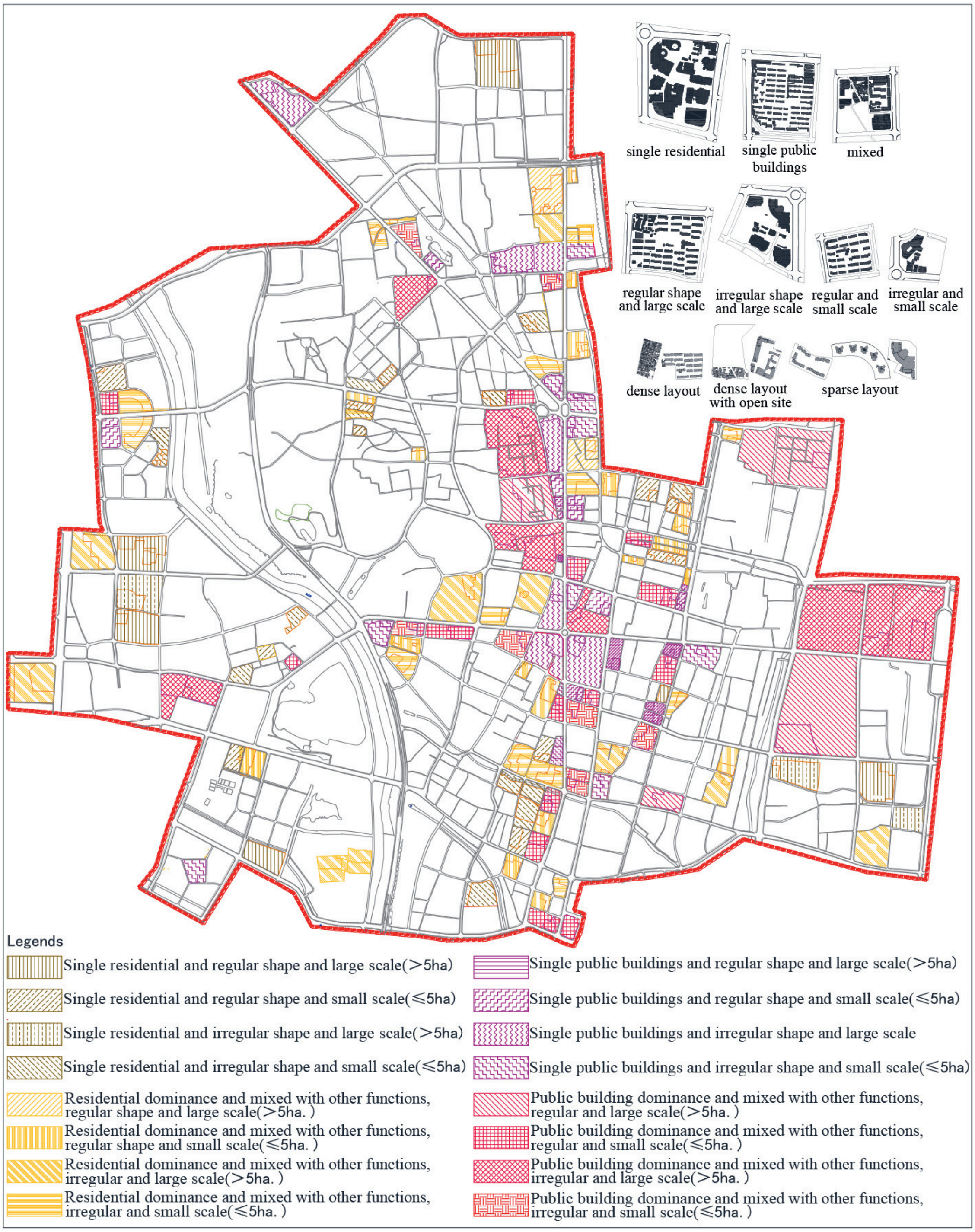


Figure 3. Classification of the morphological attributes of plots: land use, plot shape and size, and the layout of buildings in plots.

People's Government of Nanjing (PGN), 1978). In the transition period from 1978 to 1987, with the shift from a planned economy to a market economy, 'detailed regulatory planning' emerged, mainly focusing on the indicators controlling land functions and development intensity (PGN, 1987). In the third stage, from 1987 to 2009, the market economy era, a ‘technical’ tendency emerged, with an increased government control having insufficient emphasis on human and natural environment protection (PGN, 1995, 1998, 2004, 2007; Standing Committee of the National People’s Congress (SCNPCPRC), 1990, 1999; Ministry of Housing and Urban-Rural Development of China (MHURDC), 1990, 1999). From 2009 onwards, the fourth stage has been a period of rapid urbanization, promoting the implementation of a new model integrating land preparation, planning standards and urban design guidelines adapted to local conditions (SCNPCPRC, 2008; Standing Committee of Jiangsu Province (SCJPRC), 2010; People’s Government of Jiangsu Province (PGJP), 2010; MHURDC, 2011; Standing Committee of Nanjing (SCNMPC), 2012). These stages highlight the continual evolution and refinement of urban planning policies in response to socioeconomic shifts.

Review, classification and numerical analysis of relevant land-use regulations

This study evaluated 6,063 items from 119 urban planning policy documents at national, provincial (Jiangsu), and municipal (Nanjing) levels based on the four periods of Nanjing’s planning regulations and the criteria related to morphological elements in land-use provisions. This review identified 2,724 clauses related to urban form, within which there are 1,291 clauses of relevant land-use provisions. Using a quadrant mapping method (see Gauthier and Gilliland, 2006), these relevant land regulations were categorized into directly mandatory, directly guiding, indirectly mandatory and indirectly guiding (Figure 4A), following the mandatory and guiding criteria set by the *Nanjing urban planning approval guidelines* (Nanjing City Planning Bureau (NCPB), 2005). However, analysis of the number of relevant clauses shows that such highly operational mandatory land-use provisions, which significantly affect form, were relatively few, with 8.6 per cent directly and 10.9 per cent indirect mandatory land provisions in the 2,724 clauses related to urban form (Figure 4B). These are typically included in the local regulatory planning documents. Most other provisions belong to the guiding categories, including proposals for urban land layout, functional zoning and environmental coordination.

Primary land indicators related to street-block and plot forms

In these relevant land-use regulations, land indicators are key provisions affecting urban form, including land use, plot and building layout indicators, primarily in the direct and indirect mandatory regulation categories. First, land-use indicators regulate urban construction through the scale of land-use units, nature and compatibility of land, the proportion of land-use composition, plot divisions and other variables that influence changes in street-block forms. For example, Figure 5 provides a graphical analysis of crucial land indicators related to urban form. Figures 5A and 5B illustrate the analysis of proportional composition of land use, articles 2.0.1, 2.0.5 and 4.3.1 of the *Classification of urban land and standards for planning construction land* (MHURDC, 1990), and the plot divisions, articles 5 and 6 of the *Compilation guidelines of detailed regulatory planning in Jiangsu Province* (PGJP, 2006, 2012).

Secondly, plot and building-layout indicators control land development intensity and building locations on the plot by specifying the minimum site area, the upper limit of FAR and BD, sunlight and fire distances between buildings, and building setbacks from land boundaries and roads. All of these are related to the plot attributes and then to the form of building combinations. Figure 5C is a graphical example of the upper limit of FAR and BD in the technical regulations of local planning.

Correlation between land-use regulations and morphological characteristics of street-blocks and plots

To verify the relevant influence of land-use regulations on urban form, the relationship

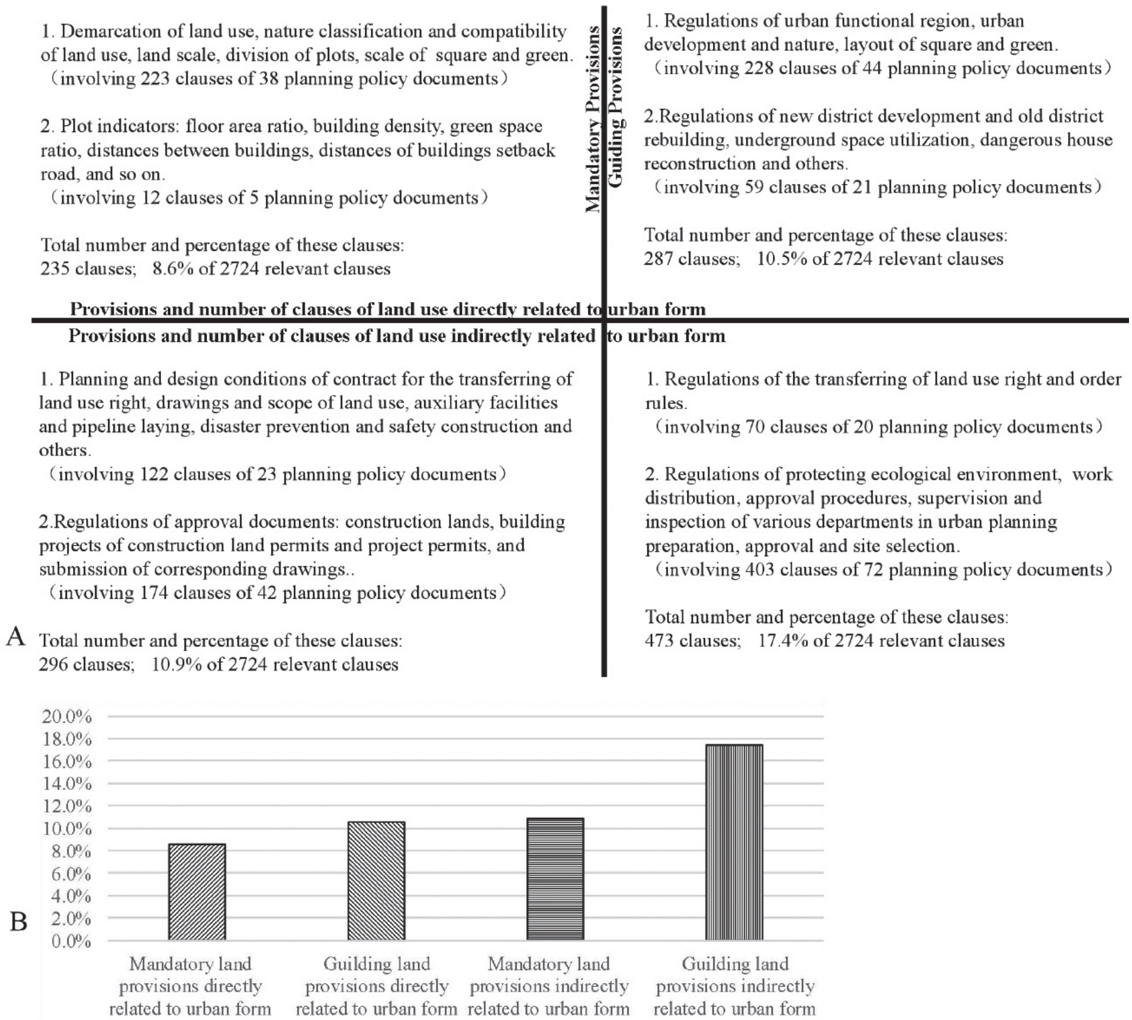


Figure 4. A) Classification of land provisions related to urban form mapped in four quadrants; B) Numerical analysis of land-use regulation clauses.

analysis was conducted from two aspects of theoretical analysis – creating the morphological model and correlation evaluation chart, and empirical analysis – involving examining street-blocks and plots in Nanjing's historical city.

Creation of the morphological model and the correlation evaluation chart

First, a morphological model of the street block following the land use indicators was constructed. This process primarily involves utilizing a key existing land use indicator – 'proportion of land-use composition' –, selection of the ratio of residential land area (RLA) as a standard parameter, and proposing a new morphological indicator, the degree of complexity of plot divisions (DCPD). DCPD indicates the morphological characteristics of land division, pattern and use within street blocks. A fundamental attribute, the number of plot divisions (PN), is a correlation between land indicator regulations and morphological characteristics.

Due to the lack of prescriptive morphological indicators in current policy, this study proposes the use of DCPD to examine the morphological characteristics of land use and layout within street blocks. It is calculated by dividing PN by RLA. The reason for using

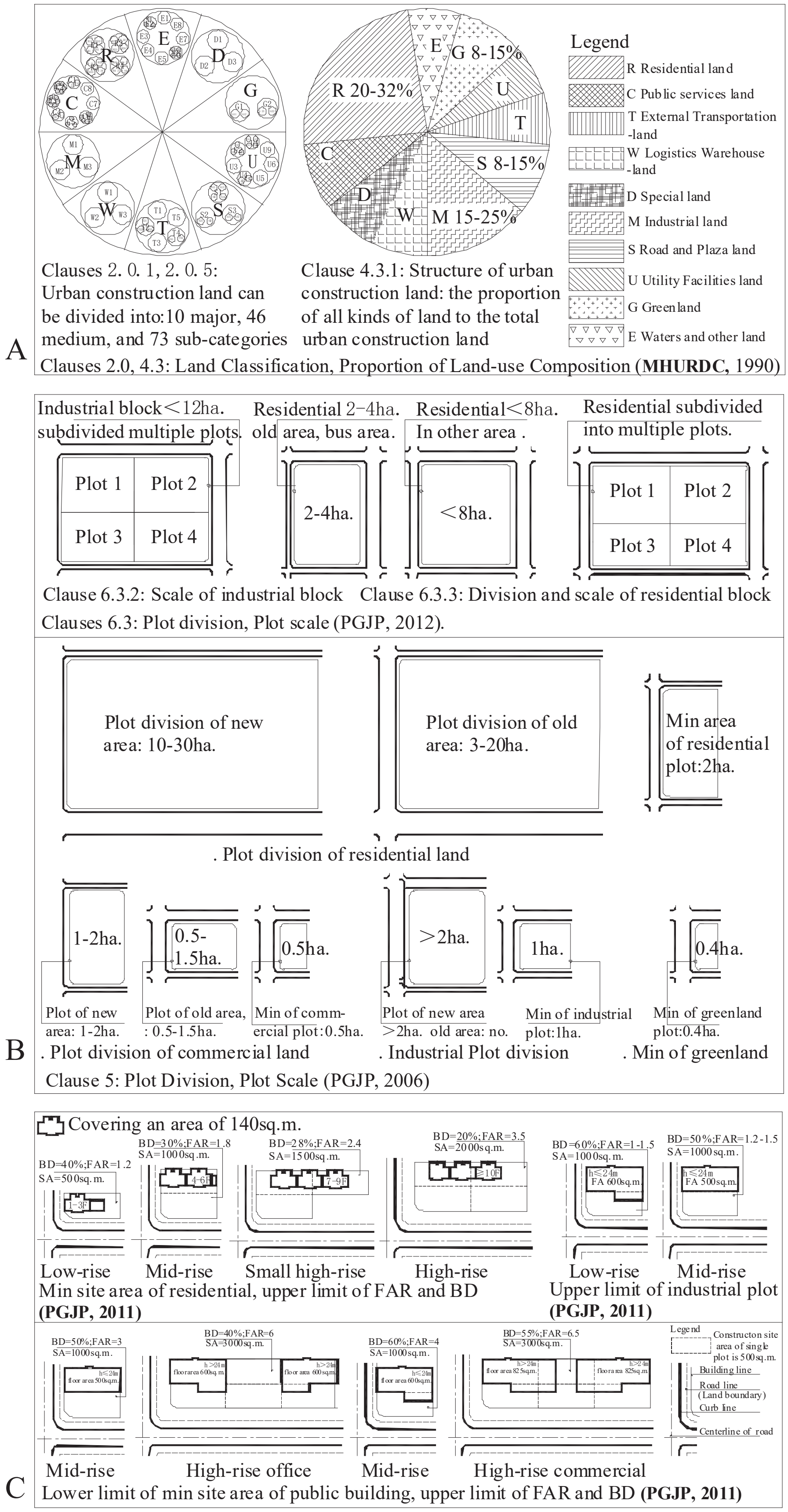


Figure 5. Graphical analysis of primary land indicators: A) proportion of land-use composition (MHURDC, 1990); B) provisions of plot divisions (PGJP, 2006, 2012); C) upper limit of FAR and BD (PGJP, 2011).

RLA as the standard parameter for the proportional composition of land use in this formula is because the residential-oriented blocks have a more orderly layout and systematic plot division in Nanjing's street blocks.

Consequently, three morphological models integrating DCPD, RLA and PN were created to illustrate the relationship between the street-block form and land-use regulations from a theoretical perspective, as shown in Figure 6. Model 1 (Figure 6A) represents a theoretical model of the DCPD related to PN changes within a block where RLA is constant. For instance, if RLA remains at 50 per cent and PN varies at 10, 20, 30, 40 and 50, the corresponding DCPD would be 0.2, 0.4, 0.6, 0.8 and 1. This model demonstrates that an increase in plot subdivisions corresponds to more change in land-use composition from the physical morphology structure. However, other cultural and social factors also influence this. Model 2 (Figure 6B) shows a theoretical model of DCPD associated with the RLA changes while PN remains constant. Assuming PN of 10 and varying RLA at 20, 40, 60, 80, and 90 per cent, the corresponding DCPD would be 0.5, 0.25, 0.17, 0.125 and 0.11. Model 3 (Figure 6C) serves as a comprehensive model to further verify the correlation by combining various land-use indicators such as the land units, proportion of land-use composition, nature and compatibility of land use, and plot divisions (according to MHURDC, 1993, Article 3.0.2; PGJP, 2012, Article 6). A primarily residential block with public service facilities of commercial and office space was designed in an approximately 3 ha area, with a percentage land-use composition of 50 residential, 18 public buildings, 10 roads, 12 green space and 10 other uses, following the land indicators. This model demonstrates that diverse block form types were related to various changing indicators.

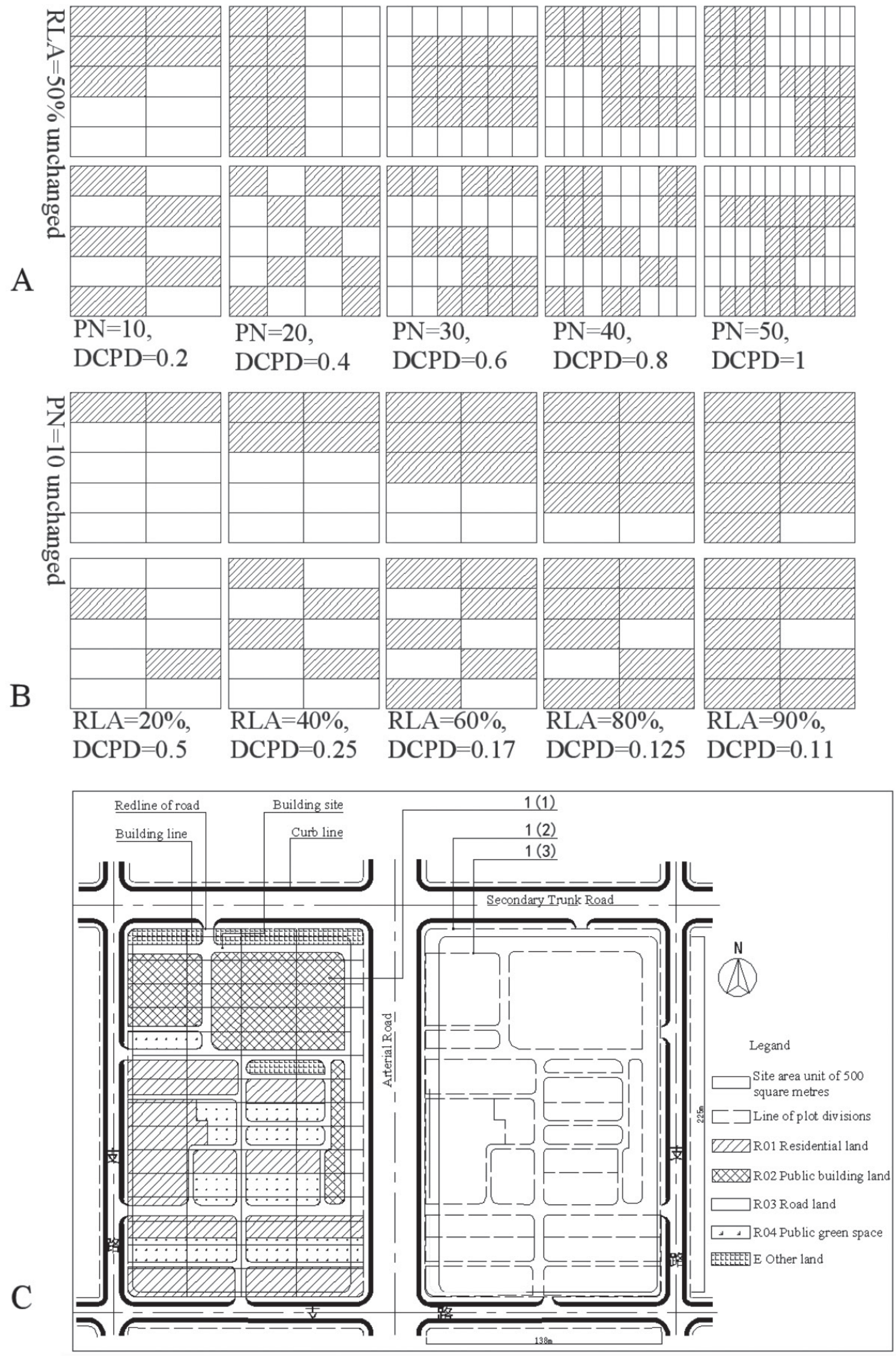
Secondly, the theoretical morphological model following the plot indicators was constructed. According to the relevant regulations (PGN, 2007, clauses 42–4; PGJP, 2011, clauses 2.3, 3.5, 3.6), plot and building-layout indicators related to urban form primarily encompass the FAR, building density (BD), sunshine distance between buildings (SDB), and fire distance between buildings (FDB). The number of building stories (BS), as another attribute, is also a correlation between plot indicator provisions and morphological characteristics of building combinations in the plot.

Consequently, three theoretical morphological models were developed (Figure 7). Model 1 (Figure 7A) relates BD to the change in FAR and BS within the same plot. For instance, with constant BS, BD morphological changes are tied to FAR. As the figure shows, if BS remains at 10 stories, when FAR is 1 and 4, BD is 10 and 40 per cent. Moreover, similar correlations exist with FAR or BD unchanged.

Model 2 (Figure 7B) indicates morphological changes in building combinations on a residential plot, relating BD and the open site ratio (OSR) to SDB and FDB, given a constant FAR. This analysis proposes the morphological indicator OSR, as the open area of the site divided by the ground floor area of buildings, or 'building footprint'. For instance, residential buildings have the same length, width, and number of storeys (BS) in the plot: when BS is 3, SDB and FDB are 13.5 m and 6 m, BD is 30 per cent and OSR is 0.78. The same correlations exist when BS is 6 and 10 storeys.

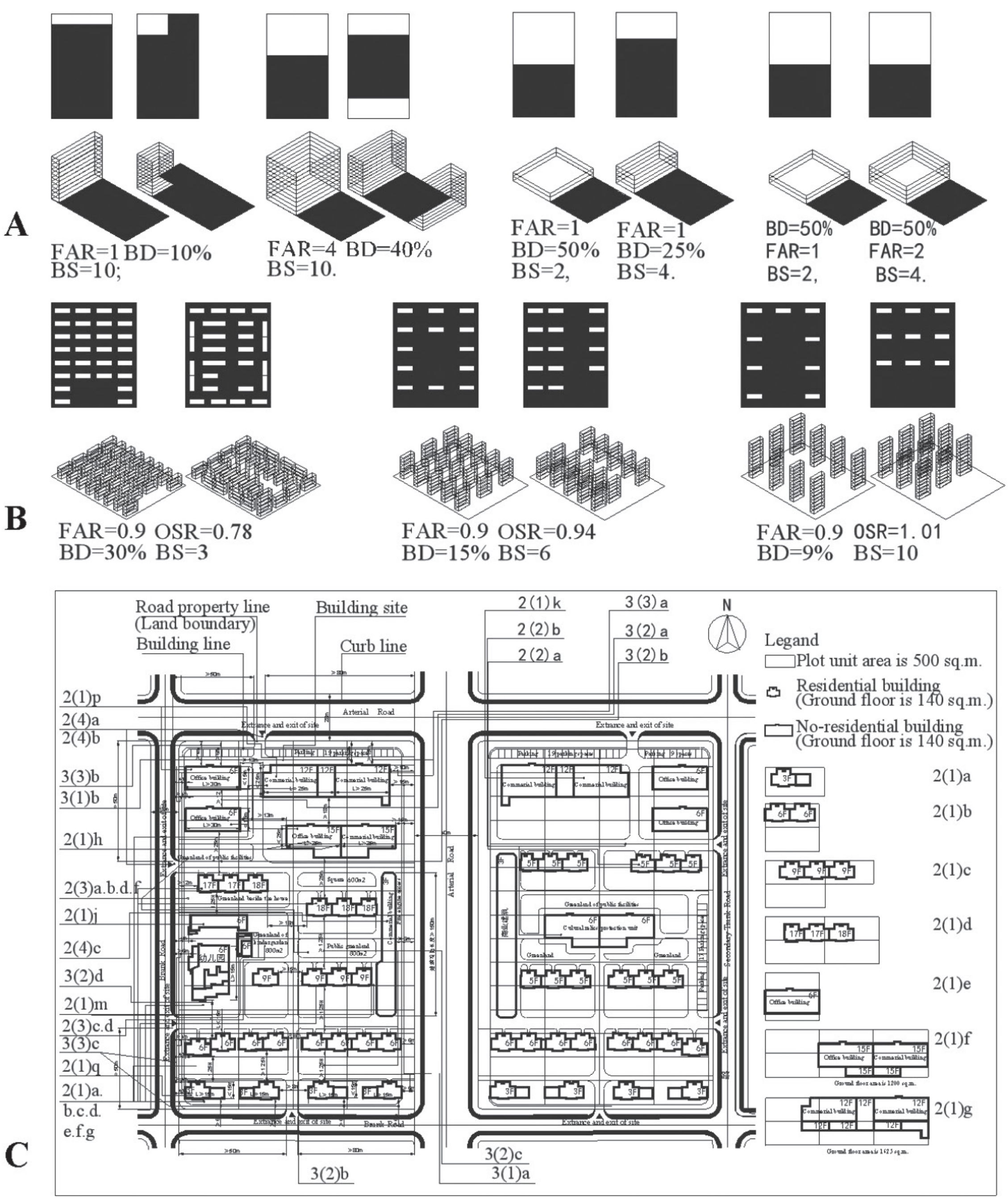
Model 3 (Figure 7C) is a comprehensive morphological model for building combinations within a 3 ha block. This model highlights the effects of multiple plot indicators on block and plot form. In this model, the residential plots (500 sq. m for low-rise, 1,000 sq. m multi-story, 1,500 sq. m small high-rise, 2,000 sq. m high-rise residential), the public building plots (1,000 sq. m multi-story, 3,000 sq. m multi-story public buildings corresponding to different ranges of BD and FAR), the green spaces and squares were arranged from south to north according to the upper and lower limits of each indicator. It showed that the diverse form types of building combinations in plots related to changing multiple plot and building-layout indicators.

Thirdly, the correlation evaluation chart was established (Figure 8) to verify the relationship further. Figure 8A indicates that the



Annotation: Relevant provisions of theoretical morphological model
1 Regulations of land use
1(1) Provisions of nature classification and compatibility of construction land, land proportion of planning and construction;
1(2) Provisions of block scale: residential block scale is 2 to 4 ha in old district;
1(3) Provisions of plot divisions: block is subdivided several plots.
According to :
1(1): Clause 3.0.2 (MHURDC, 1993); 1(2), 1(3): Clause 6 (PGJP, 2012).

Figure 6. Theoretical morphological model: A) RLA 50% unchanged, DCPD changes associated with PN; B) PN10 unchanged, DCPD changes associated with RLA; C) comprehensive model.



Annotation：Provisions corresponding and related to theoretical model

2 Regulations of plot indicators:

2(1)Building density and floor area ratio；2(2)Building Height;

2(3) Green ratio in building site; 2(4) Entrance and exit in building site.

According to: Clauses 2.3, 3.4~ 3.6 (PGJP, 2011).

3 Regulations of buildings layout:

3(1) Distance of buildings setback roads; 3(2) Distance between buildings;

3(3) Distance of buildings setback land boundary line.

According to: For3(1), 3(2), 3(3), Clauses 42 and 43 (PGN, 2007);

For 3(2)a, Clause 3.2 (PGJP, 2011).

Figure 7. Morphological model of building combinations in the same plot associated with plot indicators: A) model related to the changes of BD, FAR and BS; B) model of a residential plot related to the changes of OSR, BD, SDB and FDB; C) comprehensive model.

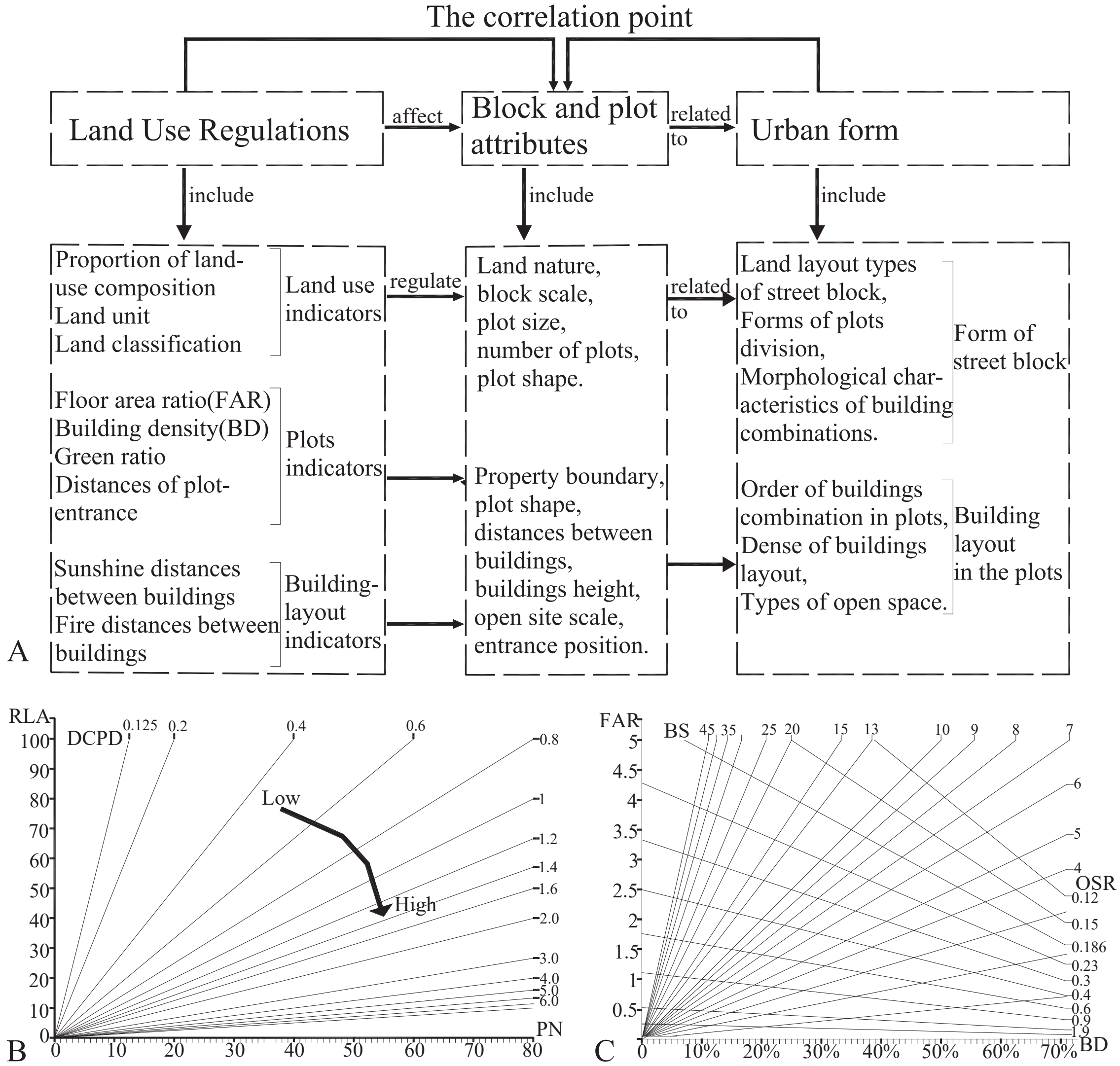


Figure 8. Correlation evaluation chart: A) correlation point; B) correlation chart between land use indicators and street block form, combining the RLA, PN and DCPD; C) correlation chart between plot indicators and buildings combination form in the plot, combining the FAR, BD, FL and OSR.

correlation point (block and plot attributes) between land-use regulations and urban form is the key to analyzing the relationship. The land indicators are critical land-use regulations, and the morphological indicators reflect the morphological characteristics. While land-use indicators control the land development intensity and building locations, they could promote changes in attributes, thereby influencing changes in the morphological characteristics of blocks and plots. Figure 8B represents the correlation between land-use indicators and street-block form, combining land indicators of RLA, the attribute parameter PN and the morphological indicator DCPD. This chart evaluates the morphological types of land layouts in the block corresponding to the different ranges of land-use indicators in the empirical case analysis. Figure 8C illustrates the correlation between plot indicators and the form of building combinations, integrating the plot indicators FAR and BD, attribute parameter BS and the morphological indicator OSR. This chart evaluates the

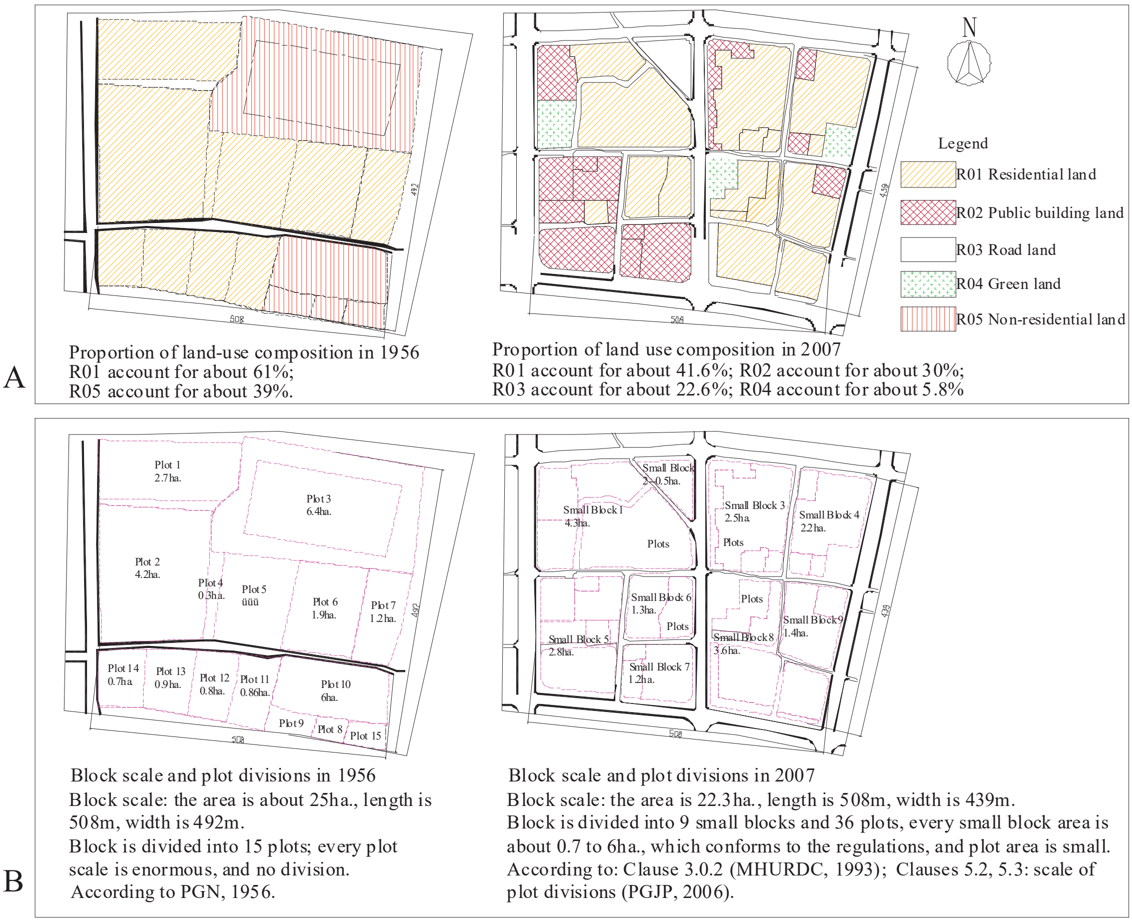


Figure 9. Ju Anli block: correlation analysis between block form and land indicators from 1956 to 2007: A) analysis of the change in proportion of land-use composition; B) analysis of the change in plot divisions.

morphological types of building combinations corresponding to different ranges of plot indicators for the empirical analysis of cases.

Relationship between the morphological characteristics of street-blocks and land-use indicators in the historical context

The plan of land-use composition and plot divisions of the five sample blocks in the year of approval and 2007 was plotted, based on the planning approval maps of relevant plot development boundaries and the 2007 topographical map of Nanjing, to examine the relationship between the land-use indicators and the morphological changes of the street-block layout over time. This is demonstrated using the example of the Ju Anli block (Figure 9), approved in 1956. This block's land-use composition underwent a significant transformation, changing from 61 per cent residential and 39 per cent non-residential use in 1956 to a more diverse composition in 2007: 41.6 per cent residential, 30 per cent public buildings, 22.6 per cent roads and 5.8 per cent green space. According to the *Nanjing building management rules* (NMG, 1948) and *Urban residential areas planning and design code* (MHURDC, 1993), residential use should account for 60 per cent and public buildings 15–25 per cent. This shows that the land use of the block gradually changed from a single land function before 1956, not strictly following the regulations, to meet the land-use provisions in 2007.

This block's plot divisions have also changed, from one large street-block surrounded by the original roads into nine smaller blocks divided by new roads. Further, the plot divisions within the block changed from 15 large-scale plots with fewer plot subdivisions pre-1956, to 36 plots ranging from 0.7 to 6 ha in 2007, which follows the provision that "the scale of residential blocks in the old city is 2–4 ha and not more than 8 ha" (PGJP, 2006). This transformation demonstrates that the regulation of plot division scale from a lack in 1956 to a relevant provision in 2007, with plots evolving from large to small, the land use changing from single-function to a diversity, and greenery and public space decreasing. Consequently, the block form evolved from a simple concentration to a complex, disorganized layout. Four other sample blocks were examined using a similar method (Figure 10).

A morphological correlation chart between land-use indicators and street block form was prepared for the five sample blocks to evaluate the relationship. The RLA, PN and DCPD of the five blocks in the planning approval year and 2007 were calculated and plotted on the correlation chart. For example, the Ju Anli block was represented as point b in 1956 and point b' in 2007. The transition from b to b' signifies the degree of complexity of block form change.

Figure 10 shows that the morphological changes of the street blocks were related to the land indicators. With the policy evolving from a lack of regulation to the indicators, the five sample blocks changed from a high proportion of residential land, single function, fewer plot divisions, and regularly-shaped plots in the planning approval year to a prescribed proportion of residential and various land uses, detailed plot subdivisions, and irregular shapes by 2007. This change indicated that, with the changes of relevant regulations over the years, land use had been gradually changed by the land indicators. However, while indicators effectively controlled the land development within blocks, it precipitated the degree of complexity of plot divisions changing from low to high, and the block layout forms shifted from regular and single to complex and diverse.

Relationship between the morphological characteristics of building combinations and plot indicators

The correlations for the 68 sample plots containing public buildings were verified in two steps. Step 1 examined the ratios between conforming to and breaking the limits for provisions of FAR and BD in each plot, to evaluate the effectiveness of the control of land development and building location by plot indicators. Based on the 2007 map, the FAR, BD and BS parameters were calculated for each plot and compared to the upper limit provisions. Finally, the ratios of conforming and breaking were calculated. Due to the lack of indicator provisions in Nanjing for the approval year of each plot or earlier, the plot indicators of the *Technical regulations of Jiangsu urban planning* (PGJP, 2011) were set as the consistent basis for comparison. Eleven plots exceeded the FAR upper limit, four exceeded the BD limit, but most complied with the regulations (Figure 11). This indicates that the plot indicators effectively regulate land development and influence the morphological change of building combinations. But, corresponding to the FAR and BD, about 80 per cent of the buildings with variable heights and mass are likely to reflect the developers' responses to the policy aiming to provide urban space through increasing the building capacity, such as increasing the height of the buildings while keeping the building volume unchanged.

Step 2 analyzed the relationship between plot indicators and morphological characteristics of building combinations. First, the BD, FAR, average BS and OSR for each plot were calculated and marked in red on the correlation chart (Figure 12 upper). For example, point 1' in circle A corresponds to plot B6 of the courtyard unit type in the old city centre. Secondly, the varied morphological types of building combinations within the plots corresponding to the different ranges of BD and

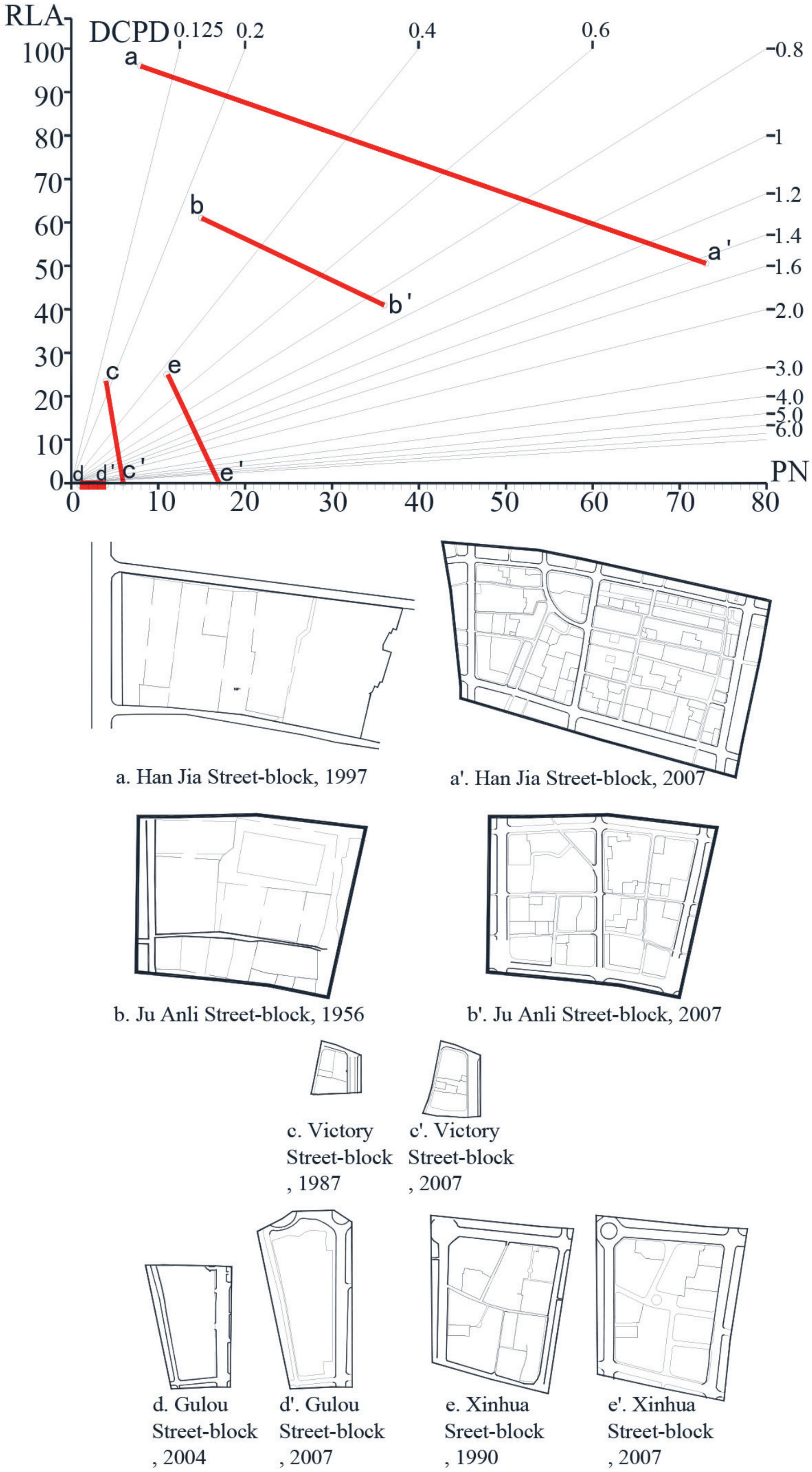


Figure 10. Correlation analysis between morphological characteristics of five street blocks and land indicators.

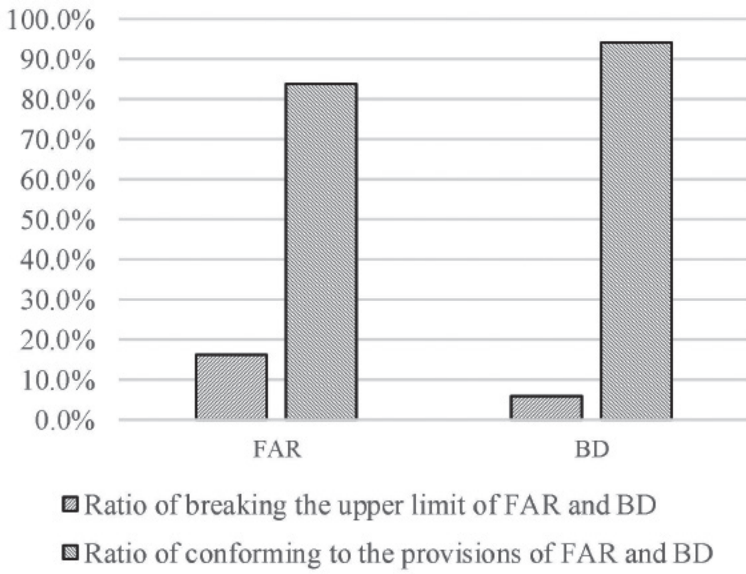


Figure 11. The conforming and breaking ratios of FAR and BD for 68 public building plots.

FAR were classified by circles A to G. These types are principally defined by their building functions, heights, density of building layouts, open space types, and locations in the city centre or fringe areas. For example, circle A represents the morphological type of low or multi-rise public buildings with unit compounds in the city centre or fringe areas, or residential plots with densely arranged buildings in the fringe areas, accompanied by large open spaces, lower BD – less than 20 per cent – and FAR less than 1.5, and OSR higher than 1.5. Circle B indicates the plots mainly composed of low or multi-story public buildings with dense, complex and disorganized building layouts in the city centre or fringe area, and a higher BD of between 50 and 70 per cent. Circle C corresponds to three morphological types with multi-storey residential or public buildings or a mixed layout, BD between 25 and 35 per cent, FAR 1–3, and OSR 0.3–0.9. The morphological types of other circles are illustrated in Figure 12. These findings illustrate that most plots in Nanjing's old city contain multi-story and high-rise public buildings; some are occupied by one to three multi-storey and super high-rise libraries and hotels and others. These plots generally conform to the upper limit of the plot indicators, and they have a higher BD of 35 to 60 per cent, higher FAR of 3 to 6, and lower OSR of 0.1 to 0.4.

Secondly, a similar methodology was applied for the 74 sample residential plots. In step 1, key parameters including BD, FAR, average BS and OSR of each plot were calculated and marked in yellow on the correlation chart. In step 2, the morphological types of building combinations within the plots, associated with different ranges of BD and FAR, were classified and represented by circles. For example, point 1 within circle C corresponds to plot B5, a multi-story residential plot in the old city. This analysis reveals that most multi-storey residential plots in the old city of Nanjing have a BD of 30 to 45 per cent, a lower FAR of 1 to 1.2 and a higher OSR of 0.25 to 0.45. Some multi-storey, high-rise, and super high-rise plots, predominantly residential, have a higher BD of 30 to 60 per cent, a higher FAR of 3 to 6, and a lower OSR, below 0.2. In the fringe of the old city, some new high and super high-rise residential plots, built after 2000, conform to the regulations of BD between 20 and 40 per cent, a higher FAR of above 6, but a small OSR of between 0.05

and 0.15. Some low-rise residential plots, built before 1995, possess a high BD of 80 to 90 per cent, FAR of 1 to 3, and small OSR of 0.04 to 0.07.

The results of the relationship analysis indicate that the morphological characteristics of building combinations are closely related to the plot indicators. These indicators effectively regulate the development intensity, construction capacity, and building location of plots. However, this regulation affects the changes in attributes such as plot size, shape, and plot property boundaries: subsequently influencing the morphological characteristics of building layouts and open spaces. Plot indicators of urban planning policy could be weak in regulating morphological development, instead presenting a more varied and complex fabric form. The layout forms in the plots dominated by public buildings are dense and disorderly; the residential plots have a dense building layout with less public open space in the old city and sparse layouts in the fringe area. A severe problem of urban form is that low-rise and old residential plots have very dense layouts because of a lack of relevant BD limit provisions at the time of construction. These plots exceed the upper limits of current plot indicators.

Conclusions

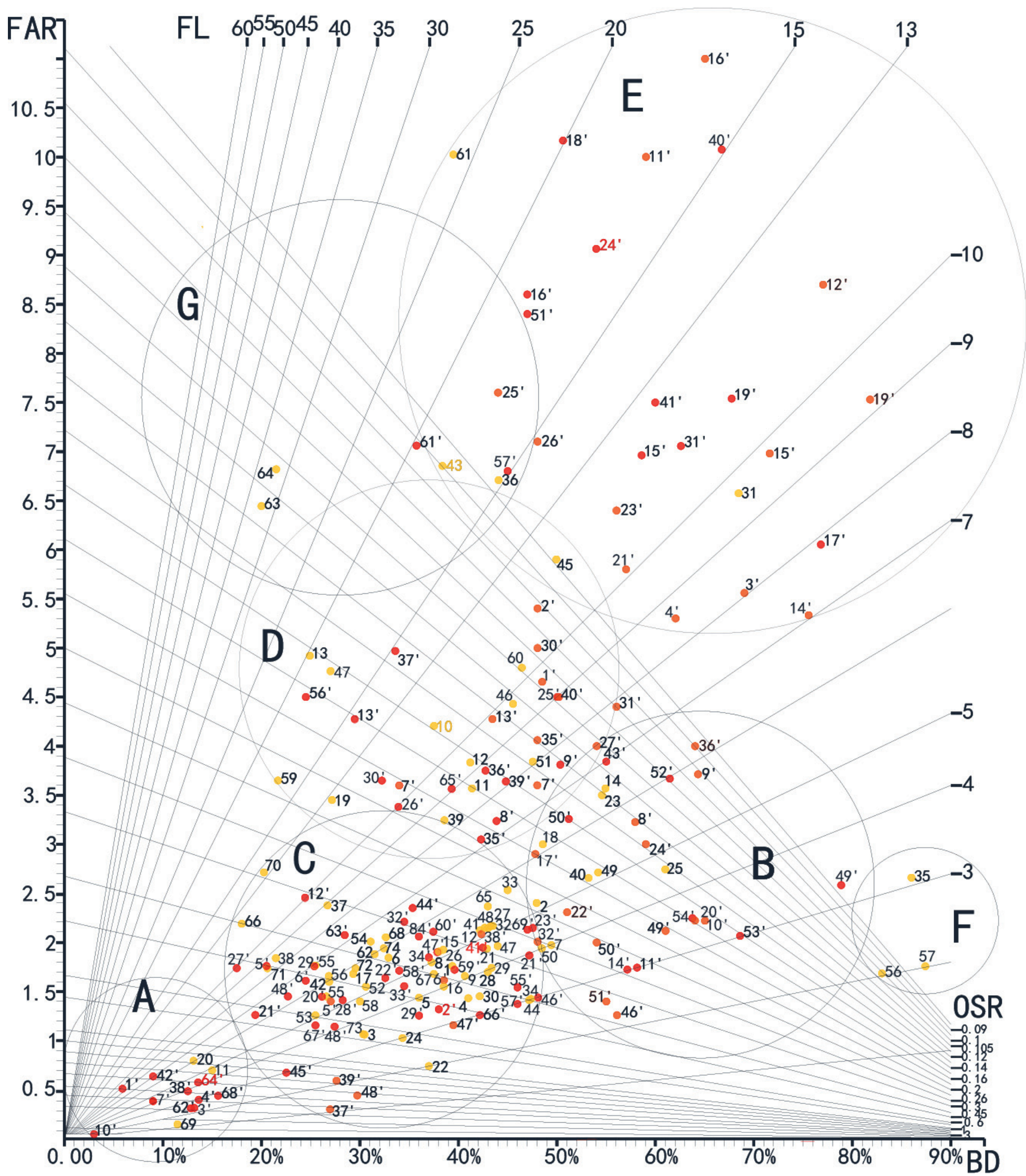
The gap between morphological research and practice in planning and design is a significant concern. The formation and subsequent development of urban form, since the mid-twentieth century or so, are closely linked to urban planning and design policy. Regulations have been frequently adjusted to meet market needs and address health, safety, and other functional issues, as a basis for design and construction. This has led to the attributes of plots and street blocks changing, and has influenced the morphological characteristics of urban form. However, morphological issues are not a direct result of regulatory control but form unexpected results. Hence urban planning policies also face a transition from solving problems of urban function to shaping an urban form of livable quality. Therefore, this study of one major Chinese city has a significant contribution in the morphological model creation, theoretical research value, and practice reference for improving urban planning and design policies.

First, the morphological model is an effective method of morphological research. This paper developed a morphological model and a correlation evaluation chart, to examine the relationship between land-use regulations and urban form through theoretical and empirical analysis. Thus, this study verifies the influence of the correlation; moreover, it provides an innovative perspective and complete path from the theoretical generation of morphology to the practical development of historical deduction of morphology by urban policy. It is an essential basis for understanding how urban form has changed and been shaped.

Secondly, urban planning policy is an essential and universal mechanism influencing the generation of urban form, thereby increasing the theoretical value of morphological research. It is demonstrated through examining the literature on the perception and vital operational elements of urban form and the relationship between urban form and relevant regulations, reviewing Chinese urban planning policies that influence urban form, and analyzing the correlation between regulations and form in historical scenarios.

Thirdly, mandatory regulations with quantitative indicators are currently the key factor in shaping urban form in China. Through theoretical analysis and empirical validation, the relevant regulations of land use and plot indicators directly and effectively regulate the scale and shape, land use and layout structure of urban blocks, and the development intensity of plots. However, these indicator regulations are also closely related to the morphological characteristics, associated with vague and disorderly block forms, complex land layouts, and disorderly organization of building groups, and further face some social problems of separation of different land functions, local characters, lack of public space, and so on.

Finally, from the practical perspective of urban morphology, this study provides a basis



A: Plots of public buildings with unit compounds or open spaces in the city centre or fringe areas. The morphological units include military compounds, schools, book and exhibition centres, hospitals and hotels. Alternatively, public buildings and squares occupy a whole plot.
Low or multi-storey (below 5 storeys); lower BD (less than 20%) and FAR (less than 1.5); and higher OSR (1 or more). Conform to the upper limit provision of plot indicators.
Plots dominated by residential use. Dense layout, orderly, and with large open spaces.
Low and multi-storey (below 7 storeys); lower BD (less than 20%) and FAR 0.2–0.7; and higher OSR 1.5–5. Conform to the upper limit provisions.

B: Plots dominated by public buildings in the old city centre or fringe area. Dense layout, and disorganized.
Low or multi-storey; very high BD (50–70%) and lower FAR (less than 3). Conform to the upper limit of indicators.

C: Corresponding to three morphological types of plots: first is predominantly multi-storey residential; second is public buildings; third is mixed layouts, in the city centre, fringe and the new area.

- First, plots dominated by residential, dense layouts, the part of residential plots are rhythmic and orderly, and the combination form of public buildings is complex and disorganized.
  Higher BD (30–45%), FAR 1–2 and higher OSR (0.25–0.45).
- Second, plots with mixed residential and public buildings, with open space in some hospitals or schools. Orderly residential fabric, complex and disordered public buildings.
  BD 25–35%, FAR 1.5–3, and 0.3–0.9, conform to the provisions of plot indicators.
- Third, plots are dominated by multi-storey public buildings, or mixed residential and public buildings.
  BD 20–50%, FAR 1–3, and OSR 0.3–0.6.

D: Corresponding to three morphological types of plots: first is multi-, high- or super-high-rise residential; the second is public buildings; and the third is mixed, in the city centre or fringe or new area.

- First, multi-, high- or super-high-rise residential plots or plots of mixed buildings.
  Dense layout, orderly residential plots, and transparent fabric; cluttered and disorganized public building layout.
  BD 30–60% and FAR 3–5, OSR below 0.2, a few plots break the upper limit of indicators.
- Second, plots are mainly occupied by multi-, high- or super-high-rise public buildings, with public areas at the front and rear of each public building as car parks or green squares. Complex and varied building combination forms with variations in building heights.
  Higher BD (35–55%) and FAR 3–5.5, OSR 0.1–0.4. Conform to the provisions.

E: Plots dominated by high- and super-high-rise public buildings in the old city centre.
Variable building heights, separated and disordered form of buildings combination.
Very high BD (50–70%) and FAR (5–11), and very low OSR (0.03–0.09), some plots break the upper limit provisions.

F: Low-rise residential plots in the fringe of the old city centre or new area. With a very dense layout, lower building heights, and a lack of public space.
Most of the plots are in the process of renewal.

G: High- and super high-rise residential plots in the fringe of the city centre or new area, well-arranged and ordered building combination, sparse building layout, with ample public space.
Lower BD (less than 25%), higher FAR (2–5), and OSR 0.2–0.5.

Figure 12. Relationship analysis between the plot indicators and morphological characteristics of building combinations in the plots.

for preparing and revising morphological indicators, urban design codes and planning policy. Moreover, it could be used with existing regulations to strengthen the operability of urban design and evaluate urban form. For instance, after ensuring no conflict with the present policies, it would be possible to introduce more morphological elements in relevant urban design guidelines, planning technical regulations and local planning, and this is essential for improving urban construction and raising the quality of the sustainable urban environment.

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