

The Urban Development Dynamics: Simulating the Spatial Urban Gravitational in Fukuoka Urbanized Area, Japan

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Abstract

Understanding urban development dynamics is crucial to advance knowledge regarding urban planning. Building positioning and street layout are the main factors that generate the spatial structure of a metropolitan area. Urbanized areas are intensely populated and designs must include recreational areas. Careful land usage will enhance the attractiveness of an urban development and increase its socioeconomic value. This study applied knowledge of urban dynamics and development phenomena to assist town planners in decision-making processes. The urban gravitation phenomenon was examined using the gravity index which runs on the Geographic Information System (GIS) platform. Urban gravitational maps detailing concentrated urban activity clusters were interpreted and analyzed for four major building types in Fukuoka City, Japan. These included public facility, mixed use, residential, and commercial buildings. Results illustrated the attractiveness characterized by each type of building. Moreover, the spatial concentration of land development reflected the dynamics of urban potential as well as the concept of metropolitan physical transitioning dynamics.

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Introduction

Urbanization is a growing phenomenon (Assche, Beunen, Duineveld & Jong, 2013, 177-198). A successful urban development is dependent on its configuration, with complex installation systems required for several elements such as sanitation, utilities, infrastructures, land usage, building construction, and transportation (Jenks & Jones, 2010). The development of cities with densely concentrated populations can be interpreted in terms of the physical growth as expansion (horizontal) and intensification (vertical).

Following the spatial planning scale of Assche and Verschraegen (2008), urban characteristics (Pan, Gourab, Coco, Manuel & Alex, 2013, 1-32) can be defined as a consequence of the centrality dynamic process based on fundamental configurational forces. The concentration of any urban activity (Sevtsuk, Onur, Farre & Reza, 2013) in specific areas acts like a magnet to attract other activities for settlement.

Krings, Calabrese, Ratti and Blondel (2009) used Newton's law of universal gravitation to explain the interaction of urban configurations and road networks with the surrounding buildings. Urban gravity can be represented by the spatial attractiveness of an urban area to bring in further development and land usage in specific areas or districts. The attractiveness of a place depends on the beneficial features for work, social interaction, or sightseeing (Girardin, Vaccari, Gerber, Biderman, & Ratti, 2009, pp. 175-200). Measuring and estimating the affordability of housing, well-connected transport systems (Williams, Elizabeth & Mike, 2000), other public infrastructure, basic services and employment capacity also impact on an area's desirability.

People perceive urban areas through their personality and physical awareness which are associated with the urban form elements (Jenks & Jones, 2010). Humans choose specific places to perform particular urban activities such as commercial business, recreation, entertainment, or dealing with public services; these factors determine where they choose to live.

The density of urban activity in a built-up environment refers to the characteristics of the area (Li, Fisher, Brownson & Bosworth, 2005, pp. 558-564). Density is one of the major factors of urban attractiveness and can be interpreted in forms of spatial weight and volume which are measurable by observing the building structure, the intensification of land usage, and the development tendency. In addition, this investigation considered the building environment and capacity of the city to maximize its urban attractiveness. Along with the urban layout, transportation infrastructure, networks and the environmental condition all affect the interpretation of urban attractiveness which is associated with public awareness of places, and eventually leads to decision-making processes.

The perception of the building environment and urban activities can also influence town planners who manage the city and control urban development. Regulations on land use are put in place to provide an appropriate function for land development. Under these circumstances, the perception of urban planners also influences the development of the area through recognized legal planning processes.

The Fukuoka urban area is continuously developing due to strong economic competition as it is centrally located in the south of Japan. In 2013, Fukuoka City had the second highest ratio of newly constructed commercial buildings in Japan at 38.2 percent (Goto, Hatakeyama & Yamada, 2013). Many of the newly constructed buildings were in areas with easy access to the railway networks.

This study focused on the urban areas with high concentrations of buildings and infrastructure. Train stations in Fukuoka City are located predominantly in districts with large amounts of building development. Urban activity patterns are influenced by the spatial attractiveness of development, and this has caused the gravitation phenomenon.

Urban gravitational studies are inspired by the gravity model of migration. This urban geography model is derived from Newton's law of gravity and used to predict the degree of interaction between two places (Rodrigue, Comotois & Slack, 2013).

The majority of previous empirical studies on urban development dynamics relied on the interaction between buildings, train stations and road networks. Fukuoka urban development has concentrated on public transport infrastructures such as train stations and subway lines which transport people to the city, and urban activities which drive the economic organization of land usage and planning.

These elements interact with the Fukuoka urban expansion in terms of real estate development surrounding the train station areas. There are significantly different densities between station districts and outer areas, and new urban development is concentrated in the station areas. In other words, this phenomenon is shaping the city toward the concept of Transport Oriented Development (TOD) which incorporates features to encourage transit ridership.

To understand the transit ridership influence on building development, Taylor and Fink (2003) identified three external factors that affect user behavior of public transportation as socio-economic, spatial and public financing. The socio-economic factors are implied by the crowds of public transportation users, and also affect building development for either commercial or residential use. The spatial factors are influenced by the effects of new urbanist principles which encourage dense building

development for mixed use and increases the capacity of urban accessibility. Public financing partly controls the volume of both transit users and the related building development.

To address the potential of station district areas for major land use, this study examined the interaction between buildings and road networks in Fukuoka urbanized areas to quantify the potential of urban development in each building area, and observe the relationship between potential areas and public transport infrastructures.

Overview of Data

The simulation was conducted in urbanized areas of Fukuoka City located in the southern part of Japan. Fukuoka City is a metropolitan area which has been promoted as the capital of Kyushu Region with high population density and economic wealth as a major transportation hub. Fukuoka City consists of seven municipalities with a population of 1,538,510 within a total area of 340.60 square kilometers.

The railway and bus networks are the main public transportation systems which relate to the spatial development, land use planning and urban activities in the area.

Therefore, this study conducted a simulation of urban gravitational effects to investigate the physical development dynamics. The investigation focused on the elements of urban configuration such as building volume, street networks and public transportation systems. **Figure 1** illustrates the urban configuration areas used in this study.

The study focused on the major type of building usage in Fukuoka urban areas which consisted of four types as public facility, mixed use, residential and commercial. The volume of each unit of building data was calculated from its area and number of floors. Details of each building type are presented in **Table 1**.

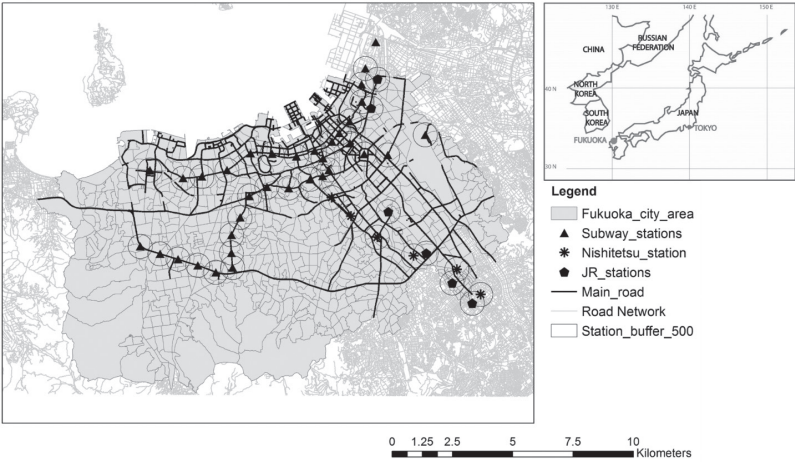


Figure 1. The urbanized study area of Fukuoka City, Japan.

The urban gravity study focused on the spatial interaction between buildings and road networks. The data was analyzed using building information, such as the type of uses and values for a 500-meter radius from the center of each railway station. The boundaries of the in-bound areas were illustrated by 500-meter buffer areas (Figure 1).

The data represented the intensity of each building type and related to actual building usage in terms of real estate development. This included public facilities, mixed use buildings, detached houses and commercial buildings. All were analyzed against Fukuoka City's road layout which is a system of interconnecting lines that represents the street network for the whole city. A road network provides the foundation for network analysis; for example, finding the best route or creating service areas (Wade & Sommer, 2006).

The data required to interpret the relationship of density intensification studies (Equation 1), illustrates the pattern of the gravity model to explain the urban concentric theory and ascertain the elements or significant factors which define urban attractiveness behaviors.

$$\text{Density Intensification} = \frac{\text{Total Floor Area}}{\text{Total Land Area}} \quad (1)$$

Figure 2. Illustrates the comparison of urban density intensification between the study areas(in-bound)andouterareas(out-bound).

Methodology

The study proposed the simulation of four major building types in Fukuoka City to investigate the development behavior and attractiveness of individual urban activity, focusing on the urban intensification which generated the volume of attraction considered against the transportation network of the urbanized area. The research flow chart is illustrated in Figure 3.

Table 1. Information simulation of building type.

Number	Type of building	Description	Number of units
1	Public facility	Public services that provided for basic needs in urban areas such as education, administration, hospitality and transportation infrastructures.	2,934
2	Mixed use	The combination of activities in the same building. The various functions of buildings sharing the infrastructure with each other.	42,743
3	Residential (Detached housing)	Housing as shelter and accommodation. Separated by density of users such as detached houses and apartment buildings which are controlled by land use regulations.	106,176

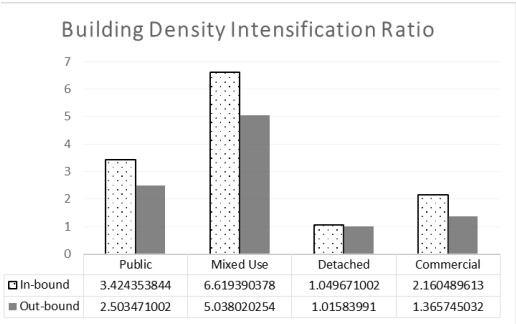


Figure 2. The building density intensification ratio comparing intensity in the subject areas and outside the study area.

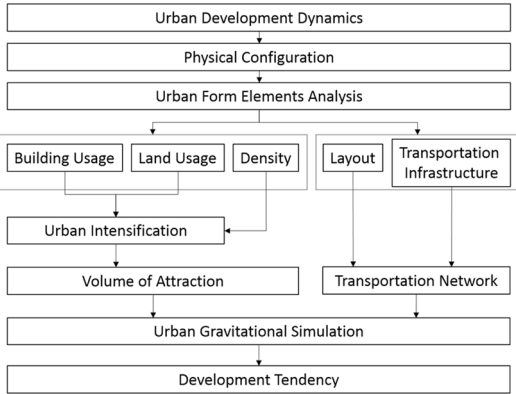


Figure 3. Research flow chart.

This study operated centrality tool assay, using the Gravity Index in Urban Network Analysis (UNA) toolbox which runs on the Geographic Information System (GIS) platform. UNA is particularly used to simulate the potential of urban development which represents the capacity for metropolitan growth.

The study compared three indexes given by the centrality analysis of UNA as reach, gravity and closeness. The gravity index is the most appropriate measurement to simulate the attractiveness of district areas. It uses the weights of the destination building as the enumerator, along with additional factors such as the impedance in the overall spatial analysis (Sevtsuk & Mekonnen, 2012). Therefore the Gravity Index represents the calculation of spatial interaction among the buildings themselves, and also the interaction between the buildings and the surrounding road network.

The Gravity Index mechanism measures the gravity $r(i)$ of a node i in graph G at a radius r , based on the interpretation that centrality is inversely proportional to the shortest path distance between i and each of the other nodes G that are reachable from i within a geodesic distance r . The normalization of the Gravity Index is illustrated as Equation 2.

$$Gravity^r(i) = \sum_{j \in G - \{i\}; d[i,j] \leq r} \left(\frac{W[j]}{e^{\beta \cdot d[i,j]}} \right) \quad (2)$$

where β is the exponent that controls the effect of distance decay on each shortest path between i and j and $W[j]$ is the weight of a particular destination j that is reachable from within the radius threshold r (Sevtsuk & Mekonnen, 2012).

Results

The results illustrated the urban gravitational maps of the subjected building types as public facility, mixed use, residential and commercial. Figure 4 shows the Spatial Gravity value of the road network and locations of railway stations in Fukuoka urbanized area. Results show differences in gravitation characteristics accordingly to the type of building which are explained as follows:

Public facility area:

The highest values for public facility were in the range of 80-100. The existing development conditions of public facility areas were distributed throughout Fukuoka City, particularly in highly accessible areas. The services were clustered in railway station districts and dispersed between adjacent railway stations. A high level of attractiveness was located in Central Business District (CBD) area and sub-city center areas.

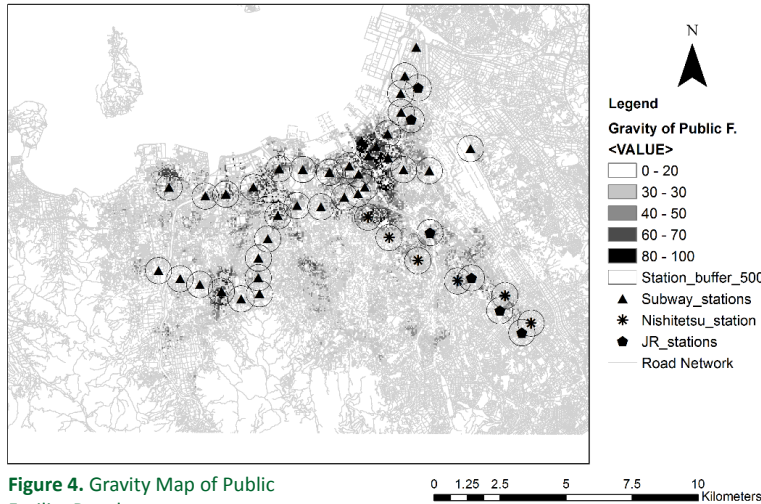


Figure 4. Gravity Map of Public Facility Development.

Mixed use area:

Mixed use buildings combine at least two uses. Mixed use functions cause the city to be compacted, and the tendency of mixed use area development is significantly related to railway transportation systems to establish a higher capacity of land in station districts or any mass transportation service areas. The clustering of gravity value occurred notably around station areas which indicated the highest value as 2,000 located at the interchange area between the subway system and the Nishitetsu Line. Figure 5 indicates that 500 boundaries of railway stations have significant attractiveness for mixed use building development.

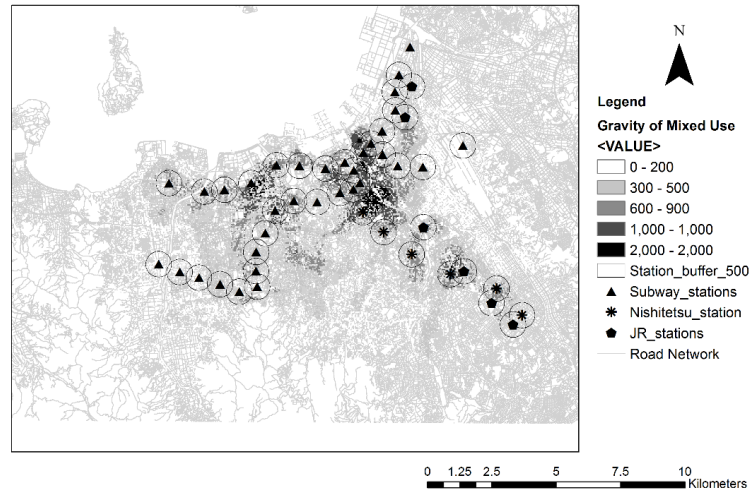


Figure 5. Gravity Map of Mixed Use Development.

Residential area:

The gravitation phenomenon of residential area development was reversed to other observed building types in this study. The residential area was developed far from CBD through planning and policy. However, the sub-city center is significantly clustered for housing development. In the residential zone, the areas with easy access to more than one railway station, or areas in-between stations that are attractive for residential development (Figure 6).

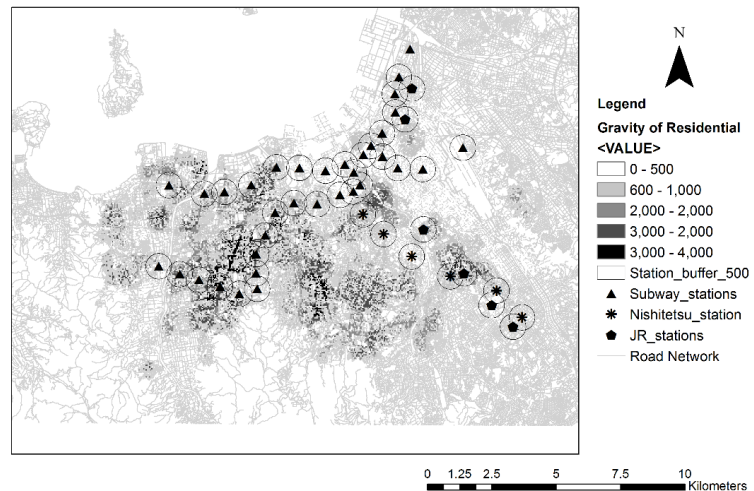


Figure 6. Gravity Map of Residential Development.

Commercial area:

The gravity value of the commercial area is greater in CBD and its vicinity and also in the sub-city center as the main commercial and business hub of the city. The commercial area development tendency is to develop in the same direction with mixed use and public services, but the details of clustering were slighted shift to concentrate in specific areas at CBD and the sub-city center (Figure 7).

The gravitational value relationship with transportation contexts was considered to interpret the land use development dynamic. Comparison of the gravitational ratio between the buildings in the transportation system service area (in-bound) and the buildings located outside the service area

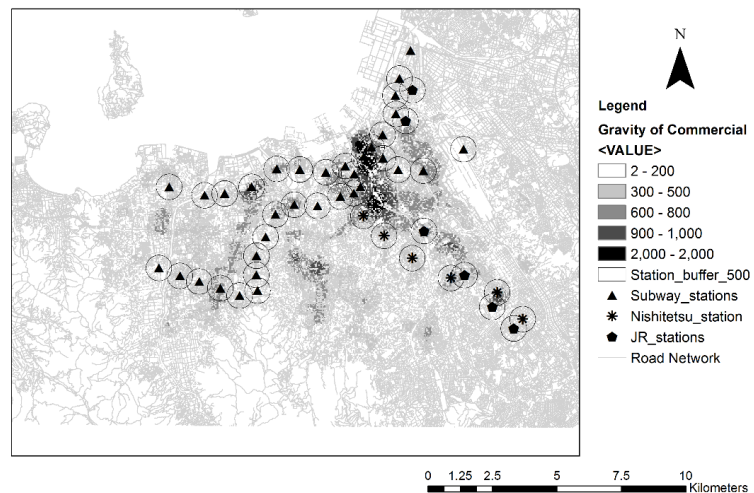


Figure 7. Gravity Map of Commercial Development.

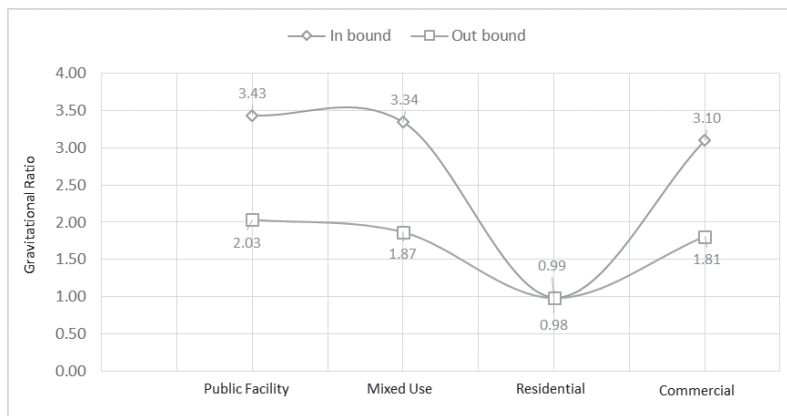


Figure 8. Gravitational ratio between in-bound and out-bound areas.

(out-bound) illustrated the attractiveness for urban development (Figure 8). Service areas were 500 meters from railway station districts and the main road network (larger than 13 meters width).

The gravitational ratio of main road service areas was approximately three times higher than the out-bound areas, except for residential districts which were represented differently for gravitational ratio between in-bound and out-bound areas. The gravitational ratio of railway station service areas was approximately two times higher than the out-bound areas. Also, residential areas were different, with a value of 0.98 for the gravitational ratio between the in-bound and out-bound areas (Figure 8).

Discussion

Residential buildings showed fewer differences for gravitational ratio between in-bound and out-bound areas. Values of residential gravitation ratio were 0.99 on main roads and 0.98 in railway station service areas, respectively.

We have argued that the urban development dynamics of residential areas were developed by different mechanisms of urban planning. The study results defined values on gravitational ratio between the in-bound and out-bound areas of public facility, mixed use, and commercial buildings. The paradox of residential housing has been discussed regarding two issues as the characteristic of residential land development itself which resulted in less influence of transportation networks, and the service area of transportation networks that possibly affected residential development at greater distances than 500 meters radius from transportation infrastructures.

Residential buildings were developed in low density areas because high density districts were mostly used for multi-functional mixed use development. In this case, building physical density was significant for urban development, and had a strong relationship with public transportation infrastructure accessibility.

The transportation network service area for residential development showed almost no difference between the ratio of building density intensification and gravitational attraction. Results suggested that service areas of transportation networks were not significant and did not influence low density residential development such as detached housing. On the other hand, service areas for residential development were larger than 500 meters as specified in this study. To explain this issue, an option of feeder transportation was suspected to transit the users from their accommodation to major transportation infrastructures such as cars or buses. In addition, the land rent theory (Rodrigue, Claude & Brian, 2013) described spatial urban economics for land price structures and rent patterns which were highest in the center of the city but decreased in the outer areas.

Conclusions

This study simulated existing urban gravitational value by describing the development phenomenon in metropolitan areas where activities have mushroomed due to mass transportation. The pull of urban areas was related to the behaviors of the users and the location of prime attractions.

The ratio between the in-bound and out-bound traffic for public facility, mixed use and commercial buildings reflected significant urban development dynamics related to the major transportation systems. The service area of transportation networks particularly influenced the level of urban development and the attractiveness of specific building use development which favored high density areas.

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