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Examine Sustainable Urban Space based on Compact City Concept

Hsueh-Sheng Chang [α] & Tzu-Ling Chen [σ]

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I. Introduction

The United Nations Conference on Environment and Development (UNCED) in 1992 recommended compact urban patterns with high density and mixed land use as ways to control urban sprawl and save energy (Mindali et al., 2004). The concept of compact city has been practiced to single-core urban area to encourage the aggregation tendency from periphery to downtown area (Breheny, 1995). The concept of compact city has evolved from the beginning the protection of environment and agricultural land to contemporary livability and diversity. With the challenges of global climate change and energy crisis, compact city become paradigm to integrate economic development, urban reconstruction and growth adaptation. Previous studies emphasized comprehensive analysis comparing city compactness (Burton, 2002; Thinh et al., 2002; Kasanko et al., 2006; Schneider and Woodcock, 2008). However, the results might able to cluster the cities but unable to sketch out the interaction within cities accurately.

Many measurements have been proposed to analyze the physical environment and urban function of compact city. Li and Yeh (2004) used landscape fragmental index to analyze the physical pattern of compact city. Burton (2002) constructed three dimensional indicators including density, mixed, and intensity to analyze urban function. The application of compact city measurement can help to categorize cities according to the compact degree but ignore other urban development features. In fact, urban development might be varied for different location, terrain, scale or industry (Catalan et al., 2008). The combination of natural resource, industrial type, technical progress might construct various compact city types. Therefore, the single measurement of city compactness should be the first step to detect the compact city, and there is necessary to apply other measurement to explore the relationship between compact city and urban feature.

With the completeness of compact city concept, there are four aspects altitude, density, efficiency, and flexibility (Dantzig and Saaty, 1973；Burton, 2002).High density urban space, clustered economic effect, the decrease of travel distance and high efficiency urban development might help to practice sustainable development. However, high population density and intensified activities have already impacted livability seriously such as congestion (Breheny, 1995; Balcombe and York, 1993) and the increment of crime ratio and housing price (Lin and Yang, 2006). According to the statistic of Ministry of Interior, the housing price has increased 20% in the past 10 years while the household income has only increased 5%, such housing price to income ratio (PIR) has indicated the decrease of livability in urban space.

Compact city pattern has way beyond single-core aggregation to disperse multi-core connection. Therefore, this study attempts to categorize urban space according to the urban features. Furthermore, the limited urban space with increasing population emigration might impact urban livability while such impact might be varied due to the compact city pattern. Firstly, this study applies principle component analysis (PCA) to analyze compact city pattern and the change tendency in two different time periods. Next, the impact of housing price to income ratio (PIR) is then discussed by using geographical weighted regression (GWR). Section 2 presents the evolution process of compact city. Sections 3 and 5 discuss the methodology and results. The paper concludes in the last section.

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II. The History of Compact City Concept

The concept of compact city has evolved. The original concept of compact city is the protection of natural environment and agricultural land from urban expansion. Recently, compact city has become a measurement to fight against global climate change and energy crisis. The followings are the evolution of compact city (OECD, 2012).

a) The emergent compact city

The ancient compact city emerged in the Middle Ages. Residents got well protected inside the wall which become an ancient compact city pattern. However, the eighteen-century Industrial Revolution and large amount of people moved into cities had radical impacts on the wall.

b) Improve living condition in urban space

In eighteen- and nineteen- century, large-scale urbanization has cut down open spaces. In addition, insufficient public facilities were unable to process sewage water and garbage and resulted in serious public health issue. During that time, garden city proposed by Ebenezer Howard and radiant city proposed by Le Corbusier had become the transforming compact city. Such buffer zone of urban environment and natural environment has contentedly become the core of urban planning in England, Japan, Hong Kong, and other countries (UK Department of the Environment, 1995; Kuhn, 2003; Tang et al., 2007; Kim, 2010).

c) The emphasis of diversity and livability

After 1960, livability became an important issue in urban planning field. The green buffer zone is not only a segregation of urban space and natural environment but open space and leisure. In addition, the vitality of urban activities and mixed land use might improve livability in urban space (Jacobs, 1962). Until Dantzig and Saaty (1973), compact city has finally addressed with high density development and avoiding excessive urban sprawl.

d) Urban sustainability and green growth

Green Paper on the Urban Environment (Commission of the European Communities, 1990) indicated that compact city is one of the planning measures to achieve sustainable development. In fact, the compact city not only achieve sustainability but satisfy multiple purposes such as the clustered economic effect, the decrease in travel distance and urban efficiency (Thomas and Cousins, 1996; Churchman, 1999).

III. Methodology

a) Study area

This study subjects to Taipei metropolitan area as the study area where has been regarded as the 46th metropolitan area in the world, 40% entire population clustered in 3,700 km2 (see Fig.1). Large amount population and industries aggregation extends the development area and become multi-core metropolitan area.

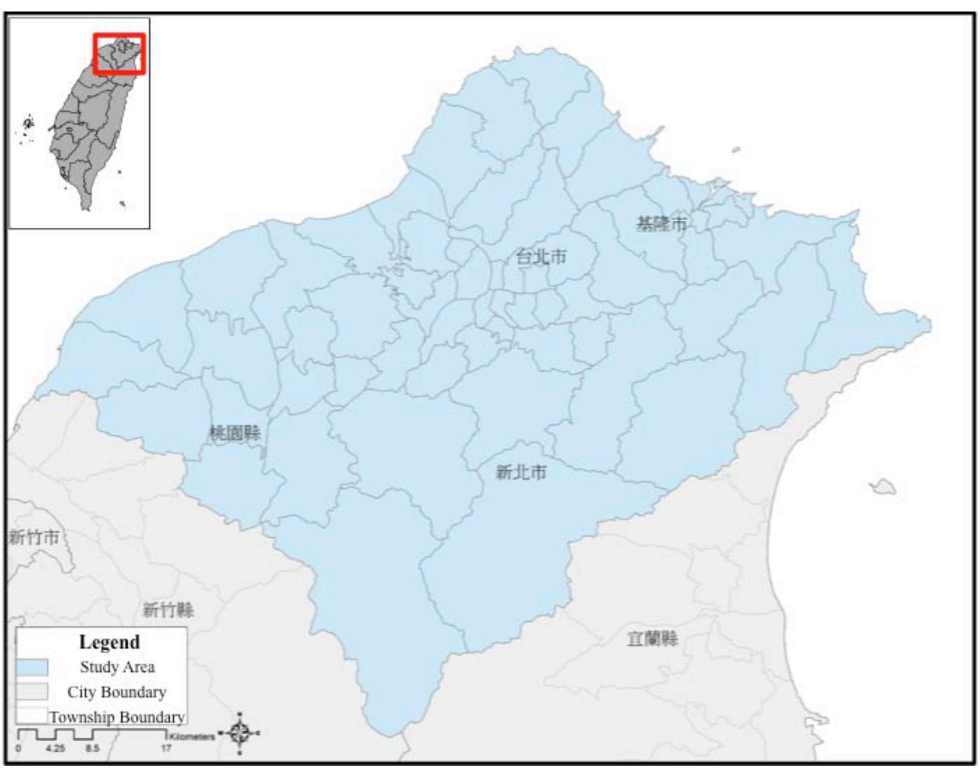

Fig. 1 : Study area

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b) Variables

i. *Compact measurement*

Previously, the measurement of compact city emphasized various dimensions such as Thinh et al. (2002) discussed compact city based on the spatial distribution of built enviroment, Li and Yeh (2004) focused on the urban physical pattern, and Burton (2002) considered diverse urban development aspects including density, mixed use, and intensity. Due to the compact city indicators proposed by Burton having a comprehensive consideration of urban development, this study follows Burton measurement to do the rest measurement. In addition, this study follows the principles representativeness, relation, and in consistency to Taiwan feature to select the variables. (See Table 1)

Table 1 : Variables in compact measurement

Variables		Description	Resource
Density	Population density	Population/Area	Urban and Regional Development Statistics
	Sub-core population density	The highest population density of village/ Village area	Household Registration Division
	Building density	Householdamount/ Developmental land area	National Land Surveying and Mapping Center, the Census Administration
	Residential density	Residential area/ Total area	
Mixed use	Facilities	Residential area/ Non-residential area	
	Mixed land use	(Residential area+ Commercial area+ Industrial area)/ Total area	
	Employment	1-[(Local employment in tertiary industrial sectors/ Local population)-(Taiwan employment in tertiary industrial sectors/ Taiwan population)]	Commerce and Service Census
Intensity	The increment of population density in sub-core	[(2006 population density – 2005 population density)/ 2005 density]×100%	Household Registration Division
	Population increment	(2006 population – 2005 population)/ Total population	

ii. *Urban feature*

Three categories have been defined to discuss urban feature urban development, economic development, and population distribution. The variables in urban development include residential area, commercial area, industrial area, and public infrastructure area. The variables in economic development include employment in manufacturing sector, construction sector, transportation sector, and tertiary sector. The variables in population distribution include population density, household amounts per hectare, and the ratio of population increment. (See Table 2)

Table 2 : Variables in urban development feature

Category	Variables	Source
Urban development	Residential area	National Land Surveying and Mapping Center (1995 and 2006)
	Commercial area	
	Industrial area	
	Public infrastructure area	
Economic development	Employment in manufacturing sector	Commerce and Service Census (1996 and 2006)
	Employment in construction sector	
	Employment in transportation sector	
	Employment in tertiaryindustrialsector	
Population distribution	Population density	Household Registration Division (1995 and 2006)
	Household amounts per hectare	
	The ratio of population increment	

iii. *Housing price to income ratio (PIR)*

Housing price to income ratio is often used in assessing the affordability of housing, and such measurement has been regularly used in The Economist and the OECD Economic Outlook (Chen et al., 2007; Zhang and Zhang, 2011; André et al., 2014). The measurement is the total house price divided by household income, and the higher value indicates the housing prices outpacing household income growth, and vice versa. The annual real estate market price and average household income of township from the Department of Land Administration, Ministry of Interior have been adopted in this study.

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c) Methods

i. *Principle component analysis (PCA)*

A linear transformation is processed in principle component analysis (PCA) from a series of correlated variables to uncorrelated principle components based on multivariate analysis (Sun et al., 2009; Abdi and Williams, 2010; Shi, 2013). Through the process, the first principle component (PC) is designed to have the largest variance, and the ranking of PCs is according to eigenvalues. The following is the PCA formula:

$$\begin{cases} U_1 = l_{11}x_1 + l_{12}x_2 + \cdots + l_{1p}x_p \\ U_2 = l_{21}x_1 + l_{22}x_2 + \cdots + l_{2p}x_p \\ \cdots \\ U_m = l_{m1}x_1 + l_{m2}x_2 + \cdots + l_{mp}x_p \end{cases} \quad (1)$$

where *n* denotes to spatial units, *p* denotes the number of variables, x_p denotes the original variables, and U_m denotes principle components. U_1, U_2, …,U_m (m≤p) are linear combinations of x_p.

ii. *Geographically weighted regression (GWR)*

Ordinary Least Squares (OLS) is one of the conventional global regression models to analyze the pattern of the data by fitting a model to the observed data (Hutcheson and Moutinho, 2008; Hutcheson, 2011). However, conventional global regression models ignore spatial heterogeneity and summarize across the entire area. In fact, many processes are spatial heterogeneity and might produce various responses (Fotheringham et al., 2002). However, geographically weighted regression is an increasingly popular method of analyzing spatial heterogeneity in urban geographic analyses (Lafary et al., 2008).

In order to identify the spatial relationships between urban compactness and housing price to income ratio (PIR), this study applies GWR model. The following is the GWR model:

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i)x_{ik} + \varepsilon_i \quad (2)$$

where (u_i, v_i) refers to the coordinate location of each observation*i*in a space, β_0 and β_k are estimated parameters, and ε_i is the random error at *i*.

Bandwidth selection is important in GWR model, and there are two measures: a fixed-distance kernel and an adaptive kernel. A fixed-distance kernel indicates a constant radius while an adaptive kernel indicates a constant number of neighbors. Due to the wide range of spatial units, the application of adaptive bandwidth might be more appropriate. In addition, there are two ways to measure the number of neighbors: cross-validation (CV) and the Akaike information criterion (AIC). Both measures will be applied and compared to determine the appropriate bandwidth.

The following is the adaptive Gaussian kernel:

$$\begin{cases} w_{ij} = \exp\left[-\frac{1}{2\left(\frac{d_{ij}}{b}\right)^w}\right], when\ d_{ij} \le b \\ w_{ij} = 0, when\ d_{ij} > b \end{cases} \quad (3)$$

where d_{ij} refers to the spatial distance between observations, and b refers to the bandwidth of variables.

IV. Results

a) Cross analysis of urban compactness in 1995 and 2006

According to the compact measurement, both the high density and intensity are extended outward and they are increasing in both periphery townships, and the mixed-use degree remains high and increasing. The cross analysis of compact degree in 1995 and 2006 shows that there are four types of compact city pattern in Taipei metropolitan area including high compact, medium compact, low compact, and special urban development. (See Fig. 2)

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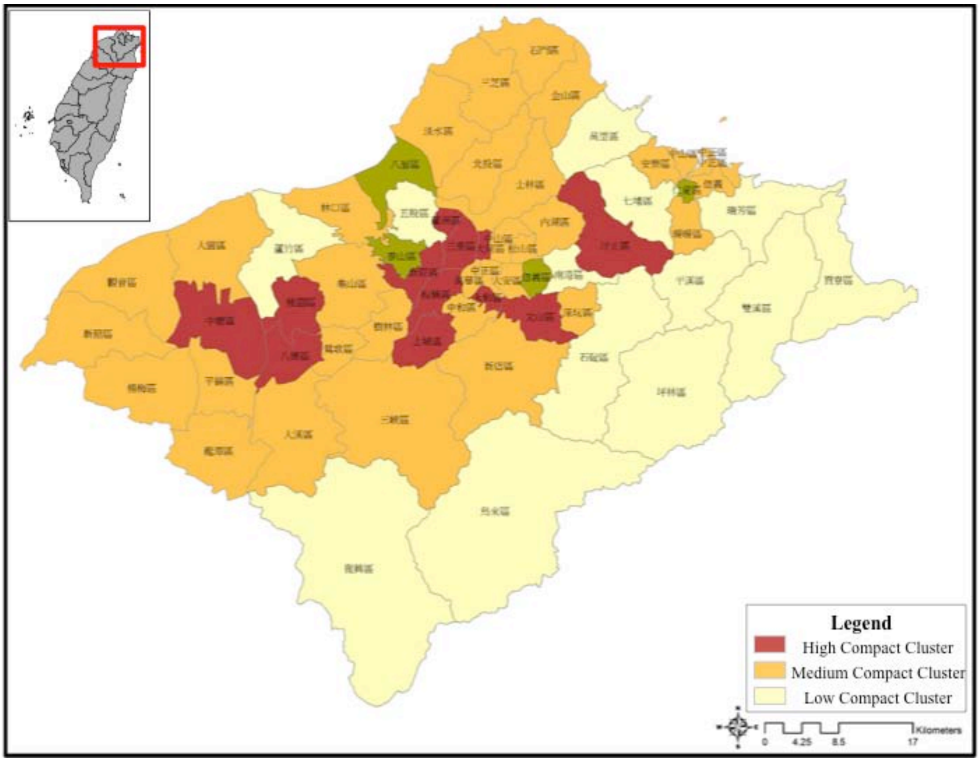

Fig. 2 : The cross analysis of urban compactness in 1995 and 2006

b) Category of urban feature

This study further applies principle component analysis (PCA) to various compact clusters. In high compact cluster, the results show that industrial activities are the main development feature in 1995. Nevertheless, it has become much diverse in 2006. In addition, the significance of public infrastructure and transportation in 2006 indicates that the improved accessibility and convenience in high compact cluster.

Table 3 : Component matrix of high compact cluster

Urban Development Feature	1995		2006	
	PC1	PC2	PC1	PC2
Residential area	-0.336	0.900	0.851	0.490
Commercial area	-0.095	0.422	0.789	0.230
Industrial area	-0.705	0.679	0.931	-0.262
Public infrastructure area	0.009	0.367	0.111	0.920
Employment in manufacturing sector	-0.759	0.147	0.667	-0.438
Employment in construction sector	0.649	-0.050	-0.085	0.370
Employment in transportation sector	0.535	-0.205	-0.424	0.716
Employment in tertiary industrial sector	0.724	-0.147	-0.670	0.335
Population density	0.322	0.312	-0.158	-0.141
Household amounts per hectare	0.637	0.167	-0.024	-0.399
The ratio of population increment	-0.666	-0.723	-0.241	0.034
Eigenvalue	3.379	2.320	3.391	2.342
Proportion (%)	30.715	21.086	30.825	21.289
Cumulative (%)	30.715	51.801	30.825	52.114

In medium compact cluster, population aggregation seems to be the reason of the compact development for “employment in tertiary industrial sector”, “population density”, “household amounts per hectare”, “residential area”, and “industrial area.” In 2006, industrial development is still the main driving force of such compact pattern but attracts commercial activities and public infrastructure.

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Table 4 : Component matrix of medium compact cluster

Urban Development Feature	1995		2006	
	PC1	PC2	PC1	PC2
Residential area	0.138	0.847	0.785	0.196
Commercial area	0.582	0.088	0.769	0.225
Industrial area	-0.651	0.686	0.412	0.906
Public infrastructure area	-0.088	0.561	0.917	-0.086
Employment in manufacturing sector	-0.686	0.343	0.273	0.744
Employment in construction sector	0.457	-0.312	-0.466	-0.125
Employment in transportation sector	0.066	-0.413	-0.266	-0.161
Employment in tertiary industrial sector	0.698	-0.185	-0.076	-0.758
Population density	0.701	0.027	-0.022	-0.395
Household amounts per hectare	0.643	-0.155	-0.122	-0.442
The ratio of population increment	-0.696	-0.425	0.158	0.129
Eigenvalue	3.349	2.135	2.627	2.455
Proportion (%)	30.442	19.409	23.885	22.320
Cumulative (%)	30.442	49.849	23.885	46.206

In low compact cluster, both urban development features in 1995 and 2006 are similar. The comprehensive development for "residential area", "commercial area", "industrial area", "public infrastructure area", "employment in manufacturing sector", "household amounts per hectare" and "the ratio of population increment" are positively significant in both years.

Table 5 : Component matrix of low compact cluster

Urban Development Feature	1995		2006	
	PC1	PC2	PC1	PC2
Residential area	0.756	-0.265	0.877	0.376
Commercial area	0.841	0.083	0.810	0.002
Industrial area	0.921	-0.270	0.999	0.039
Public infrastructure area	0.671	-0.242	0.763	0.637
Employment in manufacturing sector	0.610	-0.285	0.833	0.047
Employment in construction sector	-0.412	-0.181	-0.413	-0.013
Employment in transportation sector	0.321	-0.527	0.291	-0.359
Employment in tertiary industrial sector	-0.493	0.606	-0.761	0.060
Population density	0.437	0.036	0.436	0.717
Household amounts per hectare	0.036	0.994	-0.014	0.673
The ratio of population increment	0.125	0.815	0.832	0.150
Eigenvalue	3.674	2.621	5.417	1.673
Proportion (%)	33.398	23.827	49.245	15.205
Cumulative (%)	33.398	57.225	49.245	64.450

V. Spatial Heterogeneity of Compact City and PIR

This study compares traditional ordinary least square (OLS) and geographically weighted regression (GWR) to see if there is any spatial heterogeneity. The result shows that R square is higher and AICc value is lower in GWR suggested that GWR has better explanation for considering spatial heterogeneity. (See Table 6)

Table 6 : ANOVA of OLS and GWR

Item	OLS	GWR
AICc	254.084	133.11
Adjusted R^2	0.479	0.918

The significant spatial scale dependence occurs in the relationships between urban compactness and PIR. At a spatial scale of 25 neighbors, the AICc value has the lowest value. Therefore, 25 neighbors has become the acceptable bandwidth to model the relationship between compact city and PIR.

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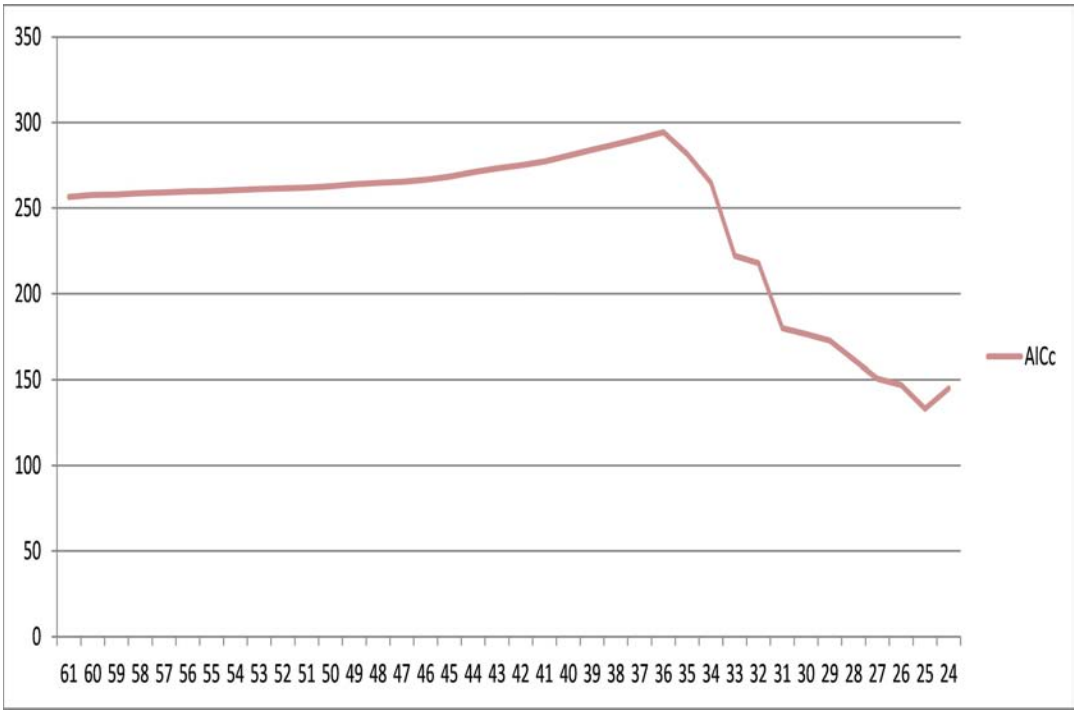

Fig. 3 : The bandwidth and AICc value

The study investigates the varying relationship between urban compactness and PIR based on the slope parameters (β coefficients) and local R^2. The coefficient represents the intensity on such relationship. The local R^2 ranges from 0 to 1 measuring the fitness of the model. The average local R^2 is 0.784, and the western study area has relatively higher local R^2 suggested a better-fit model. The Monte Carlo test shows that all variables except "facilities", "the increment of population density in sub-core", and "population increment" are significant. (See Table 7 and Fig. 4)

Table 7 : The AICc value, adjusted R^2, and Monte Carlo test in GWR

	AICc	Adjusted R^2	Monte Carlo Test	
			Slope	Intercept
Population density	270.073	0.231	-3.031	***
Sub-core population density	262.735	0.319	1.462	***
Building density	273.111	0.212	0.699	***
Residential density	271.802	0.231	5.055	***
Facilities	279.203	0.071	-1.144	-
Mixed land use	264.326	0.459	-0.743	***
Employment	273.979	0.205	-1.94	**
The increment of population density in sub-core	280.231	0.079	0.408	-
Population increment	279.596	0.052	0.293	-

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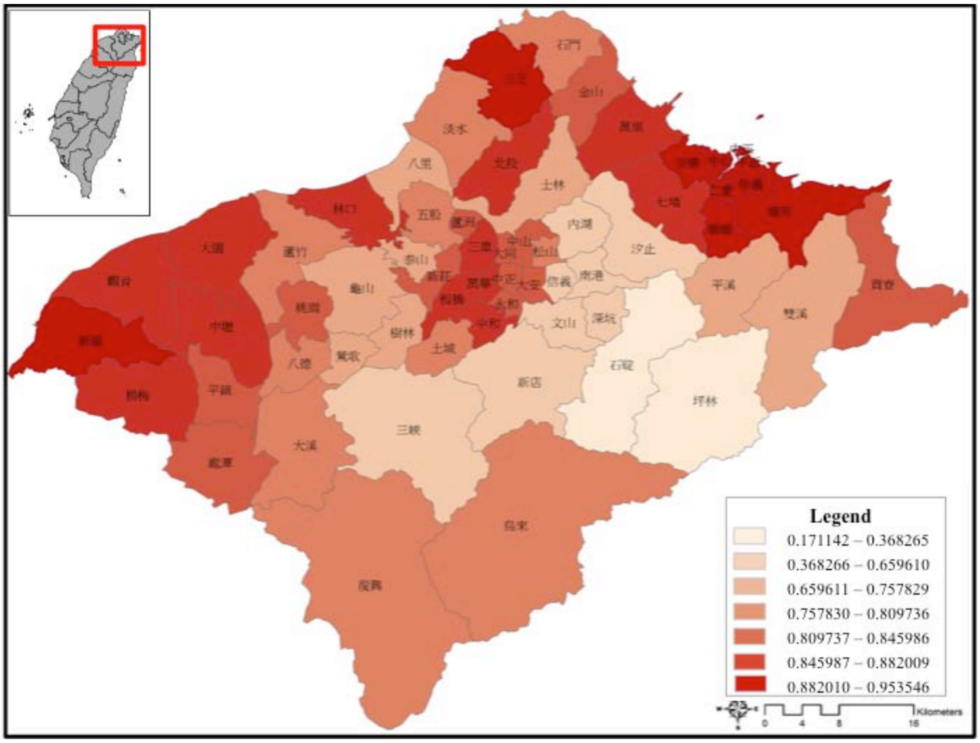

Fig. 4 : The spatial distribution of local R^2

a) The impact of population density to PIR

The average coefficient value in population density is -3.066 indicating a negative relationship between population density and PIR. However, in the city center and the eastern area have relatively positive effect suggesting a relative high housing price.

b) The impact of sub-core population density to PIR

The average coefficient value in sub-core population density is -0.02 indicating a negative relationship between sub-core population density and PIR. Only western districts and some southern districts have positive effect while those districts are sub-core area in practice. Therefore, the increment of population might have relatively impact on the housing price and further increase the pressure on house affordability.

c) The impact of building density to PIR

The average coefficient value in building density is 2.187 indicating a positive relationship between building density and PIR. Only partial districts show negative effect for relatively lower built environment in the southern districts and rapid developing in city center. In rapid development districts, the increment of building density is able to mitigate the housing affordability.

d) The impact of residential density to PIR

The average coefficient value in residential density is 2.184. The study area except the eastern districts show positive effect indicating the higher residential density equals to the higher housing demand and might result in an increasing pressure in housing affordability.

e) The impact of mixed land use to PIR

The average coefficient value in mixed land use is -0.776and all the study area show negative relationship between mixed land use and PIR. The increment of mixed land use is not only improving livability but increasing local employment. The satellite town is able to stabilize housing affordability.

f) The impact of employment to PIR

The average coefficient value in employment is 0.106. The study area except the eastern districts show negative relationship between employment and PIR. The increment of employment indicates a more mixed land use pattern and such economic development might mitigate housing affordability by providing more housing units and increasing household income.

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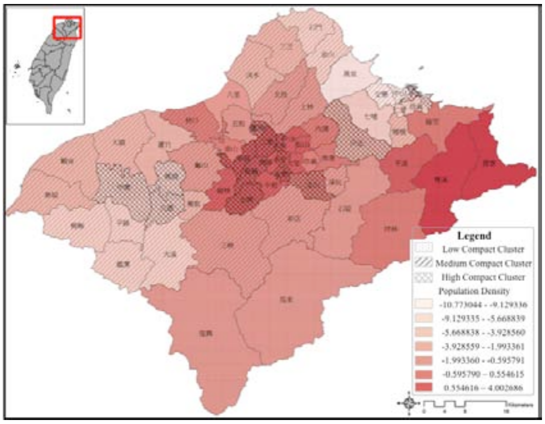

Fig. 5 : Population density

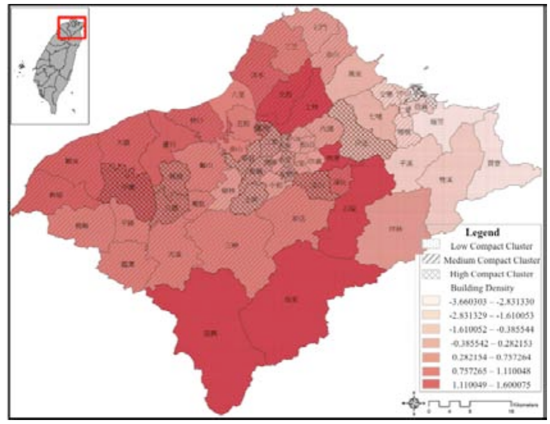

Fig. 6 : Sub-core population density

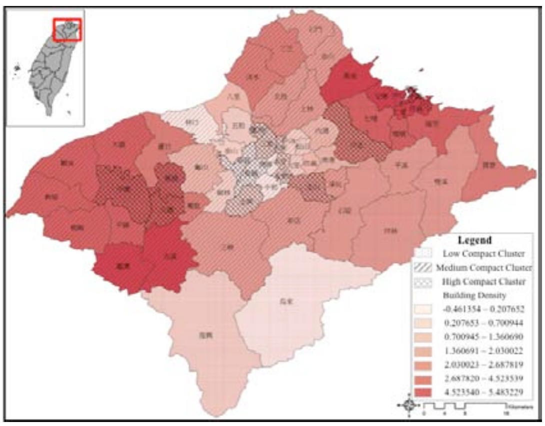

Fig. 7 : Building density

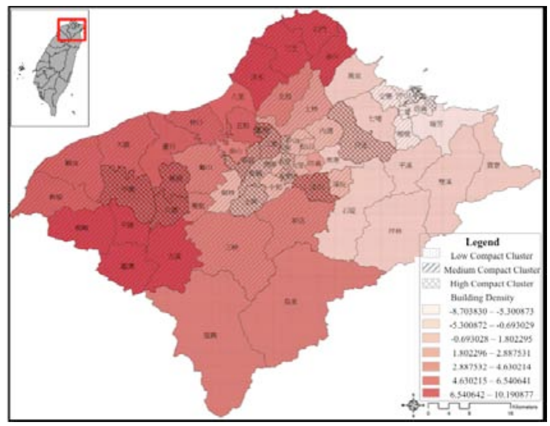

Fig. 8 : Residential density

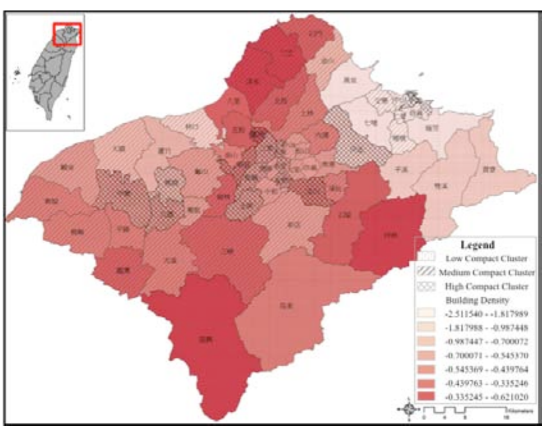

Fig. 9 : Built environment

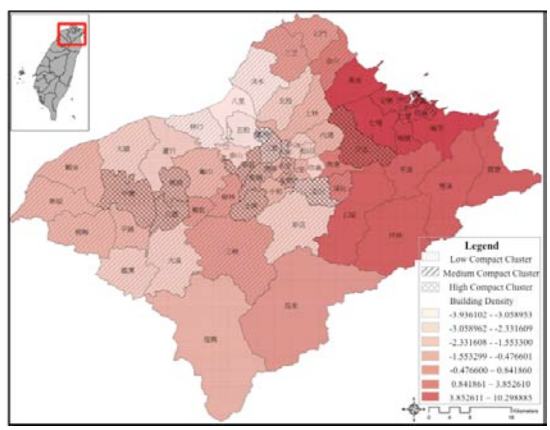

Fig. 10 : Employment

VI. Conclusions

This study discusses beyond categorization of urban compactness but comparing urban compactness across different time periods. The results show that high compact cities show an improvement on public infrastructure and become more livable. Medium and low compact city stay similar urban features such as manufacturing and residential. In addition, the results of GWR show various relationships between urban compactness and PIR. Among them, population density, building density, residential density have positive effect indicating the more people aggregate might increase the housing pressure. On the contrary, mixed land use and employment have negative effect indicating a more mixed-use environment might attract diverse industries to increase household income.

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