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A Study of the Planning and Designing of the Built Environment under the Green Transit-Oriented Development

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***Abstract*—**In recent years, the problems of global climate change and natural disasters have induced the concerns and attentions of environmental sustainability issues for the public. Aside from the environmental planning efforts done for human environment, Transit-Oriented Development (TOD) has been widely used as one of the future solutions for the sustainable city development. In order to be more consistent with the urban sustainable development, the development of the built environment planning based on the concept of Green TOD which combines both TOD and Green Urbanism is adapted here. The connotation of the urban development under the green TOD including the design toward environment protect, the maximum enhancement resources and the efficiency of energy use, use technology to construct green buildings and protected areas, natural ecosystems and communities linked, etc. Green TOD is not only to provide the solution to urban traffic problems, but to direct more sustainable and greener consideration for future urban development planning and design. In this study, we use both the TOD and Green Urbanism concepts to proceed to the study of the built environment planning and design. Fuzzy Delphi Technique (FDT) is utilized to screen suitable criteria of the green TOD. Furthermore, Fuzzy Analytic Network Process (FANP) and Quality Function Deployment (QFD) were then developed to evaluate the criteria and prioritize the alternatives. The study results can be regarded as the future guidelines of the built environment planning and designing under green TOD development in Taiwan.

***Keywords*—**Green transit-oriented development, built environment, fuzzy Delphi technique, quality function deployment, fuzzy analytic network process

I. Introduction

THe earliest urban transportation planning using the TOD concept is proposed in the United Sates in order to replace the original car-oriented urban development planning mode. The purpose of TOD is to reduce the low usage of land resources, air pollution, and over-use energy due to the car-oriented development and to attain a sustainable urban development. As of now, many American cities are developed as TOD cities, such as San Francisco and Atlanta [1]. Although Taiwan's urban and transportation planning has followed the US, the adoption of the US car-oriented urban development planning brings up many transportation problems in Taiwan now. Now Taiwan tries to solve the transportation problems by introducing the US's TOD concept to its major cities, such as Taipei city, New Taipei city, and Kaohsiung city, to plan and build public transportation systems. Cervero & Kockelman [2] provided a definition of TOD in 1997 and their definition mainly focused on 3Ds, including high density land use, diversified mix land use, and bicycle and pedestrian friendly street design. However, this type of development seems to lack a consideration to the ecology and environment issue. A simply use of TOD concept to plan for transportation is inadequate to build a sustainable urban environment. The transportation planning should incorporate the planning of peripheral areas in order to build a sustainable urban environment. Therefore, if the ecology and environment issue can be incorporated into the TOD concept, which is the so-called the Green TOD concept, the urban development can reach the sustainability goal.

The Green TOD concept mainly combines TOD and Green Urbanism which can promote environmental design, maximize the utilization efficiency of resources and energy, use green building construction techniques, and develop a city that connects protected area, ecology, and community [3]. Such constructs not only include a transportation system that has characteristics of sustainability, balanced ecology and energy conservation, but also are closely connected to the built environment of transportation corridor peripheral areas. They are helpful to the upgrade of urban ecosystem function and the improvement of urban built environment. In the past, urban construction ignores environmental protection and urban landscape because of the need of developing economy and transportation. This study uses the Green TOD concept to plan for urban transportation and peripheral areas' built environment and explore design criteria. This study hopes to improve the built environment and to make the whole urban development towards sustainability.

II. Literature Review

The construction of the built environment can be conducted through urban design, and [4] stresses that future urban construction must consider land use, residential housing, the commercial and industrial development, transportation routes, protection, environment pollution, urban disaster prevention, etc. Frank et al. [5] point out that urban environment and various facilities form the urban built environment, and also point out that applying a high density use and a pedestrian friendly design around transportation corridor peripheral areas will have positive effects on residents' health. Sehatzadeh et al. [6] point out that the built environment has impacts on automobile ownership and automobile frequency of use. In

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their studies, Handy et al. [7] show that proper development facilities are important to urban built environment and trip behavior, and combine urban design, land use pattern and transportation system can facilitate people to walk more and ride a bicycle in order to create a more active, healthy and livable community environment. Many empirical studies have proved that the built environment has effects on walking behavior and residents' health [6], [8], [9].

This study mainly explores urban built environment under the Green TOD, and the built environment under this situation must have a close relationship with TOD stations. Rodriguez et al. [9] use items of the built environment and street design to assess and study the relationship between the peripheral area of train station and pedestrian activity. These items include: (1) Pedestrian friendly land use, (2) Mixed land use, (3) Buffer zone setting between sidewalk and ordinary roadway, (4) The wide and quality of pedestrian crossing, and (5) Installation of clear location and direction signs. The result proves that the more land-use mixes the more pedestrian activity, the pedestrian-friendly built environment reflexes on the number of pedestrians using crossing, the wide and quality of pedestrian crossing (e.g., the installation of long benches and trash cans) and clear sign designs, etc., are helpful to the increase of pedestrian activity and to build a closer relationship between train station and pedestrian activity. Cho et al. [10] also analyze the build environment and the ratio of walking, and classify the built environment into roadway safety, the density of local roads, the density of crossroads, land use mix, and pedestrian-friendly and comfortable street design. In their study of the relationship between the built environment and the safety of pedestrian and bicycle rider, Cho et al. prove that the design of the built environment affects the safety of pedestrian and bicycle rider, and a higher car accident ratio occurred in a high land use mix area where there is no pedestrian-friendly built environment design. In their study, the physical built environment includes density, land use mix, street connectivity, path material, and bus transit. Ewing & Cervero [11] point out that the classification of the built environment affects urban travel behavior.

One can find from the content above that the built environment includes constructs that have very wide scopes, and indeed affects pedestrians' daily life behaviors which, in turn, improve the environmental quality of the city as a whole. It is useful that Green TOD concept can be conducted to design the built environment around train station. The concept includes land use type, density, building material, plant height, transportation system and public facilities. Besides, we also need to realize that urban built environment with a higher-density and stronger and more mixed land use, more open space and pedestrian space and friendly bicycle system as well. And, through the formation of a public transportation system to reduce energy consumption, we must be able to provide more friendly community and more sustainable urban environment [12].

The Green TOD concept mainly combines TOD and Green Urbanism to promote environmental design, maximize the utilization efficiency of resources and energy, use green building construction techniques, and develop a city that connects protected area, ecology, and community [3]. The purpose is similar to the TOD concept, hope to reach urban sustainable development, and through more concrete way to conduct.

Green TOD is derived from the TOD concept. It is a friendlier TOD planning method to the environment. It is learnt from some European urban development patterns [12]. It adopts sustainable transportation system and adjusts to the design of surrounding areas. Its final goal is to build a self-sufficient and sustainable urban development. The Green TOD concept mainly combines the important elements of TOD and Green Urbanism. The combination of both realizes the Green TOD possibly in several ways [12]: (1) higher densities, including high population density, high density housing, to make TOD stations to recover its original effectiveness in order to increase the usage and passenger loading rate as well as to reduce the consumption of renewable energy; (2) mixed land uses: Developing from the station and including areas that are built for residential use, commercial purpose, working, shopping, library service, and other daily activities; and, use more designed crossways and bicycle routes to increase the use of walking and bicycling; and, build green communities around transportation corridor peripheral areas; (3) reduced surface parking and impervious surfaces: Diasa [13] points out that ground parking spaces will consume half the land resource of many suburban houses, create more green urban open space through parking space reduction, and increase urban permeable surfaces in order to reduce heat island effect caused by over-urbanization.

The promotion of TOD is mainly induced by the concept of urban sustainable development, which is a supply-oriented urban development and provides convenient and interconnected urban transportation system, through this to bring about people, activities, and economics, and to reduce transportation problems caused by AOD-oriented urban development in the past. The main basic concept of TOD is the 3D built environment introduced by Calthorpe [14], and it is an urban design with the orientation of land use mix, urban tight development and pedestrian/bicycle. Later, the 5D built environment development pattern is developed because many researchers introduce the 2D concept to include both the destination accessibility and the distance to transit in the TOD design [15]-[17].

The vision of Beatley's Green Urbanism [18] can be divided into six categories. However, Lehmann [19] proposed three Green Urbanism principles as follows: (1) The reuse of energy and materials, (2) The protection of water resources and biology variety, and (3) The focal of urban planning and transportation planning, as shown in Fig. 1. These three visions affect the proposed 15 green urbanism principles, including the interrelationship among all urban development related energy, resources, and design. However, the 15 green urbanism principles proposed by Lehmann has a triple-zero framework: (1) Zero use of fossil fuel energy, (2) Zero waste, including all buildings can be torn down, and be fully recycled for future use, (3) Zero emission (target for low carbon emission and zero

carbon emission). The triple-zero framework can develop full and feasible green urbanism principles. However, Lehmann's 15 green urbanism principles [19] are not totally usable in this research. In this research, we aim to develop the design and planning criteria of urban built environment under the Green TOD. The emphasized construct is the physical built environment construct instead of those non-physical or the construct that requires large implementation areas such as food supply chain, educational research and knowledge, city management etc. The later empirical research paragraphs will construct criteria and delete non-physical construct. The study will explore the criteria of both TOD and built environment as the basis of building empirical models finally.

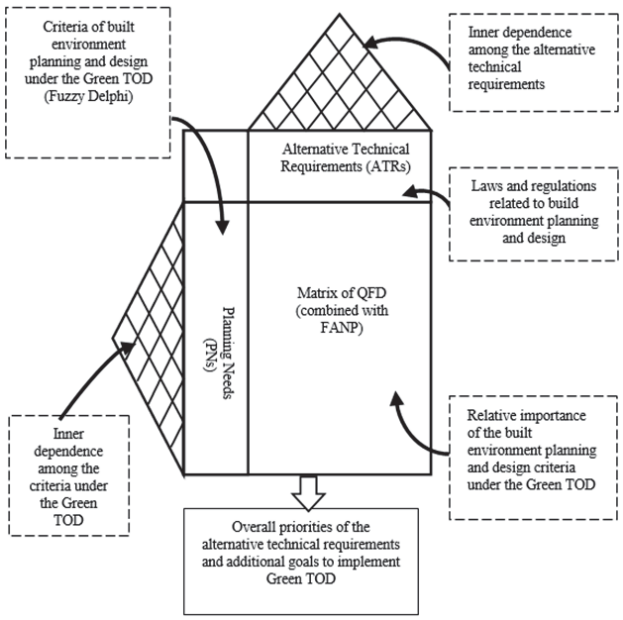

Fig. 1 Research Model of Built Environment Planning and Designing under the Green TOD

III. Research Design

This study conducts urban built environment planning and selection/weighting of designing criteria under the Green TOD through FDT, QFD, and FANP methodologies. The research design model and steps are shown as:

Step 1: Construct a HOQ of "the built environment and design under the Green TOD," incorporate the requirements of both the urban design for the built environment and the land use restriction, which are imposed by current laws and regulations, into the HOQ in order to explore whether the Green TOD concept can be incorporated into current laws and regulations as well as be put into practice in the Taiwan area.

Step 2: Conduct a literature review to explore the criteria factor of built environment planning and design under the Green TOD.

Step 3: Examine existing laws and regulations related to built environment planning and design, and explore the related laws and regulations that are concerned with the built environment planning and design for the location identified to be the experiment area of this research, and these will be seen as the technical requirements of the top side of the HOQ model proposed in this research.

Step 4: Through the HOQ model developed in this research, combine FANP to conduct the phase two expert questionnaire in order to obtain the inter-weighting relationship between planning need and technical requirement, through matrix calculation to obtain the priority weights of the planning need criteria and the existing related laws and regulations for the built environment planning and design, and these will be the references for future planning of the built environment of public transportation corridor peripheral area towards Green TOD concept in Taiwan.

IV. Empirical Analysis

This research selects the built environment of Taipei rapid transit station (Y18) and its peripheral area located in the Xinzhuang District of New Taipei City as the experiment target. The Y18 station corridor peripheral area has a large number of population supporting a proper operation of a metro system. The Xinzhuang District is seen as a future major district in New Taipei City where many preplanning projects already have stated and the replanned area requires new construction based on the two aforementioned points. This research believes that the Xinzhuang District can be developed towards the Green TOD concept and the built environment of the Y18 station and its peripheral area is selected as the experiment target. This research explores the TOD scope under the Green TOD scope, from the literature review, we can know that the suitable scope for TOD is within 500 meters, this is a walking distance accepted by pedestrians; moreover, the planned service scope for each metro station in Taipei is also within 500 meters.

Fig. 2 is the map of research scope location, red-colored mark is the location of the Y18 station, and the research scope is the black-colored circle with a 500-meter radius.

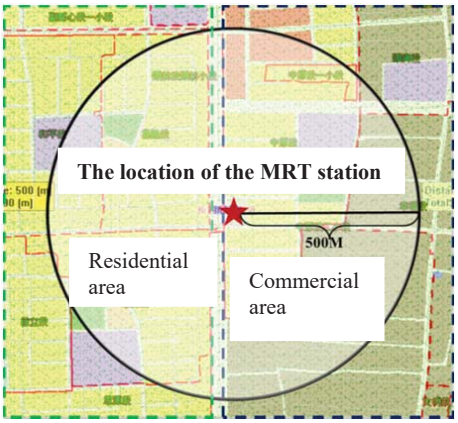

Fig. 2 The Map of Research Scope Location

TABLE I
THE RANKING OF INTER-DEPENDENT WEIGHTINGS FOR THE GREEN TOD BUILT ENVIRONMENT PLANNING AND DESIGN CRITERIA

Ranking	Planning need criteria	weighting
1	Destination accessibility	0.2329965
2	Development of Transportation corridor peripheral area	0.2003882
3	Mix Land Use development of Transportation corridor peripheral area	0.1882463
4	Land Use Density	0.1400682
5	Urban Design	0.0861426
6	Low-carbon transportation planning	0.0610123
7	Urban open space	0.0340939
8	Use of Renewable Energy	0.0290643
9	Green Building Design	0.0279878

In order to construct the built environment planning and design criteria under the Green TOD, this research first identifies criteria for both TOD and Green urbanism through the literature review, following by conducting expert survey which is designed using the FDT method and selects "the compact urban land use" criteria which is defined as: use high density and high intensity land use pattern, combined with mixed land use plan and flexible special zoning district plan to develop cities. One can include the definition from land use density, land use mix, and low carbon transportation planning; therefore, this research deletes "the compact urban land use" criteria before selecting suitable criteria using the FDT method. FDT selects from initial criteria and predefines consensus threshold as 6.36 in order to select representative criteria. There are 10 criteria factor above the consensus threshold (6.36); and criteria below the threshold 6.36 are reuse water resources, transit station identity, and zero waste community; these three criteria are deleted.

In this research, we combined the built environment planning and design factors and the related laws and regulations (the New Taipei City Urban Design Review Principle and the Xinzhuang District Land-use Control Zoning Regulation) for the studied area. This research tried to construct a built environment planning and design QFD under the Green TOD concept. Through the integration of QFD and the expert survey designed using the FANP technique to construct a HOQ model, we will be able to prioritize the criteria of the built environment planning and design under the Green TOD.

Through the calculation steps of HOQ matrix, the questionnaire and survey results are described in this section through the weight calculation obtained from the expert survey. We are able to obtain the matrix for each step and its interrelated prioritized weights to identify the best project and understand the priority of the technique mix required to conduct the built environment planning and design under the Green TOD concept. The survey integration is conducted according to the suggestion given by Satty [20], use the consistency ratio to determine whether experts reached a consensus among their answers, if the CR value below 0.1, the paired comparisons in the matrix show consistency. The expert survey result is described as follows.

Through the calculation, we can obtain the ranking of the weight for the criteria of the built environment planning and design under the Green TOD concept which is shown in Table I. And we know that the built environment planning of the 500-meter distance of the Y18 station and its peripheral area towards the Green TOD concept is emphasized on the importance of the following planning need criteria: destination accessibility (0.2329965), development of transportation corridor peripheral area (0.2003882), and land use mix (0.1882463). However, the green building design and the use of renewable energy are less emphasized importance. This shows more importance of the criteria factors under the TOD construct and less importance of the criteria factors under the Green urbanism construct.

By means of the step-by-step calculation of HOQ matrices, the need criteria of the built environment planning and design under the Green TOD can reflect on the weight (w^{FANP}) of the design technical requirement criteria for the built environment planning and design project. And then we can multiple the interdependence absolute weight (W_A) of the technical requirement criteria of current urban design and land-use control with the interdependence weight (w_c) of the need criteria factors of the built environment planning and design under the Green TOD concept.

$$w^{FANP} = \begin{bmatrix} 0.2111915 \\ 0.3033439 \\ 0.1314723 \\ 0.1109777 \\ 0.1356313 \\ 0.1073834 \end{bmatrix} = \begin{bmatrix} \text{Public open space system Criterion} \\ \text{Pedestrian Space and sidewalk System of Urban Design Criterion} \\ \text{Transportation system design criterion} \\ \text{Building mass arrangement, height, form, color, and style design criterion} \\ \text{Environmental protection facility design Criterion} \\ \text{Landscape Architecture design Criterion} \end{bmatrix}$$

Through the calculation of HOQ matrices to combine the Green TOD planning need with the technical requirement criteria of current urban design and land-use control, the result shows the impact of both planning need preference and expert perception (on the importance degree of design technical requirements) on the technical requirement weight of the built environment planning and design under the Green TOD.

V. RESEARCH ANALYSIS

For the analysis of combining ANP with HOQ matrices. Through the HOQ matrix calculation using the FANP technique of this research, we first calculate and prioritize the absolute weight of the need criteria factor of the built environment planning and design under the Green TOD concept, the computation and ranking results are: (1) Land use density (0.2009533), (2) Land use mix (0.2221168), (3) Urban design (0.1289448), (4) Destination accessibility (0.1389202), (5) Development of transportation corridor peripheral area (0.1467417), (6) Green building design (0.024178), (7) Low-carbon transportation planning (0.0820076), (8) The use of renewable energy (0.0230199), and (9) Urban open space (0.0331177). One can find that the planning need criteria that are perceived to be more applicable to the case study site are land use mix, land use density, development of transportation corridor peripheral area, and destination accessibility; these four criteria factors are included in the TOD construct, while the criteria factors that are included in the green urbanism construct are less applicable to the case study site.

One can find that through the calculation of HOQ matrix, the combination of the planning need criteria factor with the technical requirement criteria factor shows that HOQ matrices are affected by planning need preferences and expert perceptions of the importance degree of the technical requirement criteria of the built environment design under the Green TOD concept, the weights of technical requirement criteria are: (1) Public open space system (0.1843312), (2) Pedestrian space and sidewalk system of urban design (0.3051524), (3) Transportation system design (0.172987), (4) Building mass arrangement, height, form, color and style design (0.0920303), (5) Environmental protection facility design (0.1546468), (6) Landscape architecture design (0.0908523). Among these criteria, the pedestrian space and sidewalk system of urban design criterion are perceived by experts as the most important criteria, the second important criteria are the public open space system criterion and the transportation system design, the following rankings are the environmental protection facility design criterion, building mass arrangement, height, form, color and style design criterion, and the landscape architecture design criterion

VI. Conclusion

The technique requirement for designing the built environment within 500 meters of the Y18 station and its peripheral area towards Green TOD is identified in this study. When planning the built environment for an urban area, the planning must suit one's measures to local conditions, the planning may need to meet the laws and regulations that govern the selected site location, therefore thus research attempts to combine both the New Taipei City Urban Design Review Principle and the Xinzhuang District Land-use Control Zoning Regulation with the Green TOD built environment planning need criteria. Through the integration of the QFD method (HOQ matrices) and the ANP technique, we calculate both planning need and technical requirement together, and prioritize the technical requirements that are applicable to Green TOD planning need, and obtain improvement plans.

In this study, we presented the important criteria for the built environment planning and design under the Green TOD. We also tried to understand the basic theory of Green TOD and incorporate the TOD principles and the Green urbanism to construct and explore important criteria through the literature review. Through literature review, we identify 6 criteria under the TOD construct: Land use density, land use mix, urban design, destination accessibility, development of transportation corridor peripheral area, and transit station identity; 7 criteria under the green urbanism construct: Green building design, zero waste community, the recycle of water resources, low-carbon transportation planning, the use of renewable energy, urban open space. There are total of 12 initial factors.

This research classifies technical requirement criteria based on the New Taipei City Urban Design Review Principle, and incorporate the Xinzhuang District Land-use Control Zoning Regulation; therefore, technical requirement criteria can be classified into six criteria: Public open space system, pedestrian space and sidewalk system of urban design, transportation system design, building mass arrangement, height, form, color and style design, environmental protection facility design, and landscape architecture design. The final HOQ matrices computation result shows that the weight ranking of combining the planning need criteria with the technical requirement criteria, therefore although the final computation result does not identify any feasible criteria that is included in the need construct, the computation considers them into the prioritization of technical requirement criteria.

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