A temporally cyclic growth model of urban spatial morphology in China: evidence from Kunming Metropolis

Abstract:

Rapid urbanization and complexity of political-economic transition in China has brought about continuous and remarkable changes of urban morphology over the past decades, which were driven by a mixture of spatial, social-economic and institutional forces. Understanding such urban morphological evolution requires new mixed evidences and holistic perspectives. In this paper, it is argued that two dominant types of urban growth in China: low-density expansion and high-density infill might be driven by different forces at different stages. To interpret the processes of urban development, two easy-to-understand morphological indicators: expansion-induced investment density index" (EID) and "infill-induced investment density index" (IID) are defined to measure the investment density per unit of developed land and used to compare the morphological changes between different phases in a long period by integrating spatial and socio-economic data. The temporal variation of these indicators suggests a cyclic growth model (CGM), which means the periodic switch between low density expansion and high-density infill. Using Kunming metropolis as a case study, this paper has confirmed that its urban morphological evolution from 1950-2014 was periodically and reciprocally driven by a set of vis-à-vis dualistic dynamics, in which low-density expansion is led by pro-growth infrastructure oriented public investment, while the high-density infill is activated by collective and rational actions of individual enterprises and their economic behaviors. It is concluded that the confirmed CGM model, together with two morphological indicators, offers a new holistic perspective and method to easily and integrally interpret urban morphological evolution and accordingly has potential theoretical implications for reasonably understanding the urbanisation in China.

Keywords: Urban morphology; cyclic growth model; low-density expansion; high-density infill; Kunming

1. Introduction

With the dazzling achievement of economic development, China has approached a fast urbanization epoch and demonstrated a spectacular growth for three decades (Barro, 2016).The built-up area of 652 Chinese cities increased by 39,628 km^2 from 12,474 in 1988 to 52,102 km^2 in 2015, which equals to 95.39% of the total territory area of Netherlands (41,543 km^2) (NBSC, 2015). Thereby, the case studies of Chinese cities on pattern transition of urban growth offer a wonderful opportunity to understand the hidden spatial and social processes behind the fast urban morphological evolution.

Urban morphology is the tangible aspects (e.g. the shape, organization or structure of spatial entities) of social-economic forces (Whitehand, 1987). Although a city can be viewed as a product of specifically social forces set in motion by capitalist relations of production, it cannot be exclusively denied that city may be interpreted as a social ecology, subject to natural forces inherent in the dynamics of population and space. In the relevant literature of urban growth, morphological analysis involves both static geometric shape or structure and dynamic pattern of urban entity, and the morphological transition is often classified into three categories of form, namely, edge-expansion/sprawl, outlying expansion and infill (Hoffhine et al., 2003; Sun et al.,
2013; Long et al.,2017). The static pattern analysis, dominated by landscape matrix, is used to measure, monitor and compare spatial fragmentation caused by urban growth (Hoffhine et al., 2003; Sun et al., 2013). By contrast, the dynamic pattern analysis is utilized to understand and predict the patterns, processes and behavior of urban growth (Cheng and Masser, 2004; Batty, 2007). Irwin and Bockstael (2007) revealed that fragmentation rises and falls with distance and the point of maximum

fragmentation shifted outward over time, after investigating the dynamics and spatial fragmentation of land uses in a rapidly urbanizing area. This finding suggests that there are some perceivable rules of spatial-temporal interaction, which derives the spatial-temporal relationship in urban morphological shift. This has become the main concern of this paper.

Urban spatial transformation results from multiple overlapping socio-economic forces, such as population growth, economic development, and infrastructure investments (Cheng, 2003; Cheng and Masser, 2003a; 2003b). Brueckner (2000) highlighted that growing population, rising incomes, and declining cost of commuting are three main powerful factors to stimulate spatial expansion. Deng et al. (2008) confirmed Brueckner's findings through an econometric analysis of the significant negative impact of GDP on urban expansion in China. However, in contrast to the negative externalities of economic forces, market forces are capable to derive land use changes and enhance land-use efficiency internally. Du et al. (2014) analyzed the regulating role of market mechanisms in the metropolitan land economy and articulated that land price has exerted a significant influence on land-use conversion. Land price has become an effective regulator in restraining urban/town expansion. The land market in China has been criticized for long time as being less effective in managing land use changes in both the exurban and urban redevelopment areas (Song et al., 2015). As common goods, the use of land and land-use efficiency in the hand of individual entrepreneur should adhere to the collective regulation of market (Deng et al., 2008; Du et al., 2014). These regulations have demonstrated spatial and temporal variations. For example, the urban expansion occurring in the western regions of China between 1950s-1990s, was driven and led more by market forces on demand side than by government forces on supply side. However, the decentralization process and tax-share reform initiated in middle 1990s have created their thirst for revenue, thereby, local/city governments have practiced a Keynesian strategy of urban development before 2000s or a more extreme strategy of land revenue through space production after 2000s. The former means that the huge investment into infrastructure can entice manufacturing industries in suburb or commercial sectors in gentrified downtown, then the business tax can be harvested indirectly. The latter indicates that the infrastructure investment can attract real estate companies to buy land directly in the newly developed suburb (He et al., 2014). Consequently, low-density urban expansion is mainly driven by the state rather than market forces in the suburbs, while high-density urban regeneration is dominantly driven by market force in downtown. Apart from socio-economic forces, governments and their policies are more required to respond to the pro-growth based urban sprawl (Lichtenberg and Ding, 2009). Local governments at various levels take advantages of the dual land market system (Zhang, 2000; Li et al., 2015) to pursue high land revenue or as what Du et al. (2014) further stated that land is not a simple factor of production but a strategic tool for promoting urban government. The decentralization of labor and economic activities has been one of the main driving forces of spatial expansion since 1980s (Deng, et al., 2008). Zhao (2010) argued that urban expansion has been massively fueled by increasing local government autonomy and fiscal responsibility. The negative effects of sprawling development on transportation (e.g. enlarged commuting distance), reflect the government's failure to manage growth in the ongoing transformation process. Additionally, some growth oriented policies, such as favoring single-family housing regulation that contributes to unrest sprawling in California (Quigley et al., 2004), also have their considerable effects on urban expansion in the Chinese cases, e.g. China's real estate markets nowadays cater for large floor-space housing (Jim and Chen, 2007). Since urban growth, in particular inefficient sprawl is regarded as negative externalities, the institutional antidotes are requested to cope with these issues. In order to restrain inefficient urban expansion in the political-economic hemispheres, it is imperative to internalize negative externalities of urban sprawl, including some policies in practice, such as the gasoline taxes, improvement of mass transit and pedestrian access in the inner city, zoning regulations, and land tax. The policy of land bank was announced and implemented in China in later 1990s, based on the western experience, to improve the land productiveness through state intervention in land use decision-making (Lichtenberg and Ding, 2009). Furthermore, some property-led urban growth policies and practices have enhanced the intensity of inner city development through large-scale regeneration since 1990s (Zhang, 2000). The impacts of these policies and practice, to some extent, demonstrate that high-density expansion (Jiao, 2015), or even smart growth, may be driven by exogenous policy intervention in long run indirectly, such as endogenous force of economic activities.

Consequently, amalgamating the exogenous force of institution and endogenous force of economics and their spatial impacts into an integrated and dialectic framework of analyzing urban morphological evolution, which has been illustrated by Figure 1, might be an appropriate framework for understanding the interactions between different forces driving urban development, which offers a different perspective for interpreting urban morphology.

[Insert Figure 1: The dually dialectic forces of urban growth]

This paper aims to examine if the urban morphological evolution of Kunming metropolis follows a cyclic growth model (CGM) driven by the dually dialectic forces. A cycle of a dual phase of growth (Whitehand, 1987) is defined by low-density expansion versus high-density infill, and the cycle is periodically and reciprocally derived by a set of vis-à-vis dualistic dynamics resulting from the complicated interactions between macro policies (e.g. pro-growth infrastructure investment) and micro behavior (e.g. collective and individual enterprise / economic behavior). Kunming in the Southwestern China is chosen as a case study because it has experienced massive changes and shared similar spatial and economic processes with the rest of Chinese cities. This paper is organized as follows. After this introduction, section two describes the study area and its methodology including data collection and morphological indicators. Section three presents the results of morphological analyses. Section four tends to theorize the CGM model and reveal the dynamic mechanism of urban morphological evolution. The paper ends with some conclusions and recommendation for future work in section five.

2. Study area and methodology

Theoretically, the urban morphological evolution is driven by the twist of bifurcated and opposite but mutually compensated forces of external pattern shift and internal dynamic fluctuation. Thereby, methodologically, the evolution can be detected by pattern metric and social-economic and spatial indices jointly on one hand, and embodied into the metrics of switching between expansion and infill on the other hand. The analytical methods should be able to reflect both observable external pattern shift and hidden efficiency of land use, and explore the pattern switches with time. For example, some pattern metric indices including the traditional static geometrical indexes - R index (Sun et al, 2013) and average trip distance (Muñiz and Galindo, 2005), can help distinguish the categories of urban growth between suburban expansion or sprawl, and “inner” city infill development. Some other socio-economic indicators, e.g. investment per km^2, productivity of urban economic actives (GDP per km^2) and development intensity, can measure the internal dynamic fluctuation. In the following sections, two new morphological indicators will be designed and explained to achieve this purpose of integrating spatial pattern and socio-economic driving forces.

2.1 Study area

Kunming is located in east-central Yunnan Province of which it is the capital. As the third largest city in south-west China (after Chengdu and Chongqin), Kunming administers six urban districts, four counties, three autonomous counties and one county-level city (Figure 2), with a total area of 21,012 km^2 (Wu et al., 2015). It is undergoing a transition from a socialist manufacturing center to a free market service economy with a focus on tourism and bio-chemicals and flower production (Wu et al., 2015). The effects of this shift, especially in the development of a commodity housing market, have only been seen relatively recently (Zhang, 2010).

[Insert Figure 2. Location of the study area – Kunming Municipality.]

Kunming is a regional central city in South-east Asia, which dates back to Tuodong city that existed about 1200 years ago, and its morphology has undertaken massive changes in the past 12 centuries. Before the Second Sino-Japanese War (1937-1945), Kunming was a tessellated city. However, its population, economy and urban built-up area increased quickly during the war due to the migration of numerous factories, departments and schools into Kunming from coastland and inland, and this has become the fastest developing period in the modern history of Kunming. After 1949, Kunming was developed into a megalopolis, and the downtown area expanded from 7.8 km^2 in 1949 to 98 km^2 in 1995, while the population increased from 270,000 in 1949 to 1,260,000 in 1995 (KMG,1999). In the 21th century, the urban area has expanded from 136.5 km^2 in 2000 to 249 km^2 in 2007, while the urban permanent population has grown from 1,517,000 in 2000 to 1,632,000 in 2007 accordingly (KMG,1999; 2003; KBS, 2008). Kunming has witnessed the rapid urbanization, including urban sprawl (Wu et al, 2014; Wu and Waley, 2017) and residential segregation (Wu et.al., 2017) in the past four decades.

2.2 Data collection and participatory mapping

The social and economic data, including the public investment, real estate investment, urban built-up area and building floor area, were all collected from multiple sources of publicly published documents, e.g. KMG (1999, 2003), KBS (2005, 2006, 2007, 2008, 2009 and 2010), KBSM (2014) and SBYP (2014). The GIS data was digitized into ArcGIS 10.4 from the following sources: (i) the historical maps and earlier archives from local chronicles, particularly in the period from 1909-1949; (ii) master planning maps in these periods: 1943, 1953, 1957, 1959, 1962, 1982, 1987, 1995; 2002, 2006, and 2008 respectively. Spatial data sets are processed and integrated to map urban morphological evolution from 1909-2006 (Figure 3). Combining with statistical data of investments, two indicators are calculated for the entire study period, which will be explained in detail in the next sub-section.

Due to limited availability of spatial and temporal data for the urban growth occurring before 1980s, Participatory Mapping (PM) method has been extensively applied in this study to capture local spatial and situated knowledge related to evolution of urban morphology (Mapedza et al., 2003). PM, as a qualitative GIS approach, aims to socially produce or construct spatial knowledge through public participation in mapping. In this study, seven senior urban planners were invited into workshops to help recognize the development type and process of those representative building blocks (images 1-7 in Appendix 1), which indicate the urban development phases in 1950s, 1990s, 2000s and 2010s respectively, identified from Google Map and Google Earth.

2.3 Morphological indicators

Comparing to traditional geometric shape analysis, Hoffhine et al. (2003) developed a quantitative method to characterize three urban growth categories: infilling, edge expansion, and outlying. Sun et al. (2013) further defined a metric R to measure the above-mentioned three types of urban growth into equation 1:

$$R = l_c / l \qquad (1)$$

Where l_c is the length of commonly shared edge between a newly developed urban patch and an existing urban patch and l is the perimeter of the newly developed urban patch. The value of R ranges from 0 to 1. For the infilling type, $R > 0.5$ and $R < 0.5$ for edge-expansion. As outlying growth is the newly developed urban area without spatial connection to the existing urban area, $R = 0$. In our study, it is preferred to abstract the urban growth as two categories, namely infilling vs. expansion. Consequently, 0.5 is selected as a threshold value for distinguishing them. However, this indicator R, though it is easy to be calculated and interpreted from the urban morphology map (Figure 2), has less power to reveal the pattern of regeneration and reuse the dilapidated land in the existent urban built-up areas.

In economics, investment has been often regarded as the internal forces of stimulating cyclic growth (Krawiec and Szydłowski, 2017). In the previous studies of urban growth, density-based indicators have been extensively used to explain the patterns and driving forces of spatial development, such as population density and employment density. However, these indicators can hardly explain the economic behavior behind the spatial development. Economically, the investment intensity of low-density expansion determines the scale of built-up area converted from non-urban to urban uses, including transport infrastructure. The investment intensity of high-density infill development affects the magnitude and quality (e.g. total floor area) of high-rise buildings due to the profit-oriented real-estate development. Thereby, investment density, which links investment intensity with spatial development, can help better interpret the economic behavior behind the urban spatial development. Du et al. (2016) have defined an index of investment density as the division of accumulative investment by the complete developed land area in their study on impacts of land pricing on land use efficiency in Beijing. In this paper, in order to remedy a defect of the spatial indicator R, and simplify the dynamics of morphological evolution, two indicators: "expansion-induced investment density index" (EID) and "infill-induced investment density index" (IID) are defined to reflect the two distinct spatial processes: low-density expansion and high-density infill respectively (equations 2 and 3):

$$EID_i = PI_i / BA_i \qquad (2)$$

$$IID_i = RI_i / BF_i \qquad (3)$$

EID and IID are used to measure the investment intensity per unit of developed land in the urban fringe or city centre, which indicate the intendency or opportunity of triggering low-density expansion and inducing high-density infill respectively. Mathematically, *EID* is calculated as the division of the intensity of public investment (PI_i) by the total built-up area of a city (BA_i) in year i, where the public investment (in China, the public investment has been nearly equal to the investment on infrastructure since 1949). *IID* is measured as the division of the intensity of real estate investment (RI_i) by the total building floor area of a city (BF_i) in year i. The two indicators designed in this paper enable us to better understand the complicated urban growth process as they combine both spatial and economic elements into one formula.

To remove the scaling effect, both indicators are normalized by equation 4 in order to compare and reveal their dynamic relationship:

$$X^* = (x - \mu)/\ \sigma \qquad (4)$$

Where μ denotes the mean value of the whole variable and σ represents its standard deviation.

3. Results

3.1 Evolution of urban morphology

Though Kunming had been the political centre of Yunnan province, it was not set as a municipal city until 1928. Over the past one century 1900–2010, there have been many political, socio-economic historical events at national and local levels having massively affected its administrative division (Wu et al., 2015; Wu and Waley, 2017) and development of Kunming's urban morphology (Figure 3). For example, the suburban district outside the inner beltway of Kunming municipality was Kunming County from 1950 to 1956. After 1956, the Kunming County was merged into the Kunming municipality and it was further divided into two suburban districts. Although Kunming has 1100 years history, it started to experience a significantly morphological evolution stimulated by its industrialization since middle 1900s

(Figure 3). Based on the morphological evolution from 1909 -2006 in Figure 3, together with the qualitative analysis from interviews with seven senior urban planners, a conceptual model is presented into Figure 4, which divides the urban development into five phases. This model helps us form a hypothesis that the morphological evolution in Kunming metropolis is dominated by a periodic cycle of urban expansion and infill development. However it is unclear which forces contribute to the pattern switch. In the following sub-sections, some quantitative evidences will be provided to confirm the hypothesis and interpret the cycle model.

[Insert Figure 3. The morphological evolution of Kunming 1909 – 2006]

[Insert Figure 4. The five phases of urban growth of Kunming Metropolis from 1909 to 2014]

3.2 Temporal variation of morphological indicators

Combining the spatial and economic data processed, three morphological indicators R, EID and IID (equations 1-3) were calculated for the Kunming metropolis throughout the 14 periods ranging from 1950-2008 (Table 1), which help us test if the spatial patterns have matched with the morphological indicators. Apart from two short periods (1955-1962 and 2002-2003), which might be affected by the limited data quality and special events (e.g. Great Leap Famine see (Gráda, 2013)), the rest periods all demonstrate the appropriate match between both. It means the two newly created indicators are able to link the spatial pattern of urban growth with the socio-economic forces behind it. To analyze the forces for which type of urban growth, the temporal trend of EID and IID values measured for the period from 1950 to 2014 is displayed as a graph in Figure 5, from which the morphological evolution of Kunming Metropolis can be divided into four stages, namely 1950-1978, 1979-1989, 1990-2003 and after 2003 respectively (Figure 5). The dual forces and their interactions behind the temporal variation will be explained in the next sections.

[Insert Table 1. The cyclic evolution of urban morphology in Kunming]

[Insert Figure 5. The temporal variations of two indicators (EID and IID) in Kunming since 1950]

3. 3 State-dominant stage in planning economy

During this period 1950-1978, Kunming went through a few morphological fluctuation sub-stages or periods (Figure 5, Appendix 1). Over the past 28 years from 1950 to 1978, the annual growth rate of public infrastructure investment intensity had increased only by 20.27%, but the built-up area tardily increased by 6.55 times (KMG,1999).

In the early period of the First Five-Year Plan (1953-1957), the increasing public investment concentrated in inner city had stimulated a rapid high-density infill development, which was conducted by filling in the empty land between the city core and nearby enclaves, such as isolated towns or villages. At the stage of restrictive growth between 1950 to 1955, the R index value is 0.51 (>0.5) (Table 1), demonstrating an infilling growth pattern. This pattern was determined by an economic recovery from the civil war (1945-1949) and slow economic development from 1949 to 1955. The image 3 in Appendix and Figure 3 is a representative urban growth at this stage. As interpreted by several senior planners, this area results from the low-density urban expansion occurring around the inner city during 1950-1955 before the Great Leap Famine (Gráda, 2013).

From 1963-1977, Kunming was trapped in the long lag period as what other cities in China experienced as well (Figure 5). However, the public investment activities reinforced by the central government under the strong planned economy system, had led an unstable but fluctuated central-state led low-density expansion and local-state led high-density infill development. Among them, low-density expansion characterized by leap-frog development of new industrialized towns and isolated industrial complex in the follow-up four Five-Year Plans periods (1958–1962; 1966–1970; 1971–1975 and 1976–1980) (Naughton, 1996). The morphology of

Kunming was gradually transformed from a compact core to a constellation shape. At this stage, the R index values in the periods of 1955-1962 and 1962-1978 are 0.32 and 0.24 (<0.5) respectively (Table 1), indicating a tardily urban expansion. For example, the rapid extension of transport infrastructure from 1953-1957 facilitated the gradual transformation of the brim of built-up area to rosary industry corridor with *Shiba* in the east, *Ciba* in the northeast, *Puji* in the northwest and *Majie* in the west (Figure 3).

3. 4 Transition stage: from planning economy to market

Over the whole period of 12 years (1978-1990), Kunming had experienced a full morphological fluctuation period (Figure 5) with an annual growth rate of public infrastructure investment intensity of 11.28%, but the growth of built-up area only by 1.34 times from 1978 to 1989 (Table 1):

At the market-led high-density infill development sub-stage (1978-1985), the R index values between 1977-1978 and 1979-1985 are 0.57 and 0.62 (>0.5) respectively (Table 1), which demonstrate an accelerated and strong high-density infill development under the urban economic reform (Naughton, 1996). In fact, Kunming had developed a twin-core structure (e.g. northern area and inner city) internally and forged a relatively compact form different from previous constellation expansion externally (Figure 3). The annual public investment intensity during 1979-1985) was 9.46 million Yuan RMB per km^2, increased by 4.07 million Yuan RMB per km^2, compared to the annual growth rate of 17.06% in the previous period (1977-1978). Then，at the second sub-stage (1985-1990), the R index value is 0.31 (Table 1), and the IID is lower than the EID (Figure 5). It demonstrates that market-led high-density infill development gradually became a counter-balance against state-dominant force in planning economy.

3.5 State-led v.s. market-led stage of urban growth

After the transition stage, Kunming has demonstrated a tendency of balancing market-led and state-led urban growth models in the following two periods since 1990 (Figure. 5):

First, in the first period from 1990 to 2002, a continuous low-density expansion was mixed by a strong high-density infill development. This mixture is partly reflected by the change of Average Investment Intensity (*AII*), which has steadily increased from 17.69 million Yuan RMB per km^2 during 1985-1989 to 124.13 million Yuan RMB per km^2 during 1999-2002 (Table 1). Thus, the EID curve was slightly lower than the IID curve during this period, but both curves had maintained the increasing trend until 2010 (Figure 5). Nevertheless, a part of these figures and index values seem to conflict with our hypothesis that both IID and EID indices and their morphological pattern should dialectically oppose each other (Figure 4). It is clear that the morphological evolution of Kunming was twisted by two giant events (Mills and Rosentraub, 2013), namely, the newly opened housing market initiated from mid-1990s and the EXPO99. Certainly, the newly opened housing market caused the first wave of high-density market led urban expansion through the gradual high-density infill development (Zhang, 2002), which had removed the effects of low density expansion of state-driven pro-growth development in the northern suburb (image 4 in Appendix 1). While the latter then neutralized the high density infill development under the housing market, with a large number of public investment on infrastructure for EXPO99.

As a matter of fact, due to rapid expansion for hosting EXPO 99, a market-led high-density infill development has been detected by the IID or EID index (Figure 5 and image 4 in Appendix 1). During the period from 1997 to 1999, the *AII* value of Kunming was 106.54 million Yuan RMB per km^2, with an annual growth rate of 19.28% (Table 1). The investment was mainly focused on large-scale inner city renewal, such as infrastructure, real estate, and key construction projects[1] (Deng et al.,

[1] As a remnant of former planned economy, the central government has been financially supporting these key projects endorsed by National Development and Reform Commission of China since the economic reform in 1978, the rest of projects have to be fuelled by local governments through all kinds of fund-raising.

2014). However, in contrast to the high-density infill development, the pattern metric index R values of 0.51 and 0.42 corresponding to the periods of 1997-2002 and 2002-2003 respectively (Table 1), reflected a high-frequency morphological fluctuation of lower density expansion and high-density infill development. It is clear that such a high-frequency morphological fluctuation and similar tendency of both curves (IID and EID) reflect a paradoxical urban growth path experienced in Kunming. On one side, its inner city practiced a high density and large-scale infilling urban regeneration, by spending up a huge amount of local revenue between later 1990s and early 2000s (also see image 3 in Appendix 1). Unfortunately, on the other side, because of the framework of political-economic decentralization, the municipal government has to pay the bill of regeneration alone after tax share reform (Zhang, 2000). Hence, local government had to generate its revenues from land market, selling a huge quantity of land through promoting urban expansion in suburb to balance the budget. In fact, the annual newly increased urban land from farm-land reached 36.9 km^2 in 2002, much higher than the average increase of 12.44 km^2 during the period from 1990 to 2014. Therefore, a hybrid urban growth pattern was confirmed not only by a gradual switch from IID–led regeneration in the inner city (from 1997 to 2002) to state-driven urban expansion EID (e.g. image 1 in Appendix 1), for increasing land revenue (from 2003-2007), but also by infill development in the urban fringe (e.g. image 2 in Appendix 1). All these have demonstrated a similar but slight increasing tendency of both IID and EID curves since 2002 (Figure 5).

Second, Kunming has demonstrated a multiple nuclei and hybrid urban growth since 2003 (Fig. 5 and 3). Due to the frequent and sophistical intervention of local government in land market, this period (2003-2014) has witnessed a more clear morphological fluctuation stages, in which not only the R index, but also IID or EID index did clearly refer to a high-density or low-density model simply (Table 1 and Figure 5). Particularly, the urban growth after 2007 clearly shows dialectic fluctuations between a strong state-driven lower density expansion from 2007 to 2012, and a counterattack of market–led high-density infill development since 2012.

The planning of Chenggong New Kunming around early 2000s has led to a fiercely state-driven low-density expansion from 2007 to 2012. Such expansion absolutely differs to the morphological evolution in the previous period of hybrid urban growth in which both high-density infill development and low-density expansion have coexisted at same stage (Figure 4 and images 7 and 5 in Appendix 1). As a matter of fact, Kunming municipality invested a huge number of capital resource on infrastructure for the project of new Kunming district during the period from 2007 to 2011. The investment has amounted to 28.84% of the newly added built-up area (311 km^2) and 45.38% of the total infrastructure investment from 1990-2014 that is 141.3 billion Yuan RMB (KMG, 1999; KBS, 2008; KBSM, 2014). However, the residents of old Kunming are very much concerned about the increasing traffic cost and poor accessibility in the newly developed New Kunming, a large-scale empty buildings called “ghost city” has appeared (Yu, 2011; Chen et.al. 2015). Accordingly, after nearly five years state-driven urban expansion, the unsustainable low-density expansion has ended up in around 2012. Kunming has headed to a high-density infill development stage since then. For instance, the public infrastructure investment dropped to 4.71 billion Yuan RMB, only amounted to 33.34% of that in the previous stage (1997-2007) (KMG, 1999; KBSM, 2014). At this stage, local government retreated back from the front desk, however, it not only allured real estate industries to replace them, but also ordered the sub-agencies of local government to move in, then forced high density infill urban growth to boom involuntarily, which cause the phenomena of “ghost city” more seriously (Chen et al., 2015). Consequently, the IID curve has exceeded the EID since 2011 (Figure 5).

4. Discussion: a cyclic growth model

The above-mentioned results clearly reveal that the complicated urban growth and its morphological evolution may follow a cyclic and periodic growth model, as illustrated in Figure 6).

[Insert Figure 6.   A cyclic growth model of urban morphological evolution]

Batty (2007) contended that urban morphological evolution, as a complex system, should be understood or abstracted as a dynamic process of aggregating somewhat simpler systems. This thought has been successfully embodied into the simulation models of cellular automaton (CA) or multi-agent system (Batty, 2007; Cheng and Masser, 2004). Nevertheless, our results suggests that the simple systems are refined or abstracted as two basic but twisted lines of urban growth: low-density expansion and high-density infill development, based on the rational action theory of individual and group economic behaviors (Ostrom, 2010). This follows Hegel's dialectics thought on the simple systems and the urban morphological evolution does follow a reductionable process (Gallagher et al., 1999). In the cyclic growth model, the occurrence of specific urban growth, either EID or IID, is dependent on the dominance of investment source and type:

(1) Expansion dominance: the increasing infrastructure investment and capital facilitates the massive flow of land supply into market under the pro-growth land policy tools of China local governments (Deng et al., 2008; Du et al., 2014), which results in the decline of land price accordingly. Thereby, this will create opportunity for individuals, enterprises or agencies to make profits from cheap land for their social production or consumption, e.g. building and buying spacious housing (Jim and Chen, 2007; Quigley et al., 2004) or factories in rapid low-density suburbanization.

(2) Infill dominance: the retard or decrease of public investment has reduced the flow of capitals into the land market of peripheral area, and then causes a high-density landscape instead. This would relatively increase the land price or investing cost in the urban fringe and make the sites in there less attractive for real estate investment. Comparatively, the previously inefficiently utilized land or empty land in inner city would become more competitive. Consequently, the return of more economic activities or commercial investment to the inner city in small plots of regeneration will then fill the "the disparity between potential ground rent and the actual rent capitalized under the present land use" (Smith, 1979: 545).

Given the alternate dual phases in urban growth, the spatio-temporal substitution process between the urban expansion and infill development has formed a complete cycle of urban morphology as shown in Figure 6. The logic behind the process is that cities sprawl restlessly for the benefits of tapping into existing infrastructure competing with the disadvantages of high land cost in built-up areas (Chen, et al., 2015). Thus, following the process of diffusion-limited aggregation, cities incline to grow by adhering new buildings or zones along their fringe and the existing development areas，as the developed infrastructure is attractive for new development. This model implies that urban growth was essentially a sort of internal social-economic and political-economic movements, and external spatial movements, which were functioned by pairs of dual forces, mainly including global/regional capital investment and flows, economic growth, population growth, industrial policy alteration, planning intervention in urban functions, and urban industrial restructuring.

Also, the temporal phases of urban spatial growth and its internal social-economic or political-economic dynamic conversion as shown in Figures 4-6 demonstrate characteristics of reductionable periodicity. During the contradictive and dialectic interaction of urban land demand and supply, undoubtedly, the temporal changes or processes of the public investment and its substitution effect (Marshall, 2004) determine the spatial and temporal patterns of urban land use (Figure 1). The social production rate, economic fluctuation and land cost follow a simple linear trend in every cycle of urban growth. As the public investment and its consequent substitution effect have disturbed the demand rhythm of land for the urban social economic activities, the urban morphological pattern demonstrates a nonlinear fluctuation trend, which are affected by two alternate sub-processes, e.g. state driven urban expansion or low-density expansion vs. market-led high-density infill development (Figure 1):

In the periods of low-density expansion, with its grounding in Keynesian and Franklin Roosevelt's New Deal’s state interventionist approach (Davidson, 2011), the most substantial intervention into urban social economic activities of state-led market economy is increasing the public investment as it then motivates local businesses. It enables to stimulate the public consumption and impulse the benign speed and scale of the capital reproduction circling process. In such political and economic circumstances, large-scale public investment gives rise to the low-density and high-speed urban expansion or urban sprawl definitely (Xiao et al., 2006).

Whereas economic activities operate under market principles in a negotiated market circumstance, the equilibrium between minimal input and maximum outcome has become an inevitable choice for rational enterprisers. Hence, the evolution of urban morphology can also be described as the macroscopic outcomes and consequences of microscopic rational activities in urban regions. With such a rational choice, the governmental public investment enables to certainly reduce the costs of land utilization and urban infrastructure development, engendering the substitution effect in market circumstance. For instance, during the two-span stages: later 1980 and around later 1990s, it was reasonably observed that concrete social economic activities have chosen the traditional Smithianism production paradigm, meaning the substitution of expensive investment by largest-scale cheap land. Finally, the macroscopic and collective outcomes of microscopic and individual rational activities within each enterprise, namely urban low-density expansion, becomes the classic patterns of urban morphological evolution in state-led urban pro-growth and by state interventionist approach (Davidson, 2011).

In the periods of high-density infill development, it reflects the logical pursuit of enterprisers. When the public investment in land market decreases, land price will increase because the land supply tension and the cost of converting land into productive activity of each enterprise begins to rebound accordingly. Thus, the rational choice of enterprisers definitely enables to raise the land use intensity by replacing the former low-density expansion model, which will cut down the costs of land supply and transportation, and other expenditures associated with productive activities. This trade-off drives the rational social economic activities to be allocated based on a compact development model in inner city with two objectives. The first objective is to reduce the comparatively expensive land expenditure using other fungible factors or methods, for example, enhancing land use efficiency by increasing floor area ratio, reducing the land cost of unit production, or using other endogenous growth to minimize production inputs (Marshall, 2004). The second objective is to reduce the traffic and trade costs by being located in the sites with good transport access and further cut down the expenditure of urban development in inner city. Consequently, as the intensity of public investment, gradually decreases, the land use efficiency (or rather the investment intensity) is improved significantly, and the urban morphology evolves into the infill development stage.

5. Conclusions

In general, the macroscopic evolution of urban morphology has its own inherent laws and external mechanism. The case of Kunming confirms the CGM model—a cycle of dual phases of urban development: low-density expansion versus high-density infill development. This is the first time to interpret the urban morphological evolution from a cyclic growth perspective, although economic cyclic growth theory has existed for a long time and been applied for many urban processes (Eng-Larsson, et al., 2012). These dialectically morphological shifts are periodically and reciprocally derived by a set of vis-à-vis dualistic dynamics, in which low-density expansion is led by pro-growth infrastructure oriented state investment, while the high-density infill development is activated by collective and rational actions of individual enterprises and their economic behaviors. This shift of urban morphological pattern in a long period would help us interpret about land use changes and its regulation in more details, and assist us in future planning.

First, the CGM model of Kunming suggests the following points. The dialectic evolution of urban spatial morphology (i.e. external expansion vs. internal infilling) can be decomposed into a set of dual urban policies, e.g. Smithian pro-growth urban policies for exogenous growth against property-led strategies for endogenous urban growth. Thus, local government can propose different urban policies or strategies to shape the varied morphology in the CGM model. The CGM model implies that a particular pattern and its evolutional tendency reflect the outcomes from the interactions with various economic activities. Thus, urban planning organizations can apply different planning tools to echo these different economic policies. For instance, the restraints in external intervening circumstance, e.g. tight land supply policies or restricted land use policies (e.g. green belt and habitat reserve in the urban fringe), will probably lead to the convergence of land use in intensity and efficiency, which will not only echo property-led strategies for endogenous growth, but promote sustainable development as well. In fact, it has been proved by some relevant planning practices, such as the green belt in London Planning and growth boundary in Smart Growth of US (Chapin, 2012). Local government might adjust the trajectory of urban morphological evolution with a bundle of planning tools according to the MCCG model (Zhang, 2000; Lichtenberg and Ding, 2009; He et al., 2014; Zhao, 2010). In the Kunming case, the high frequency of fluctuation between HDI or LDE curves at the stage of 1997-2007, reflected that the tax-share policy transition distorted the path of urban morphological evolution (Figure 5). After the tax share reform in 1994, city/local government had to generate revenue for running development projects, or funding public consumptions (e.g. schools and hospitals). Therefore, in order to create sufficient revenue to regenerate the inner city, municipal governments had to demolish and replace a large number of villages in suburb, then triggered pro-growth urban expansion. At last, the infill development in inner city and spatial expansion in suburb occurred simultaneously, but the expansion was conducted by the financial needs of infill development.

Second, the CGM model enables us to further understand the nature of urban growth. As an instructional model of explaining urban growth, compared to traditional demographical model and complex system dynamics model, on one hand, the CGM model further reveals the nature of urban growth with a dialectic simple systems philosophy and possesses a nature of self-convergence, e.g. urban growth is fueled by social-economically exogenous force and institutionally endogenous force. As such, the morphology evolves with a temporal series of switches between spatial expansion and infill development. On the other hand, in contrast to traditional growth model, it needs only fewer variables, reflecting local dimension automatically other than global one.

At last, the CGM model also demonstrates some implications of different index for analysis of urban growth. Since urban growth is a complex spatial-economic process other than a simple process of urban land expansion or land uses conversion, traditional geometry based indexes cannot fully reveal such complexities of urban growth. For instance, the metric pattern R index only reflects that urban growth of Kunming in the past century was dominated by spatial expansion (either edge expansion or outlying growth). Because these indices overlook not only the land use intensity change (e.g. all kinds of urban regeneration and reuse of dilapidated factories, residential zones or public facilities) but also the development of unused land in the built up area. Other social-economic indices, such as EID and IID in the CGM, should be redefined to allow the index R to reveal some of missed infill movements.

Kunming as a mega city in transition has been developing very fast recently. But with mixed forces, its urban growth in the future should be smart sufficiently by considering various social and environmental impacts. The analytical methodology in this paper has left much space for further improvement due to data limitation. Methodologically, it is imperative to develop a variety of development scenarios in response to a wide range of investment sources and local policies, based on the theoretical framework proposed in this paper and using other systematic models (e.g. system dynamics and geo-simulation). At a micro scale, it is worth exploring the bottom-up processes of land development under the mixed forces from state, local municipality and real estate market using agent-based modelling methods if a wealth of urban big data can be available to support the tasks. Theoretically, comparative studies with other mega cities in the eastern and central China are urgently needed in order to examine if the cyclic growth model represents a universal process across China.

However, the complexity and uncertainty of urban systems may weaken the CGM model and make it uncertain on other scales of time and space. The following areas need further exploration in the future. For instance, CGM is still beyond reach of inner city regeneration or redevelopment, which in fact enforces the tendency of infilling actives, unfortunately, neither IID and EID indices, nor traditional spatial pattern index, could explain such geographical phenomena. There are some limitations in data sets as well although these data have validated the CGM model to some extent. With higher-resolution imagery data for the entire study period in the future, the geometric metrics of urban morphology can be analyzed in more details.

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Table 1. The cyclic evolution of urban morphology in Kunming

Stage			AII	R	EID	IID	Match
I		*1950-1955*	1.67	0.51		√	Yes
		1955-1962	4.59	0.32	√	√	Vague
		1962-1977	2.92	0.24	√		Yes
		1977-1978	5.39	0.57		√	Yes
II		*1979-1985*	9.46	0.62		√	Yes
		1985-1989	17.69	0.31	√		Yes
III	A	*1990-1993*	35.31	0.18	√		Yes
		1993-1995	77.40	0.30	√		Yes
		1995-1997	109.00	0.72		√	Yes
		1997-1999	106.54	0.51		√	Yes
		1999-2002	124.13	0.50		√	Yes
		2002-2003	130.40	0.42	√	√	Vague
	B	*2003-2007*	155.36.	0.38	√		Yes
		2007-2008	221.49	0.21	√		Yes

note: Average investment intensity(AII) is calculated by average investment (million yuan RMB) per km^2; "√" indicates the significance in "high-density infill development" or "low-density expansion"; "match" means that R matches with EID or IID in a particular span of time.

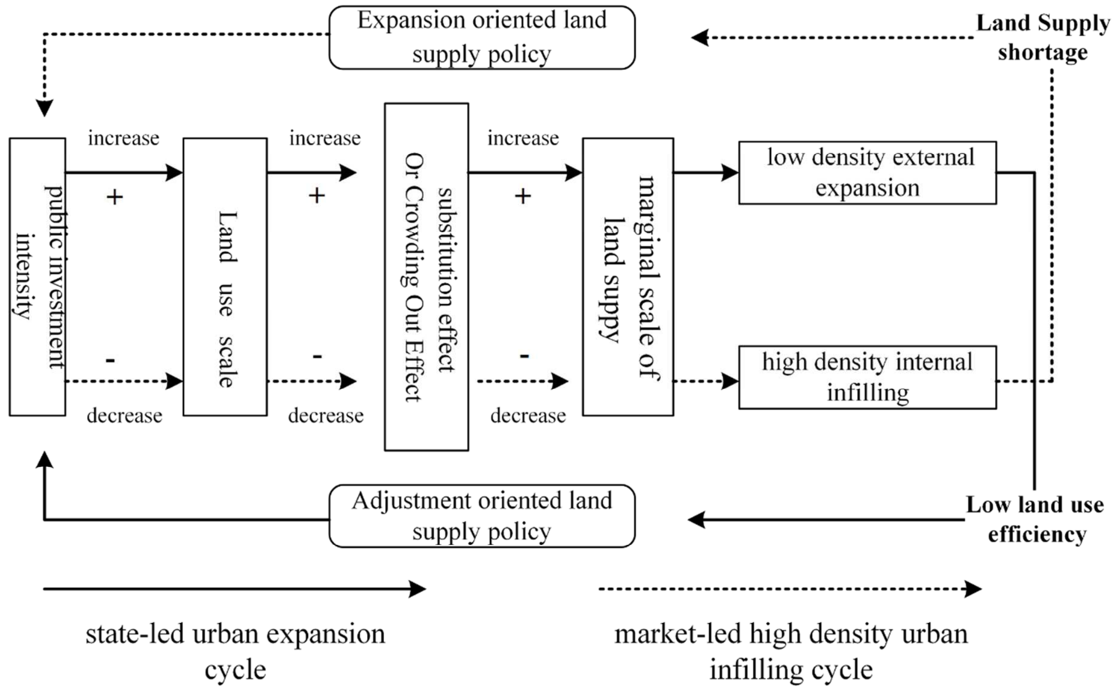
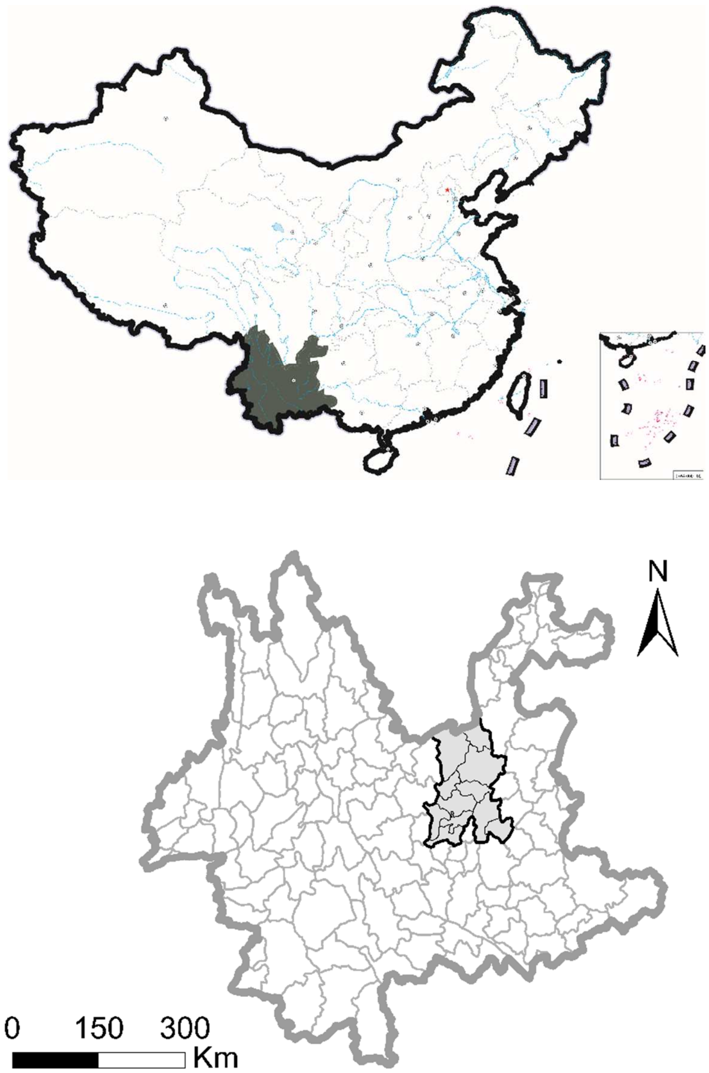


Figure 1: The dually dialectic forces of urban growth



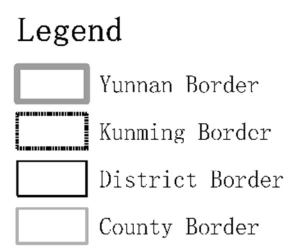


Figure 2. Location of the study area – Kunming Municipality

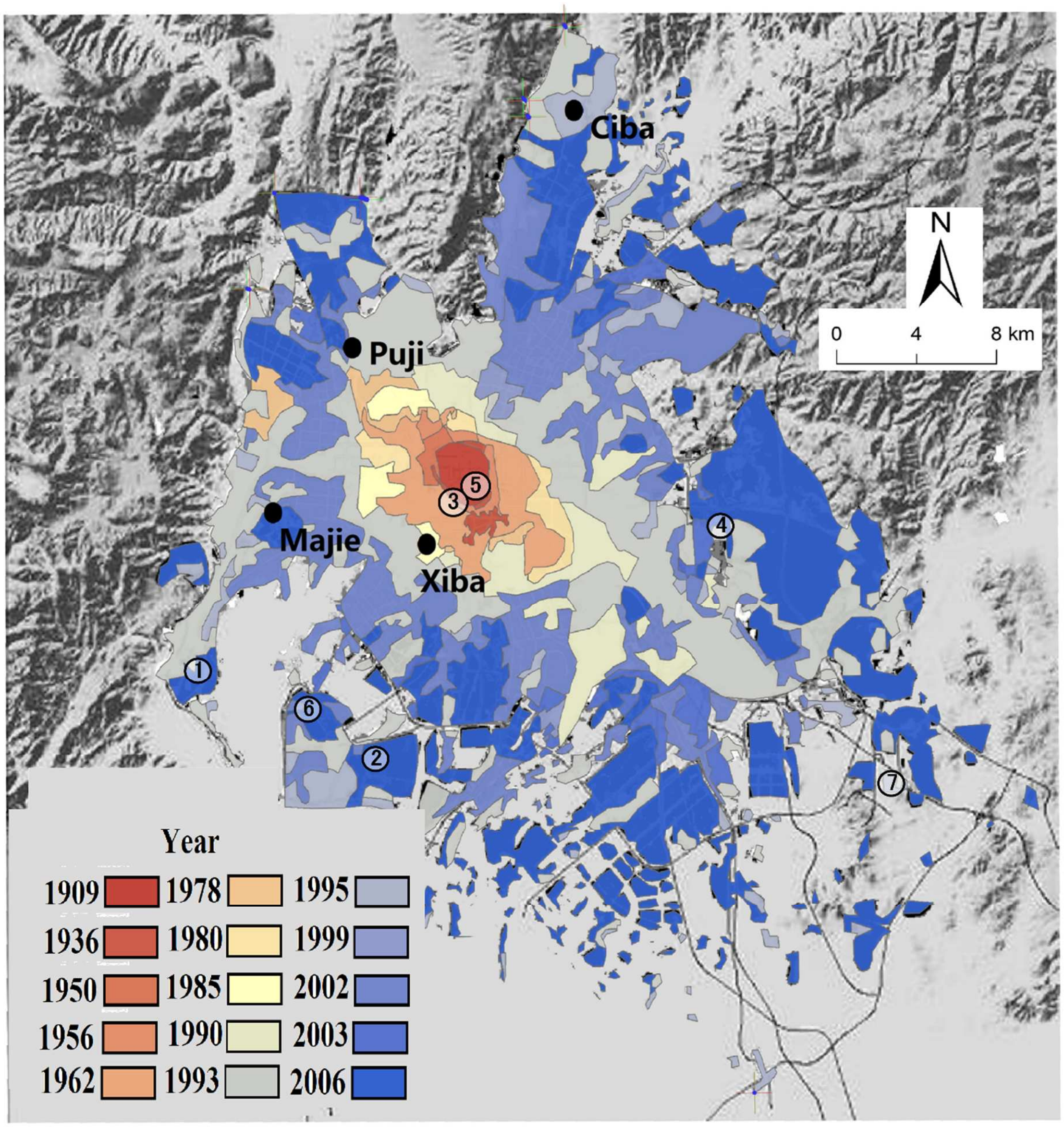


Figure 3. The morphological evolution of Kunming 1909 – 2006

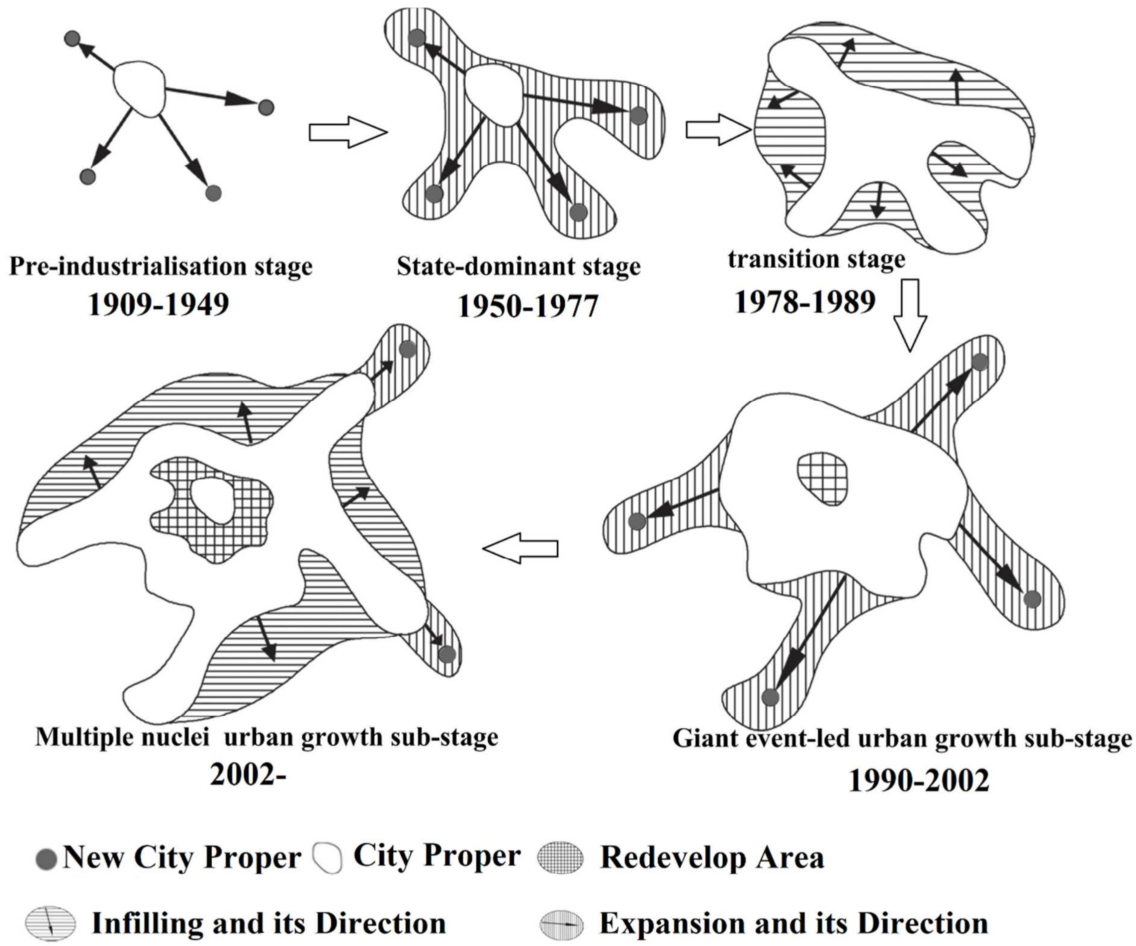


Figure 4. The five phases of urban growth of Kunming Metropolis from 1909 to 2014

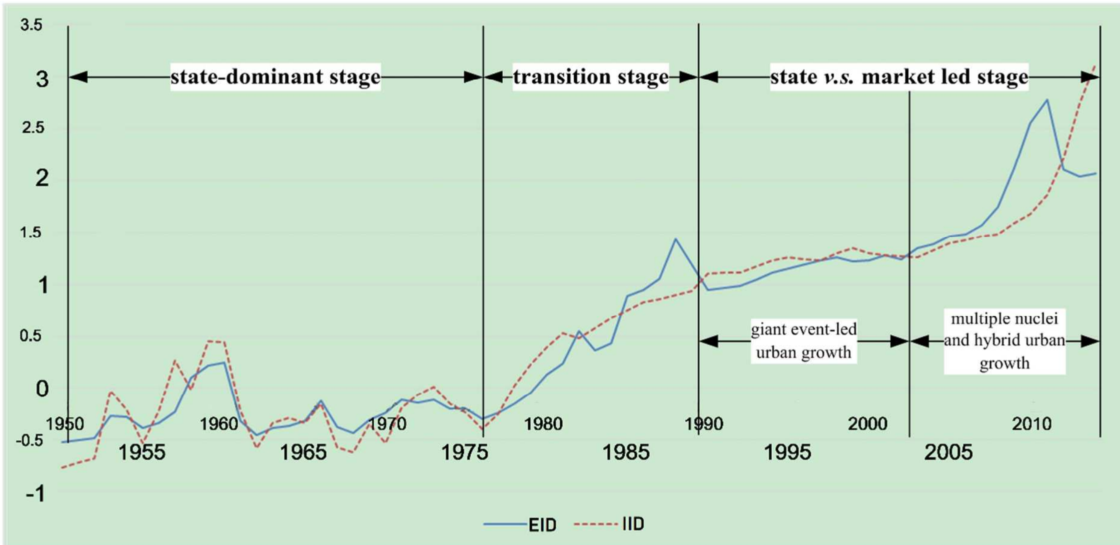


Figure 5. The temporal variations of two indicators (EID and IID) in Kunming since 1950

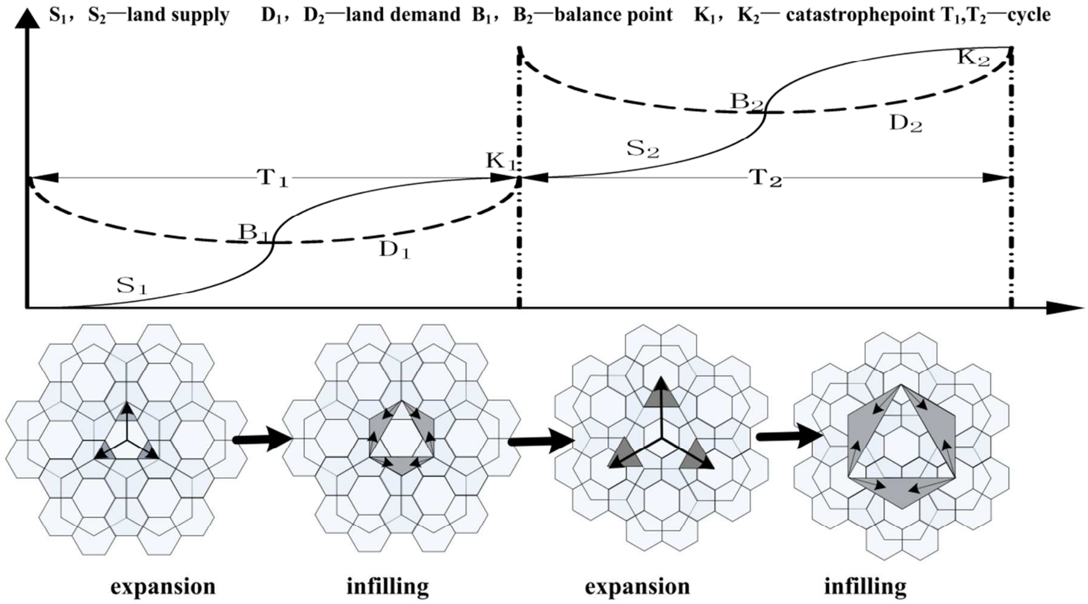
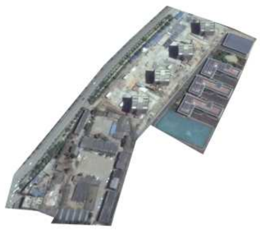


Figure 6. A cyclic growth model of urban morphological evolution

Appendix 1: Examples of high-density infill development and low-density expansion at different stages (the location of each image is shown in Figure 3)



(1) Later 1990s

(2) Early 2000s

(3) Later 1990s and early 2000s

(4) Early 2000s

(5) First developed in 1950s,
then redevelopeed in early 2010s

(6) Later 2000s

(7) Later 2000s