Nakhara: Journal of Environmental Design and Planning
Volume 18, 2020

A Generic Scenario on Urban Sustainability of a Historical City Center

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Received 2020-02-25; Revised 2020-05-22; Accepted 2020-06-02

ABSTRACT

In discussion on modern urban development issues, many researches have focused on those newly expanded areas, yet few researches have scrutinized what contributes to the vibrant life of the historical Central Business District (CBD) in inner cities. This research has examined a declined old city centre in central Taiwan by deploying Space Syntax analysis to verify possible contributions of parts-whole street network disconnection to the death of CBD in inner cities. The research findings suggest that linearity and critical street segments being properly integrated with the whole arterial street network could be crucial for future city planning.

Keywords: *urban sprawl and sustainability, street network, Space Syntax, linearity, parts-whole integration*

INTRODUCTION

This research has tried to disentangle fundamental attributes that may have a crucial impact on the issue of urban growth and sustainability. In her book *The Death and Life of Great American Cities*, Jacobs (1962) considered the life and death of urban areas related to socio-economic concerns. In this research, "sustainability" of an area means that the area continues to be socially and economically vibrant throughout time and is not restricted to an environmental position. The continuous socio-economic vibrancy of urban areas has been analyzed by Hillier (2009) who considers the nature of the part-whole structural relationship characterized in the city's street network. The relationship is the fundamental element influencing the sustainability of urban development due to its important effect on social interaction and commercial vitality. Areas designated with single land-use pattern and separated from the whole street network system tend to constrain accessibility for the public and are vulnerable to becoming un-competitive in economic development compared to others. Thus, the lack of sustainability emerges for these areas except when they are purposively designed for residential use only.

Very often, economic decay and displacement of vibrant street life within urban areas could be easily detected from on-site surveys. The reasons for this transformation in areas have rarely been explored thoroughly. Major attributes usually mentioned for the shift of social economy from one area to another include lack of parking lots or green spaces, traffic congestion or pollution, insufficient public transportation or pedestrian unfriendly problems, etc., whereas many believe uncompetitive commerce to be the fatal factor. From these surveys, street network patterns and related vehicular as well as pedestrian flows could be critical in affecting commerce outcomes in areas, which seems to be long overlooked. The Space Syntax approach (Hillier and Hanson, 1984) analyzes existing urban street networks and is able to simulate pedestrian and vehicular movements based on relative depth of these street networks. In this research, Space Syntax will be used as a diagnostic tool to analyze the urban area, and it will also project simulated changes in the street network to see what interventions could have a positive effect on the socio-economic sustainability of the area.

Study areas in this research focus on the historical Central Business District (CBD) in Taichung, Taiwan. Literature review on the issue of urban growth and sustainability is presented, and several research questions will be teased out for later study. Rationale and analytical models of the Space Syntax tool will be illustrated in the methodology part. Finally, findings from this research and several positions on city planning and sustainable development will be discussed in the conclusion.

LITERATURE REVIEW

In the second half of the 20th century, the movement of urban modernization was largely inspired by Le Corbusier (1967) in his works *The Contemporary City* as well as *The Radiant City*. Positions of zoning based on land use (such as residential, work, business, etc.) and efficient transportation system (hierarchical vehicular networks segregated from pedestrian roots, etc.) have been adopted world-wide regardless of cultural differences. One of the most famous projects based on the above concepts was realized in Brasilia by Lucio Costa and Oscar Niemeyer (El-Dahdah, 2005, Krohn, 2003, p. 39-40).

In *The Death and Life of Great American Cities*, Jacobs (1962) criticized separated land use zoning strategies because they were seen as causing the disintegration of pedestrian movements and as creating vigorless areas whereas an inclusive pattern of vibrant activities can often be detected in most traditional city centres characterized with mixed commercial and residential use as well as pedestrians being together with vehicles (p. 15). As described by Holston (1989), the critical issue derived from separated land use zoning principles is reflected in the elimination of the synthesis of public and private social life on those corridor streets defined by continuous building facades in most traditional urban contexts (p. 103-105). As a result, the separated land use zoning development has contributed to the death of the street in newly developed areas where inhabitants often find "the absence of the social life of crowds that they expect to find in the public places of a city" (Holston, 1989, p. 105).

In spite of the criticism of "The Death of the Street" by Jacobs and Holston in modern urban development, many scholars believed in the contributions of marketing, better infrastructures, healthy and safe environments developed from urban interventions and expansion. Victor Gruen created large malls and suburban shopping centres on the outskirts of cities starting the process of leaving the city centre (Gruen, 2017). Influenced by the modern movement ideologies of zoning and efficient vehicular circulation system, *Edge City* expansion asserted by Joel Garreau (1992) has emerged as the frontier proposal of secondary city centres and has been developed in rural areas of many American cities, such as Detroit's New Center, Miracle Mile in Los Angeles, etc. Moreover, led by Geoffrey Booth, the Urban Land Institute (ULI) established in 1936, the movement has invited a wide spectrum of land use and development disciplines to provide a holistic development scheme for creating Suburban Business Districts (SBD). To avoid the failed implementation of the edge city movement, ULI has reinvented the scheme of Compact SBD embracing mixed land use patterns and focusing on creating a pedestrian-friendly place integrated with public transportation system rather than the automobile dominant one (Booth, Leonard, & Pawlukiewicz, 2002).

In a study on Jaffa and Tel Aviv, the authors argued that the Space Syntax methodology can be used to study the historical development of two divided cities. In these cases, it is clear that the physical configuration of the city street network can be seen as having a dominant influence on social life, yet at the same time, there are other social forces that may have a stronger influence on urban behaviour. This kind of study can help to improve historians' understanding of "the changing interplay of configurational and social forces in the actual use of space" (Aleksandrowicz, Yamu, & Van Nes, 2019, p. 452). Furthermore, a more recent study on historical districts in Beijing and London concludes that newly created urban areas and patches "can be characterised and differentiated according to the way they are spatially embedded into the surroundings" (Yang and Hillier, 2019, p. 29). The study suggests that interaction between internal part and external whole could possibly lead to socio-economic difference in its occupants and users.

Clearly, the edge city expansion and the Compact SBD scheme were provided as new alternatives to avoid critical issues of traffic congestion and high density in inner cities. However, many historical CBD were deserted and became examples of "The Death of the District" due to the replacement of business hubs by newly established successful SBD or Edge City projects.

Given the fact of urban sprawl and inner-city decay, the Urban Task Force led by Lord Rogers in Britain adopted the "Urban Growth Boundary" model postulated by the Portland Government in Oregon, USA. The boundary limited the city's expansion within five square miles to revitalize the declined central city through maximum usage of existing facilities and services, and it has allowed for the preservation of wild green fields surrounding the city. To deal with the economic sustainability issue on urban development, the Urban Task Force (1999) has advocated the "Compact and Well-Connected City" proposal to create an integrated pattern of streets and public spaces from centre to edge to regenerate the declined city centre (p. 54-57). In the proposal, the integrated street networks of the urban whole and well-connected public spaces of urban parts was designed to include mixed-use of pedestrians, bikes, automobile, buses, etc. to recreate the vital traditional street life described by Jacobs.

The part-whole issue of socio-culture-economic development and environmental protection in relation to street networks has also been advocated by Hillier (2009). He asserted that the primary spatial structure of the street network plays a crucial role in underpinning the city's sustainable development. This is done in ways of overlapping layers of linked centres and that of the residential network to integrate and sustain the development of complexity with regard to three forces, namely environmental, economic, and social-cultural forces (p. 16-35). Clearly, Hillier argues for clarifying the rationale of sustainability of a city, which should not be constrained within the ecological domain. Moreover, he also throws a new light on the holistic scenario out of environment-economic-cultural domains based on humanistic reason, which contributes to the generic function of urban sustainable development. Though the Urban Task Force and Hillier's writing both stressed the important attributes of a well-connected street network system in sustaining historical CBD development, no further discussion has been made to clarify what contributes to (vs. prevents) the decline of the CBD while the newly established SBD or edge city expansions were created successfully.

It is believed that attributes of vehicular as well as pedestrian movements should be crucial in affecting the life or death of economic development in areas regardless of locations. More vehicles and pedestrians naturally generate higher capacity of commercial momentum; the opposite is also true for less movement. Thus, the complexity of the life and death issue on commercial development of urban areas can be put in two questions: "What could be the most plausible and reliable way to predict distribution patterns of pedestrian and vehicular movements in those urban areas under concern?" and furthermore "Could the degree of interaction between parts and the whole of the street network system be one of the major factors contributing to the life or death of commercial activities in parts of urban areas due to its crucial impact on the distribution of vehicle and pedestrian flows?" These two issues and related research design will be clarified in Method of Analysis.

METHOD OF ANALYSIS

The Space Syntax approach will be deployed for this study due to its capacity of prediction of and simulation on pedestrian and vehicular movements, which relates to the first issue of this research mentioned above. Various parameters of this tool will be introduced to exhibit different modes of simulation on different types of movement potential. The simulated movements include vehicles, motorcycles, and pedestrians, etc. Moreover, the degree of interaction between the background residential street network and the skeletal structure of the foreground commercial street network (Hillier, 2009, p. 27-32) will be illustrated to distinguish the simulated potential on the distribution of commercial momentum in different scale in contrast to the residential scatters.

Parameters of the Space Syntax analysis

Based on the software "DepthMap" three major spatial parameters of Space Syntax analysis will be introduced to illustrate ways to represent the various types of movements under concern. The parameters —measures include Global "Integration Rn" (i.e. Radius n), Local "Integration Rr" (i.e. Radius r), and "Relative Choice" as per distance. These depict different measurements of the configurational properties of each spatial element within the street network system. After the measurements are defined, the area network will be investigated for "scope of area (either local or global)" and modes of movement behavior.

Before carrying out parametric analysis, layout plans of an urban context or an architectural floor system need to be deconstructed into a more abstract spatial configuration of "axial lines map" (see Figure 1). In the axial line analysis, each axial line represents the degree of visual-access permeability, which very often appears to stretch to the longest passage crossing different intersections within the spatial network system (Hillier & Hanson, 1984, p. 91-92). On the other hand, the less abstract spatial configuration of "segments map" (see Figure 19) represents the proximal condition of topological direction and geometrical angle changes of the spatial system, and each segment will embark on and end with strategic centre points between two intersections along the passage within the spatial system. Definitions of those major spatial parameters for teasing out plausible modes of simulation on different types of movements mentioned earlier are to be illustrated as follows.

A first parameter of global integration Rn value depicting the "To movement" behavior pattern represents the level of "Accessibility" for each spatial element of axial lines or segments through calculating its relative mean linear depth from all other spatial elements in the system (Hillier & Hanson, 1984, p. 106-115). Furthermore, quantification data of the Rn value are decoded by a colour scheme in which the higher the level of Rn (i.e. higher accessibility or more integrated) the more reddish the colour will be, and the lower the level of Rn (i.e. less accessibility or more segregated) the more bluish and purplish the colour will be. The second parameter of local integration Rr represents the degree of accessibility within a designated scope of relative depth r (i.e. radius r). When the scope of radius r is assigned to 3, the integration R3 will be calculated up to three elements away from each element for representing the level of local accessibility of each spatial element within the designated spatial system. Hillier concluded that the global integration Rn can be the best parameter for simulating longer journeys of vehicular movements whereas the local integration R3 seems to correlate better with pedestrian movements of shorter journeys (Hillier, 1996, p. 134-135, p. 160-161).

Different from the simplest mode of axial lines analysis measuring how close each line is to all others, the street segments analysis not only provides the Integration value of each segment but the third parameter of "Relative Choice" as well. Based on the relative number of overlapping loops calculation (Hillier & Hanson, 1984, p. 103-104; Hillier, 2009), Relative Choice can be obtained for studying another type of movement behavior of the passing by "Through movement" pattern, which depicts how frequently a street segment would be selected as a route for trips within the designated scope of distance. Moreover, in the segment analysis, three important attributes of distance can be included for the two types of parameter-movement study (i.e. To movement vs. Through movement) mentioned above. These are variables of the first distance between central points of two street segments, the second distance subjected to topological direction changes between two segments, and finally the third distance of geometrical angle changes between two segments. In most cases, the major segments analysis based on variables combining the first distance with the third distance can be the best model for teasing out the Integration and the Relative Choice values in order to simulate the two kinds of movement behavior mentioned above (Hillier, 2009, p. 20-21). From a spatial cognition point of view, the first distance model represents the actual "Length Distance" and the third distance model corresponds to the "Continuity Distance" that one naturally recognizes two intersecting street segments as one continuous segment when they intersect with the geometrical least angle change within 0º~45º. The second distance model of topological direction changes seems to be less useful as it truly depicts the pure turns of "Direction Distance" within the configurational complex, which tends to overlook and simplify the complexity of spatial cognitions that navigators daily use intuitively.

Degree of interaction between foreground and background street networks

Prior to the analytical mode of the degree of interaction between foreground and background street networks, some theoretical positions related to a generic scenario on urban sustainability need to be introduced. Then, the different modes of analysis regarding the case study will be illustrated. From the viewpoint of a generic process of an organic city, each settlement's micro-commercial areas for daily products transactions can be created naturally on the central segment or an intersection, named the "central spatial seed" within the street network system. This central spatial seed could be located either on the higher local Integration R3, which depicts the local scale central spatial seed, or on the higher global integration Rn, which represents global intersection central seed. Thus, these central spatial seeds, either locally or globally highly accessible from all parts of a settlement, can be the starting point for later growth of commercial centres in different scales following the development of a city (Hillier, 2009, p. 24-25).

Amid the growing process of each centre within a settlement, reinforcing street segments will appear to strengthen the original seed to shape the integrated shallow core of that centre to become a commercial hub, again either locally or globally. Very often, the reinforcers occur to be orthogonal or up to 45º to the original spatial seed to form a "Linear Expansion", or on the parallel together with orthogonal alignment to exhibit a "Convex Expansion". Moreover, this pervasive solo central core of a settlement or a city tends to interact with the background residential street network and forms a multidirectional structure of routes seemingly like a "Deformed Wheel" pattern within the whole system, described by Hillier as the crucial foreground commercial street network, which would work as the driving force of various types of movements, including pedestrians, vehicles, etc., thus become the generic mechanism of sustaining the economic vitality in area (Hillier, 2009, p. 25-26).

To deal with urban sustainability, Hillier considers the foreground network to be shaped by economic factors whereas the background network is related to local social culture factors. The dual network structure in effect provides an optimizing movement efficiency model, and the fuel needed for vehicles should be minimized, i.e. energy efficiency, which contributes to environmental sustainability (Hillier, 2009, p. 27). Thus, Space Syntax analysis has shed a new light from a humanistic perspective on a generic as well as holistic development based on environment-economic-cultural scenarios.

Following urban expansion and the more frequent use of personal cars as preferred movement option, the development of edge cities and SBDs in the peripheral areas has transformed most cities from the single centre core of CBD to polycentric metropolitans. Hillier described this notion of polycentricism as "Pervasive Centrality" in that the foreground commercial network of linked centres at different scales tends to interact with the background residential network via a limited number of least angular distance called "Intelligible Distance" (Hillier, 2009, p. 24). Learning from empirical tests on the dual network study, Hillier (2009) reported that the Integration variable, measuring the to-movement potential, works better for residential predominant areas whereas the geometrical least angle segments "Relative Choice" as per distance ranging from 250, 500, 750, 1,000, 15,000 meters, etc. seems to be the most appropriate model for teasing out the foreground commercial network of linked centres as it measures mainly the through movement potential mentioned earlier (p. 21-30). Thus, studies on degrees of interaction between foreground and background street networks may help to disentangle issues of intelligible distance between the dual network and its possible influence on areas vitality or other social outcomes.

CASE STUDY

Based on the above theoretical positions, the case study selected for this research represents a typical city development growing from early village scale settlement to single CBD centre and to the latest polycentric metropolitan, which unexpectedly has suffered from a historical city centre decline for more than two decades. The analytical models of axial “Integration” and the segments “Relative Choice” as per distance will be deployed to examine the degree of interaction between the dual network to verify whether there are distinctive analytical models capable of simulating the foreground commercial network emerging at different stages of urban expansion and development. Once the most appropriate simulation model has been teased out, it is possible to clarify what attributes may lead to the death of the old CBD and further to tease out a plausible intervention proposal for reviving the declined area under discussion.

Examining the Dual Network of the study area

Taichung City is located in central Taiwan and is the third largest metropolitan city of the nation, with a demographic of more than 2.75 million. In 2010, Taichung County, consisting of 21 separate towns, was administratively incorporated into Taichung City for political reasons. These towns were suddenly renamed as districts in Taichung City, although they were never part of the city from a historical perspective (Civil Affairs Bureau of Taichung City Government, 2016). The study will focus only on the current metropolitan area which consists of 8 major districts. Central (i.e. the historical CBD), North, South, East, West, Xitun, Nantun, and Beitun areas are the total areas for spatial analysis in the present study. The ‘newly created’ surrounding 21 districts will be excluded as they were not really part of the city and also due to time constraint. There are four stages of urban expansion and development of Taichung City, which will be studied through parameters of both “Integration” and “Relative Choice” on the degree of interaction between the dual network in each period.

Taichung City is located to the west of the mountain range that is running in the middle of the island from north to south. Taichung cannot develop to the south or to the east because of this mountain range. Furthermore, the mountain range is responsible for the fact that most of the settlement development and food cultivation is located on the western area of Taiwan. There is a river to the south of Taichung city, approximately 10 km to the south, running from east to west (from the mountains to the sea). There are also a few smaller rivers and canals, running from the north to the south (related to the elevation of the land), none of which can be navigated by boats. During 1873~1898, the late Ching Dynasty, the precinct of Donda Dun (bold dashed area in Figure 1) was a prosperous settlement due to its strategic location amid the surrounding settlements (Chen, 2012). Based on the Topographic map of Taiwan Bao Tu: 1898~1904 (Center for GIS RCHSS Academia Sinica), an axial map of those early settlements near Donda Dun has been constructed (Figure 1). The Integration Rn measure revealed that three different levels on global accessibility of the Donda Dun can be identified in the embedded system (Figure 2). The result of the Rn analysis by and large correlates the historical text described by Shen Zheng Lang (Shen et al., 1979). Most retail business, such as rice merchants’ shops, grocery stores, etc., gathered around the highest accessible reddish lines on the Central Street area. The local religious temple was sited near the secondary accessible (orange) level of line on the Up Street area. In clear contrast, whole-sale open-air markets of vegetable and fish stock were to be found in the Bottom Street area where the level of global accessibility only ranked in the mid-low range of yellow color. At that time period, rice paddies, vegetable fields, and fishing area were all located outside the city boundary. The measure of Local Integration R3, though correspond with the retail business, is less pronounced than that of the Rn measure. It is noted that the global accessibility Rn measure can accurately capture and explain the notion of the later development of the Donda Dun area, which was naturally developed to form the single central core of business centre through “Linear Expansion” of “Pervasive Centrality” in the region due to reinforcers occurring to be orthogonal or up to 45º to the original spatial seed, i.e. the Central Street. However, other parameters, such as “Relative Choice” turned out to be insufficient measures for simulating the actual commercial distribution pattern occurred in that period mentioned above.

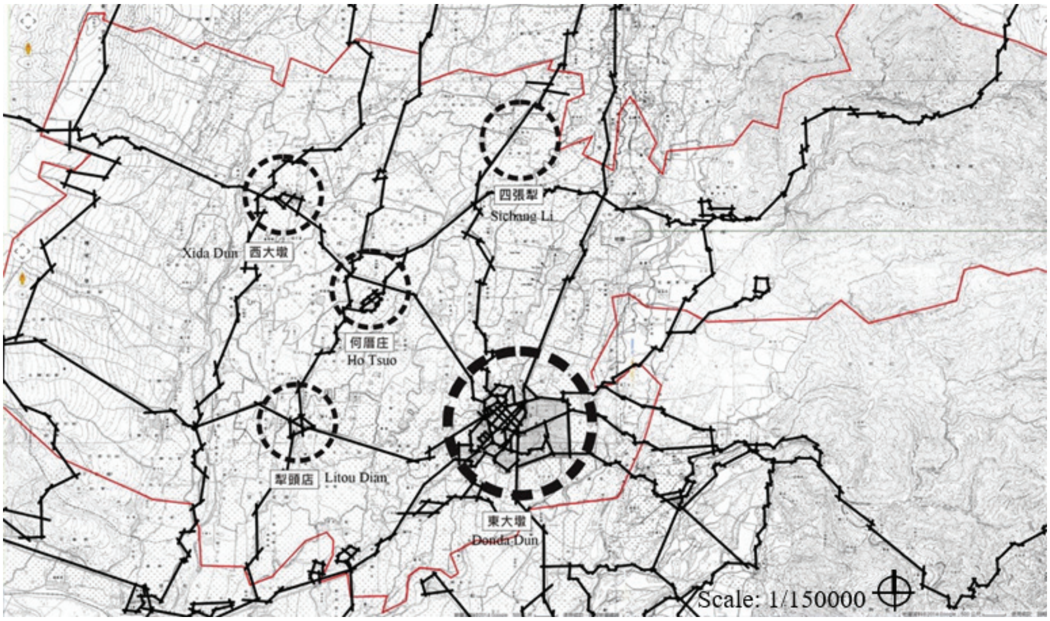

Figure 1:
Axial line map of Donda Dun and surrounding settlements before the founding of Taichung City in Ching Dynasty (Adapted from Lin, 2015, p. 49)

The red line shows the 8 districts of modern Taichung city. The circled areas were the settlements in the early period. The areas between the circled areas were paddy fields and vegetable plots. Some fields were close to the market, but many were not.

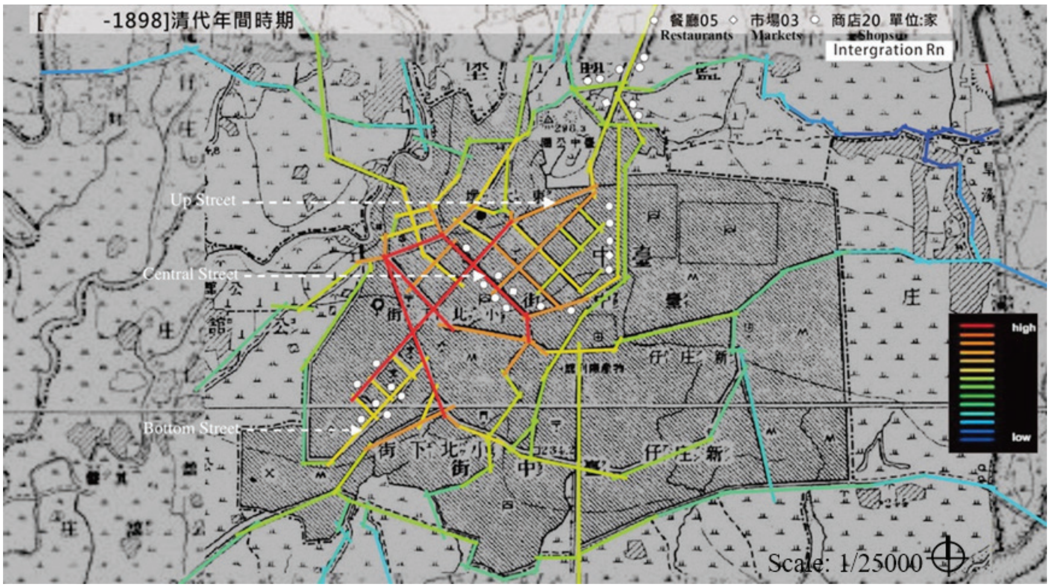

Figure 2:
The Integration Rn of the Donda Dun settlement retrieved from the embedded larger system of all surrounding settlements (Adapted from Lin, 2015, p. 50)

The name of Taichung City was laid down in the Japanese colonial period and the Donda Dun area was renamed Taichung Street in 1896. A new street network of the city was finally laid down in 1911 (Figure 3) and the street pattern was designed with a feature of 45º angle towards the north-west so that most buildings along grid pattern streets would receive enough sunlight for hygienic reason (Chen, 2012). Each square block is around 90-100 meters long on each side. The orientation of the new grid pattern also follows the axes of the two intersecting main streets of the Ching city. At this second stage development, the Taichung Railway Station was completed in 1917 and had become the major landmark of the city (Figure 4). Urban areas of administrative institutions, commercial mixed with residential for the Japanese community, commercial and residential use for the Taiwanese community, industrial areas, etc., were to be found around the train station (Shiu, 2015, p. 10).

Figure 3:
Street layout of Taichung City in the Japanese colonial period in 1911 (Adopted from Lin, 2015, p. 36)

Figure 4:
Axial map of Taichung City in the Japanese colonial period in 1937 (Adapted from Lin, 2015, p. 59)

When studying the correlation between the distribution patterns of commercial activities, which have been recorded on the map of that period (Figure 5) and confirmed (Chen, 2012, p. 174-240, Shen et al., 1979), and the Integration analysis on this second stage street network, it is noted that most retail shops and commercial business gathered on those reddish or orange streets with higher level of accessibility within the global Rn and local R3 spatial system (Figure 6, Figure 7). The above findings seem to confirm Hillier's position on the "Pervasive Centrality" that local small commercial centres exist due to the effect of local intensified grids whereas larger economic centres are to be found on those globally highly accessible street intersections (Hillier, 2009, p. 25). Meanwhile, the reinforcement of the parallel spatial seed together with orthogonal alignments have integrated with the original spatial seed to form the "Convex Expansion" of "Pervasive Centrality" of the city at this stage of development. Similar to the analytical result of the first stage development, parameters of "Relative Choice" are not sufficient to predict the commercial distribution patterns of this period.

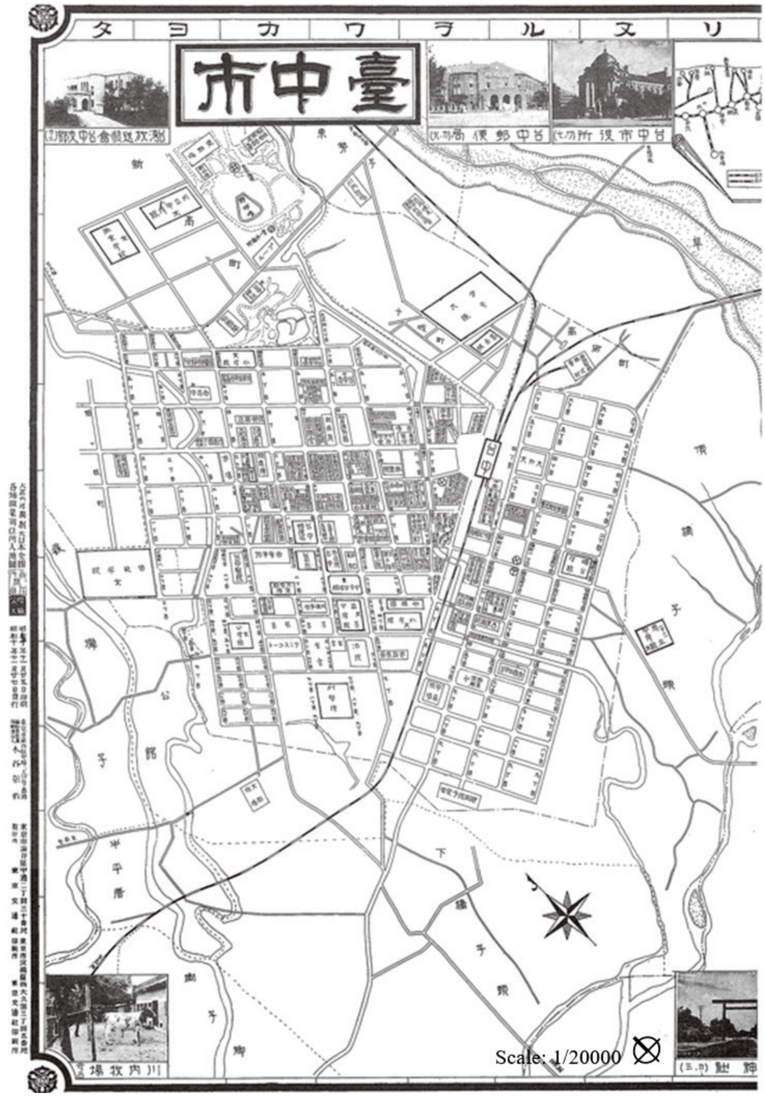

Figure 5:
Distribution pattern of commercial activities in Taichung City during the Japanese colonial period in 1937 (the Center for GIS RCHSS Academia Sinica, 2008-2020)

Figure 6:
Global Integration Rn analysis of Taichung City in the Japanese colonial period in 1937 (Adapted from Lin, 2015, p. 60)

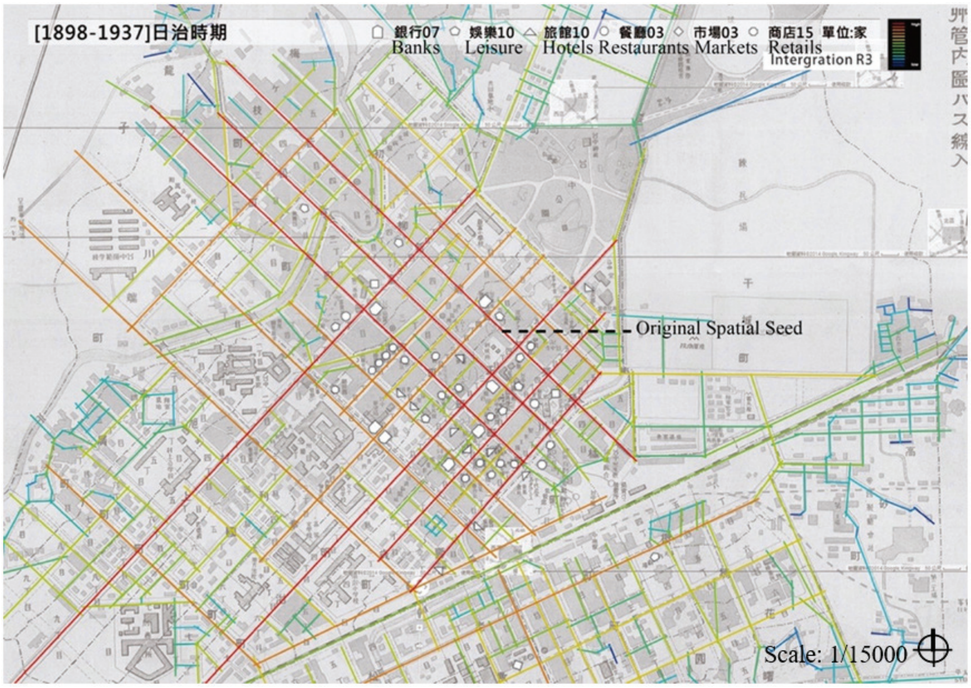

Figure 7:
Local Integration R3 analysis of Taichung City in the Japanese colonial period in 1937 (Adapted from Lin, 2015, p. 61)

During the early modern development from 1945 to 1974, the city has experienced the first phase of urban expansion in its third stage development following the original Ching settlement and after Taichung City was formally established in the Japanese colonial period. Due to the economic and demographic boom at this period, the street network drastically spread towards the north and west boundary of the city (Figure 8) from the original commercial centre developed in the Japanese colonial period (Huang & Chen, 2008). Given the wide spread of various business and retail shops, the newly emerged commercial activities of "night market" and "department store" have also occurred amid the pervasive old city centre to form the typical CBD of the city from 1960 onward.

The correlation between measures of global integration Rn and local integration R3 of this third stage period turned out to be significantly synchronized: the global highly accessible streets that were also highly accessible locally (Figure 9, Figure 10). There is a strong correlation between the two parameters. When further cross-examined with the distribution patterns of commercial activities of this third stage period, one clearly finds that nearly all of those retail shops and commercial facilities were located on those globally and/or locally highly accessible streets ranging from reddish to orange colour (Figure 11, Figure 12). It is again noted that the pervasive centrality of the old city central core has further extended towards the outskirts of the city compared to the previous stage of development. This suggests that more spatial seeds have emerged to reinforce the previous integrated commercial convex expansion of pervasive centrality initially presented at the second stage development to form the central business district (i.e. the old CBD) defined by arterial roads of Cheng Kong, Chung-Cheng, Min-Chiuan, Liu-Chuan, Tzu-You, San-Min, etc. (Figure 11). This development is partly supported by American funding and a slow increase in car ownership. Moreover, several additional reinforcing spatial seeds including Xitun Road, Wu-Chiuan Road, Taichung Road, and Chung-Ming Road, etc. (Figure 9) were developed. They helped to further extend the deformed wheel pattern into a larger system so that the foreground commercial network could interact with the background residential network in an efficient way with fewest average turns of two to three topo-geometric changes (i.e. depth) between the two networks (i.e. commercial and residential). The above findings seem to further confirm the position regarding the "pervasive centrality theory" and "deformed wheel pattern" (Hillier, 2009, p. 25-26). Two reinforcing spatial seeds both have become

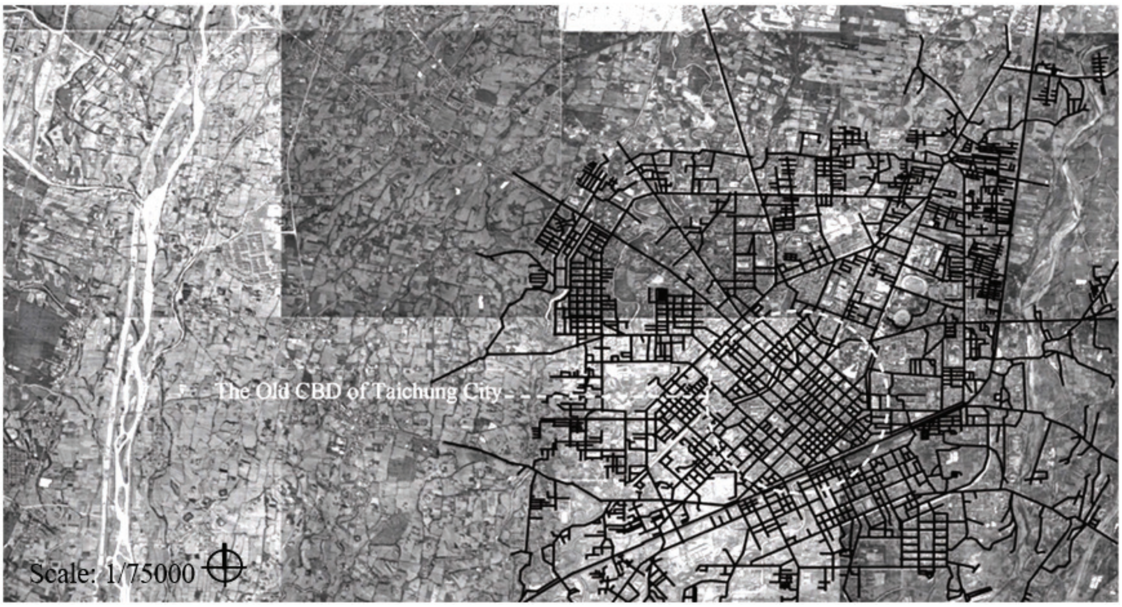

Figure 8:
The first phase of urban expansion during the third stage development of Taichung City in 1974 (Adapted from Lin, 2015, p. 69)

important elements in strengthening the larger scale of the foreground network amid the first expansion of the city. They are Xitun Road and Min-Chiuan Road. Xitun Road extends the original spatial seed of Cheng Kong Road of the old city centre towards the north-west whereas Min-Chiuan Road connects Taichung Road towards the south-east of the city. It is obvious that more attention should be paid to them in the next stage of expansion. Again, the measures of Relative Choice turned out to be insufficient in simulating the commercial distribution patterns as was the case in the first and second stage of the city's development.

Figure 9:
Global Integration Rn analysis of Taichung City in 1974

The outer residential areas are on north-south grids and the old CBD 45-degree angle grid was not extended. Therefore, there are local discontinuities and a reliance on main roads. The black areas between the CBD and the outer wheel are green spaces, large public institutions, and undeveloped areas at this time.

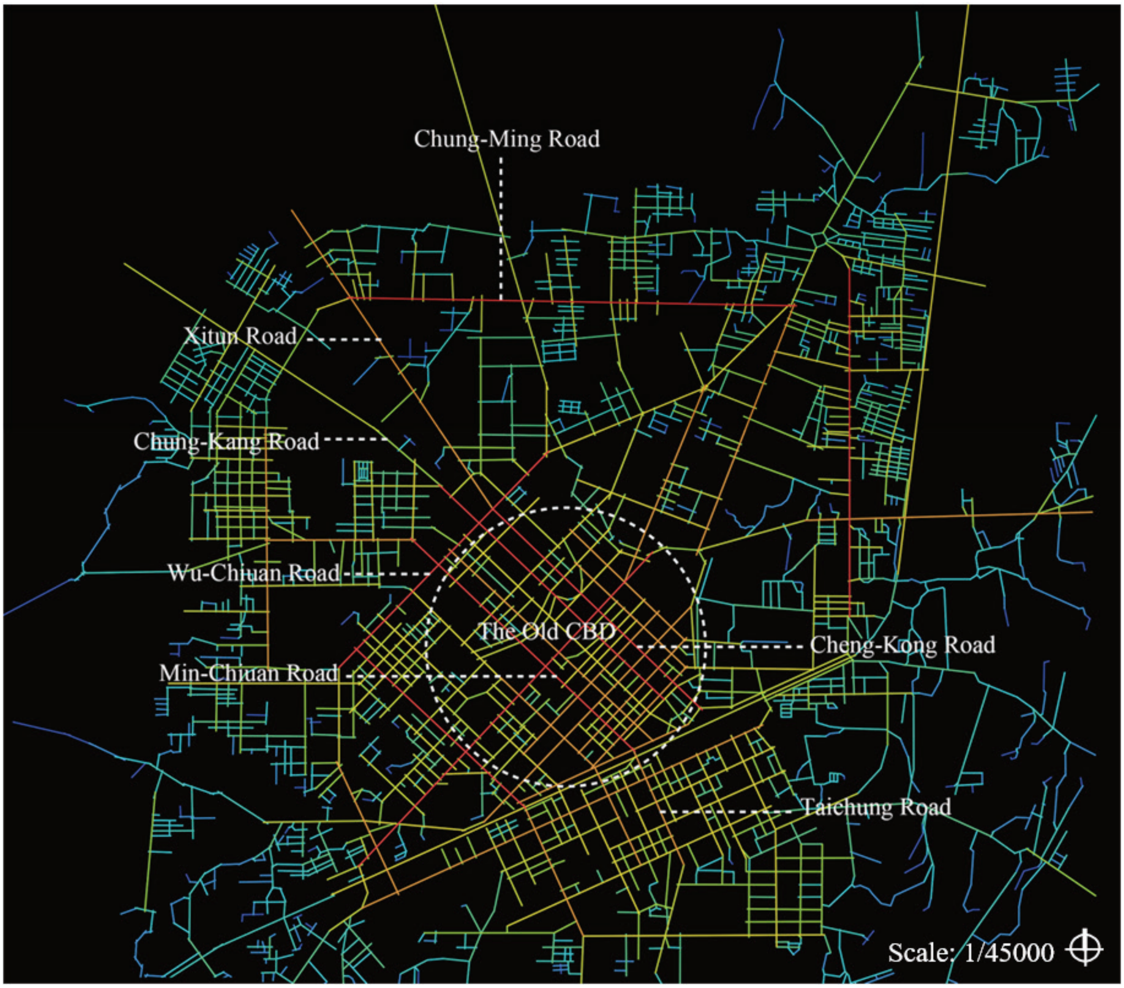

Figure 10:
Local Integration R3 analysis of Taichung City in 1974

Figure 11:
Global Integration Rn vs. Commercial Activities of Taichung City in the first expansion period in 1974 (Adapted from Lin, 2015, p. 70)

Figure 12:
Local Integration R3 vs. Commercial Activities of Taichung City in the first expansion period in 1974 (Adapted from Lin, 2015, p. 71)

In the fourth stage of the city's development, the second phase of urban expansion characterized by the major influence of "Edge City" and "SBD" has been implemented gradually from 1975 to the present date. The city has transformed from a single CBD in the downtown city centre into a polycentric metropolitan in 1990, and eight district centres at different scales can be identified within the city (Figure 13). However, the early CBD in the old city centre (the Central District) has become deserted and declined from the moment the polycentricism of the city appeared in 1990 (Shiu, 2015, p. 30). The other seven district centres have developed with great success, particularly with the case of the Xitun District where the development of "Edge City" and "SBD" has gradually replaced the old CBD. Xitun District became the new dominant commercial and administrative centre of the whole metropolitan. This is partly related to the low availability of car parking spaces in the old CBD as well as the fact that Xitun District is closer to the main interchange connecting to the national expressway and also has good links to the local airport and the seaport. On-site observation from selected samples of arterial commercial street segments, once extremely vibrant in the old CBD of the previous periods, reveals that nearly 65 % (303 out of 464 in total) of retail businesses have closed down for more than two decades, so that the suspended business rates range from Chung-Cheng Road (Figure 14) at 74% (90 out of 121), Cheng Kong Road (Figure 15) at 69% (77 out of 112), Liu-Chuan (Figure 16) at 68% (32 out of 47), Tzu-You Road at 63% (55 out of 88), San-Min Road at 52% (26 out of 50), to Min-Chiuan Road at 50% (23 out of 46). Due to length limitations, the various sub-stages of the urban expansion process from 1975 to 1990 and from 1990 onwards to the present time will not be discussed in detail, and the final analysis of the city's street network will only focus on the version in 2014.

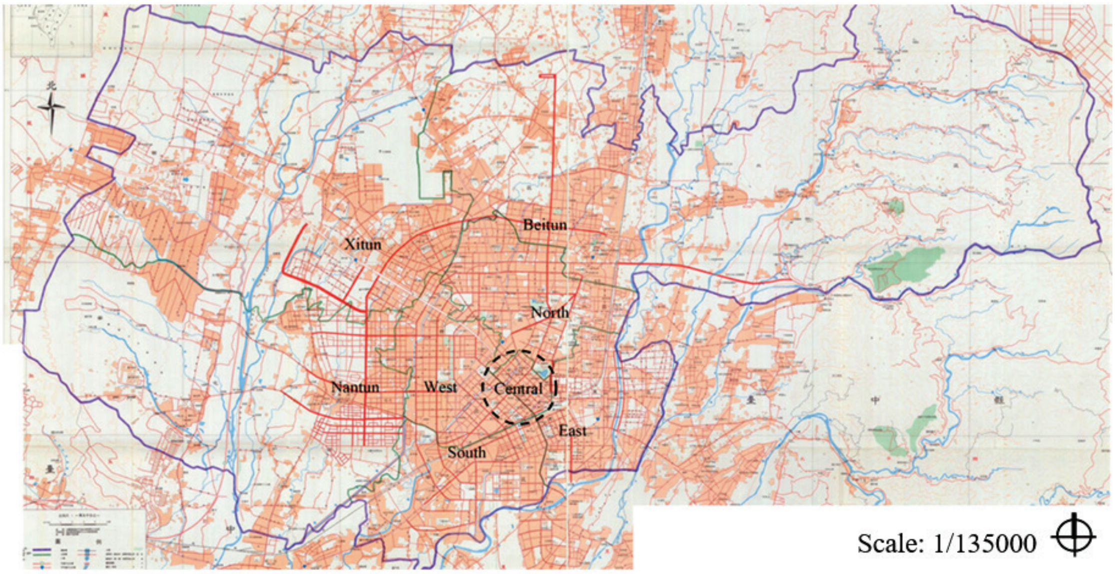

Figure 13:
The polycentric metropolitan of Taichung and the eight district centres in 2014 (Green lines represent precinct demarcation of each district. Adapted from Lin, 2015, p. 79)

Figure 14:
Retail shops closed down on Chung-Cheng Road in the Central district of Metropolitan Taichung in 2014

Figure 15:
Retail shops closed down on Cheng Kong Road in the Central district of Metropolitan Taichung in 2014

Figure 16:
Department Stores deserted on Liu-Chuan Road in the Central district of Metropolitan Taichung in 2014

In the integration analysis, measures of either global accessibility Rn (Figure 17) or local accessibility R3 (Figure 18) seem to be invalid in simulating the polycentric metropolitan at this fourth stage of urban development since none of the seven commercial district centres have been teased out by parameters mentioned above. This is likely related to the fact that these new developments are mainly accessible by car as opposed to the old CBD which is more accessible on foot and by public transport but has fewer parking spaces. Moreover, the old CBD area has mainly arcaded shop houses allowing for pedestrians to navigate whereas the new SBD areas are modern mixed-use complexes at the periphery. Also, the analytical results do not correlate to the given fact of the declined old Central district and, on the contrary, exhibit that the old Central CBD remained in the stage of the commercial core as before which is not really the case in reality.

However, different from the cases of the previous three stages in the development of the city, the segment length analyses of Relative Choice Radius 700 meters (Figure 19), 6000 meters (Figure 20), and 12000 meters (Figure 21) turn out to be powerful parameters in simulating the movement potential of pedestrian, motorcycle, and vehicle respectively. In each of these three maps the blue areas depict residential areas and the green, yellow, orange and reddish segments refer to different levels of commercial activity. The segment Choice R 700 measure clearly captures the distinctive seven district centres (refer to patches of green, yellow, orange, and reddish street segments) and the declined old CBD (refer to street segments all in bluish in the area). It is obvious that the old CBD has become a mainly pedestrian residential area whereas the seven district centres have more commercial activity (Figure 19). Moreover, the segment Choice R 6000 (Figure 20) and Choice R 12000 (Figure 21) measures seem to be quite sufficient in simulating the present major articulation of commercial street patterns (refer to those of green, yellow, orange, and reddish street segments) that connect closely and sometimes overlap with all seven vibrant district centres that are characterized by local commercial retail shops and night markets.

The segment Relative Choice R 700, R 6000, and R 12000 meters all together can be effective parameters for showing the integration between the foreground linked centres of the metropolitan city's commercial network with the background residential network. It mostly takes two to three turns to move from the blue residential line to a warmer line in a more commercial district (Relative Choice R 700). Starting from the point, it takes another two to three turns to get the next intermediate level of commercial activity (Relative Choice R 6000). Finally, another two to three steps are needed to move to the highest density of commercial activity (Relative Choice R 12000). The old CBD (i.e. the deteriorated historical city centre) has clearly become isolated from the rest of the city and has been transformed into a background residential area due to its disconnection from the surrounding district centres and its insufficient connection with the foreground network of the whole city. As mentioned above, this overall structural shift of the city centre is related to the seaport, airport, national highway, and high-speed rail developments that have all pulled the city to the north and the west.

It is noted that the misfit parts of the two important reinforcing spatial seeds of Xitun Road and Min-Chiuan Road mentioned above have both become less active in strengthening the old CBD within the dual network whole amid this second expansion. It seems that the zig zag pattern of Xitun Road (see Figures 20, 21) at this stage has not only down-graded its weight of reinforcing spatial seed to the lower light blue level from the reddish vibrant one in the previous period, but it has surprisingly contributed to the imminent demise of the original spatial seed of Cheng-Kong Road. Furthermore, the disruption of linearity of Min-Chiuan Road, that split into two 45º angle intersected streets in the north-west direction from one straight street in the old Central district, has also weakened its weight of reinforcing spatial seed as that of Xitun Road mentioned above (Figure 20, Figure 21). The result of this case study reveals that linearity combined with continuous linear arrangement plays an important role in supporting the parts-whole integration within the dual network system (Hillier, 2009).

Despite the important factor of linearity on urban expansion, it is nonetheless not the absolute determinant factor that can warrant a promising outcome of sustaining the weight of those foreground original or reinforcing spatial seeds within the dual network system. One extraordinary outcome is that one of the reinforcing spatial seeds, Chung-Cheng Road, has turned out to become down-graded to the lowest level (bluish colour) of through movement and has converted from one of the reinforcing spatial seeds (reddish colour) of the foreground commercial network in the previous first expansion period to become a part of the background residential network in spite of its direct aligned connection with Chung-Kang Road (Figure 20, Figure 21). It seems that the linear extension of Chung-Kang Road has integrated the road with the current foreground network, and it has become the highest Choice level of through movement (Figure 21) in relation to the empowerment of the global economic momentum per se. However, Chung-Kang Road does not reinforce the early developed Chung-Cheng Road to sustain its previous status of commercial hub as discussed in the first expansion period since the important through movement of Relative Choice level has drastically decreased to the lowest degree. Thus, the degree of reinforcement, out of the factor of “linearity” on those closely connected street segments occurs during different stages of urban expansion, can only be concluded pending the investigation of each spatial seed within the larger dual network system under concern.

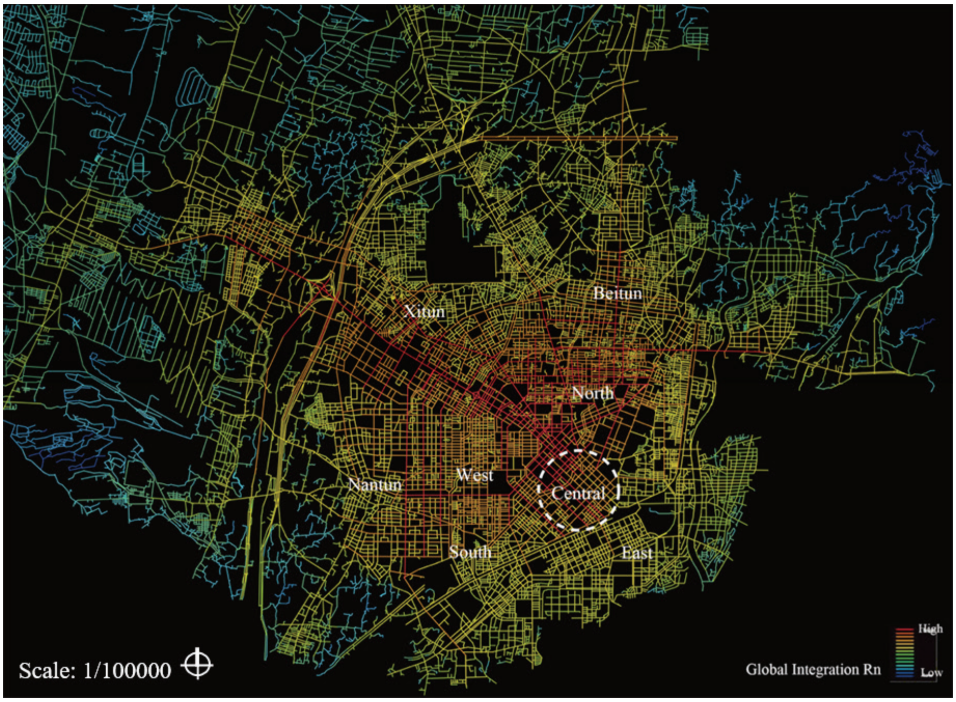

Figure 17:
Global Integration Rn of the polycentric metropolitan of Taichung in 2014 (Adapted from Lin, 2015, p. 22)

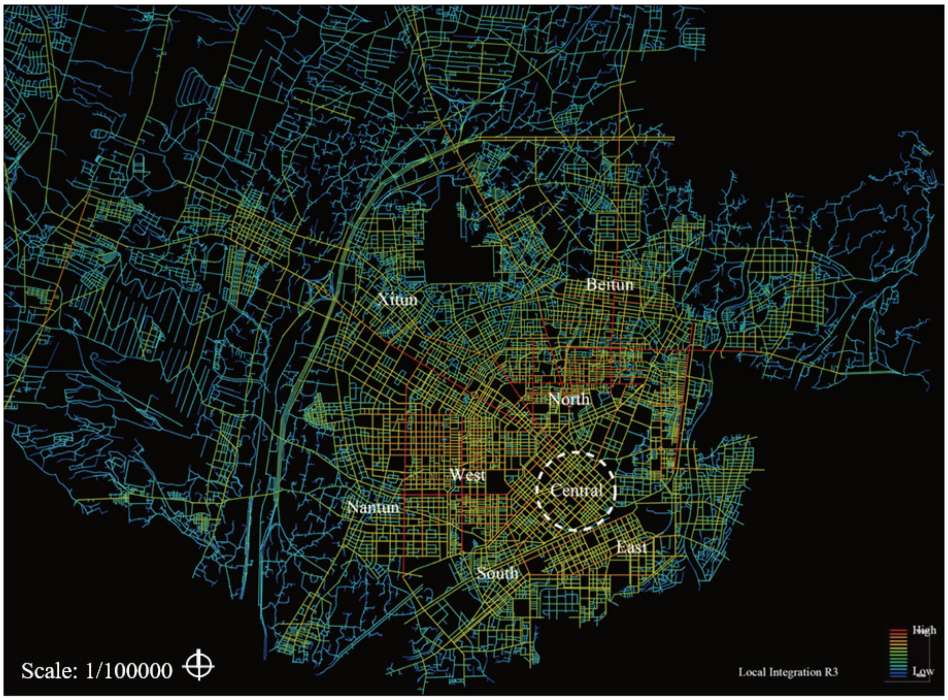

Figure 18:
Local Integration R3 of the polycentric metropolitan of Taichung in 2014 (Adapted from Lin, 2015, p. 23)

Figure 19:
Relative Choice R 700 of the polycentric metropolitan of Taichung in 2014 (Adapted from Lin, 2015, p. 24)

Figure 20:
Relative Choice R 6000 of the polycentric metropolitan of Taichung in 2014 (Adapted from Lin, 2015, p. 134)

Figure 21:
Relative Choice R 12000 of the polycentric metropolitan of Taichung in 2014

Several schemes of intervention on the misfit parts within the dual network of the metropolitan city have been carried out to verify whether the declined historical CBD mentioned above could be hypothetically regenerated. Of course, there are many factors involved in regenerating an historical CBD area. Two critical adjustments of the street connection pattern have been examined, which relates to the two reinforcing seeds of Min-Chiuan Road and Xitun Road. Based on the above position of linearity and its possible contribution of sustaining economic vitality, the strategy of continuous linear alignment has been tested for the above two reinforcing spatial seeds to verify whether the declined CBD in the Central district could be hypothetically revitalized through the proposed schemes of intervention. The first amendment is prolonging the original line of Min-Chiuan Road (Figure 22, Figure 23) towards north-west to be parallel to Chung-Kang Road (refer to the dashed oval area). From the segment length analysis of “Relative Choice” on the first amendment of Min-Chiuan Road, it is detected that the declined reinforcing spatial seeds of San-Min Road and Min-Chiuan Road seem to become more popular in terms of through movement potential as their weight has largely upgraded. Much so that they become parts of the foreground commercial network again compared to their previous conditions from the current second expansion period mentioned earlier (Figure 23). Whereas, Tzu-You Road has also been upgraded in its weight of through movement potential though less pronounced from being a part of the foreground network. The astonishing outcome of the intervention is that the initial night market area of Chung Hua Road has appeared unexpectedly to be upgraded in its weight of through movement potential though still far from being a pronounced part of the foreground network (Figure 23). Moreover, the initial reinforcing seeds of Liu-Chuan Road and Chung Cheng Road seem to be intact from the first intervention.

Figure 22:
Relative Choice R 6000 of the first intervention scheme by prolonging Min-Chiuan Road

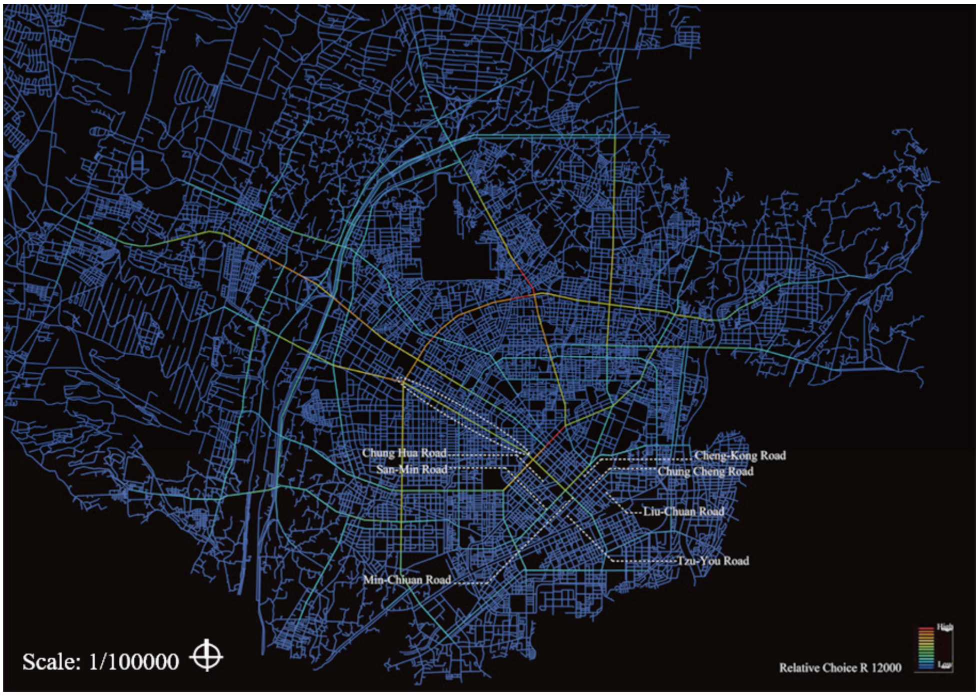

Figure 23:
Relative Choice R 12000 of the first intervention scheme on prolonging Min-Chiuan Road

Furthermore, on top of the first adjustment, the second intervention scheme (Figure 24, Figure 25) deploys the same strategy of continuous linear alignment both to Xitun Road to modify the zig zagging pattern of the street into a long linear one and to Cheng-Kong Road to extend its route toward the south-east direction to cross through the ground level of the current elevated railway line (refer to the dashed oval areas). The result exhibits a quite pronounced improvement on through movement potential of the original spatial seed of Cheng-Kong Road. Through the intervention scheme, it regains its important role of commercial foreground within the dual network system (Figure 25) as was the case of the first expansion period. It seems that both reinforcing seeds, San-Min Road and Min-Chiuan Road, have not been further strengthened in their weight of through movement choice from the second intervention though both remain parts of the foreground network. Moreover, the other reinforcing seeds of Tzu-You Road, Chung Hua Road, Chung Cheng Road, and Liu-Chuan Road respectively haven't been further strengthened and remain less pronounced in the foreground network (Figure 25) as was the case discovered in the first intervention. However, again, it is noticed unexpectedly that most of the other parts of the foreground commercial network, located in the first urban expansion area, turn out to be further strengthened significantly in through movement potential from the second intervention scheme compared to the current situation. This means that the deformed wheel pattern of the integration core of the historical CBD, that was so obvious in the first expansion period but disappeared in the current situation, has become slightly more noticeable again after this intervention, but it is still less strong than in the first expansion period.

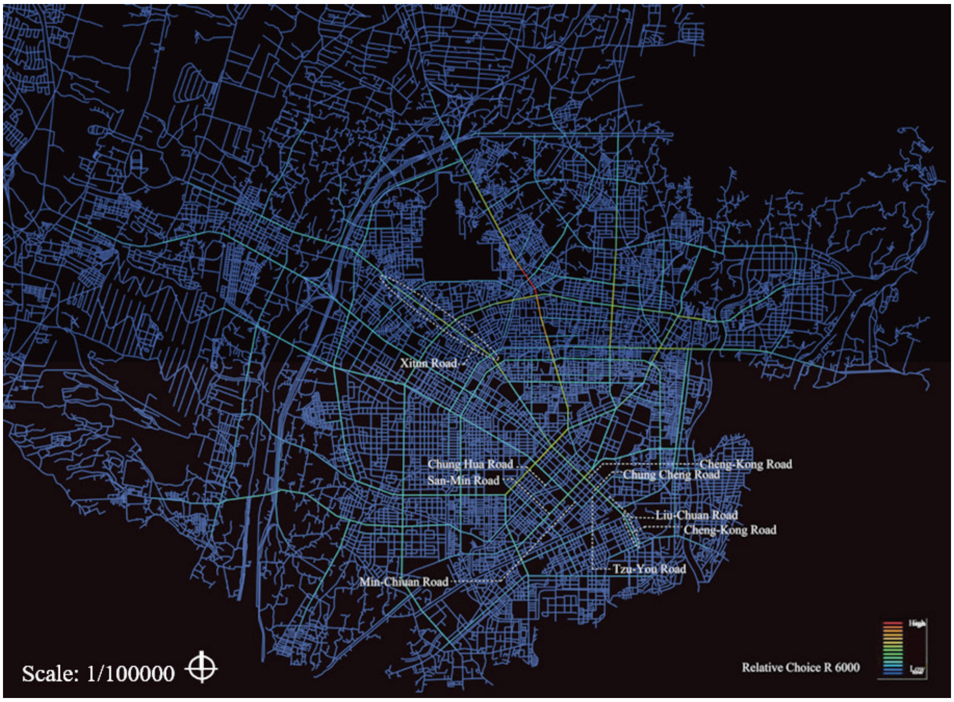

Figure 24:
Relative Choice R 6000 of the second intervention scheme on modifying the zig zagging Xitun Road

Figure 25:
Relative Choice R 12000 of the second intervention scheme on modifying the zig zagging Xitun Road

Research results from the two intervention schemes reveal that the first scheme of prolonging the crucial reinforcing spatial seed of Min-Chiuan Road seems to contribute to the reinforcement of the foreground commercial network only in the local area of the Central district. Whereas, the second scheme of further modifying the other important reinforcing spatial seed, the zig zagging pattern of Xitun Road into a linear alignment pattern, tends to produce an unexpected outcome of further strengthening the foreground commercial network to the global level. Though a zig zagging road may be more exciting for pedestrians, the changes to a linear pattern provide more overall benefits. These intervention schemes exhibit that different reinforcing spatial seeds play quite the distinctive roles in influencing the distribution patterns of the foreground commercial network in terms of scale; some related to global effect and others related to local effect. However, both levels of local and global reinforcement of the foreground network may benefit the revitalization of declined CBD in the historical district of the city as the deformed wheel pattern of the integration core is reinstated for the area in similar condition found in the first expansion period.

Findings and Discussion

The case study shows that parameters of axial Integration can simulate the single commercial hub location in the city of Taichung. Segment Relative Choice is essentially valid for simulation on the movement modes of pedestrians (Relative Choice R 700), motorcycles (Relative Choice R 6000), and vehicles (Relative Choice R 12000) for polycentric areas and on the distribution patterns of commercial activities both for global and local levels in the fourth stage (i.e. the second expansion period) in Taichung. The axial Integration measure seems to work effectively for depicting the foreground commercial network of the single pervasive centre in a residential dominant urban system whereas the segment Relative Choice measure can better predict that of a polycentric metropolitan system notable with linked commercial centres in different scales. The study in Taichung also exhibits the relationship between Pervasive Centrality and the pattern of linearity characterized with continuous linear alignment. This link shows that the linearity factor, although it does not warrant definite influences, does play a crucial role in sustaining the growth of the pervasive centrality from the local commercial part of an original spatial seed to the global level of the foreground commercial network. In this centrality, the linked deformed wheel integration core is further strengthened by those well connected linear reinforcing seeds within the whole dual network system. This is the case in every stage of the Taichung city development regardless of single central CBD or polycentric metropolitan. Moreover, some of the reinforcing spatial seeds may play a powerful impact on the final outcome of whether a local centre would be disconnected with the rest of linked centres; thus becoming isolated and deserted, or being effectively connected with other surrounding local centres to form an integrated parts and whole system based on this example.

CONCLUSION

The present research on Taichung city has disentangled the issue of street network expansion in urban development through examination on the forms of "Pervasive Centrality" of the study area. It has teased out the fundamental factor of linearity characterized with continuous linear alignment in strengthening the different scale of pervasive centres. These centres range from the original spatial seed, linear expansion and/or convex expansion of the reinforcing spatial seeds, deformed wheel integration core of the single centre of a city, to linked district centres of the foreground commercial network in the polycentric metropolitan system.

To deal with the economic sustainability issue of urban areas in future development, one crucial task should be to carefully tease out those most effective reinforcing spatial seeds within the contemporary foreground network system. Alternative intervention schemes based on strategies of linearity alignment on those effective reinforcing seeds for examining parts-whole integrated relationship of the future dual network system should be further verified to assure the final scheme would work for sustainable development of economic vitality.

In response to issues of urban sustainability, there's no doubt that beyond the street network study, other factors of environ-biodiversity, dwelling density and green spaces, pollution reduction and public transportation, etc. should be included for initiating proper schemes of future urban development. Nevertheless, this research points out the important concern of how the local parts of the historical CBD, as well as the dispersed new SBD, could be further strengthened into the global level of the foreground commercial network to reach the model of an integrated parts-whole spatial structure of dual network following different stages of city expansion. This may not only play a crucial role in sustaining economic vitality of urban areas, but could be essential for working as the generic function of the sustainable development of a city to deal with interrelated issues out of environment-economic-cultural domains based on humanistic reason (Hillier, 2009, p. 16-35).

Although this case study used the Space Syntax approach, it is clear that there are limits to the simulation of different syntactic parameters against commercial distribution patterns. Differences in local cultural habits apart from the street network may play an influence as well. For example, the Relative Choice R 700 has less power to predict pedestrian movement flow as well as local commercial distribution compared to the Relative Choice R 6000 (motorbike) and Relative Choice R 12000 (car). This could be related to cultural tradition, especially the fact that people in Taiwan seldom walk anywhere since there are few pedestrian-friendly environments (i.e. no sidewalks, humid and hot climate, etc.), especially in those historical areas. As a result, many people use motorbikes to move locally rather than on foot. Further study needs to be carried out to compare the case of Taichung city to other historical centres in Taiwan and in other countries to see whether the above findings can be generalized.

ACKNOWLEDGMENT

Ching-Kai Lin has provided technical assistance.

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