Spatial distribution of pedestrian space in central Tokyo

Regarding building, public transportation and urban renewal projects

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Abstract: Interest in and the importance of walkability have begun to grow, and efforts are now being made to support pedestrians and the quality of public spaces. Lack of information on pedestrian space, however, makes it difficult to incorporate walkable space into spatial planning. In this study, the distributional characteristics of pedestrian spaces in central Tokyo were investigated, and how pedestrian space has been created and related to building, public transportation, and urban renewal projects were examined. First, analyses of the pedestrian space distribution suggest that road area accounts for 21.8% on average in central Tokyo; this is composed of 18.8% roadway and 3.0% walkway, that pedestrian spaces are accumulated in central and sub-central areas, which have high building density, and in urban renewal projects areas. Second, walkways in the commercial area have been built with more consideration for building density and the number of passengers that are related to pedestrian traffic flow. On the other hand, walkways in the residential and industrial area have been built by constructions of roadway with less consideration for building density and public transportation compared to commercial areas. There was less priority to walkway than spaces for automobiles in residential areas with medium building density. Third, urban renewal projects did not necessarily give more consideration for pedestrians, all other things being equal. The effect of redevelopment projects on walkway ratio was limited in their scope.

1. INTRODUCTION

There are widespread acceptances and interests in walkability as an essential complement to the sustainable urban structure. Walking is considered as an alternative to automobile-oriented transportation and a core response to climate change, fossil fuel dependence, air pollution, maintaining mobility for an aging population, and health

Awareness of environmental and social problems related to automobile dependence has made many cities try to limit the encroachment of cars in the cities as well as to ensure a better balance between motorists and other

modes such as walking, cycling, and public transportation ([Gehl & Gemzøe, 2003](#)).

In the urban planning field, walkability is considered as a key factor for not only reducing automobile dependence and but also improving the quality of the community. Public space including pedestrian space has always acted as a meeting place, marketplace, and traffic place ([Gehl & Gemzøe, 2003](#)). Community-based approaches for physical activities have also received growing attention from the public health sector ([Brown et al., 2009](#); [Moudon & Lee, 2003](#)). In spite of a weakened geographical limitation in the sense of community due to advanced technology and mobility, opportunities to meet neighbours are still important for social interaction ([Francis et al., 2012](#)). Furthermore, the needs of people who have limited mobility such as the elderly, parents of young children, and the socio-economically disadvantaged can be served by resources found within the neighbourhood ([Maas et al., 2009](#)).

In spite of growing acceptance and importance in walkability, traveling on foot has decreased and modern day societies have become considerably more dependent on motorized vehicles, leading to serious health, economic and environmental implications ([Safety, ITF Pedestrian, 2012](#)). In order to cope with this automobile dependency, available spaces have been occupied by car traffic and parking ([Gehl, 2013](#); [Jacobs, 1961](#)). As a result, a common feature of virtually all cities, regardless of global location, economic viability and stage of development, is a lack of attention paid to the wellbeing of people who use urban spaces ([Gehl, 2013](#)).

[Gehl and Gemzøe \(2003\)](#) argued that “It becomes unpleasant and difficult to get around on foot, and spending time in public space is made impossible by lack of room, the need to avoid traffic and a poorer quality environment.” In this context, many government authorities have emphasized approaches to urban planning that enable residents to follow a walking-based lifestyle ([Chicago Department of Transportation, 2012](#); [Gehl, 2008](#); [Ministry of Land, Infrastructure, Transport and Tourism, 2010](#); [Seoul Metropolitan Government, 2013](#)).

Previous studies have been conducted focusing on (1) the relationship among urban structure, public transportation, and travel behavior and (2) the level of service in regard to the quantity of space under conditions of free choice. The former studies have clarified how spatial planning can be utilized to influence the amount of travel and the modal share. Physical features of walkways such as separate lanes, width, length, and street furniture have shown a positive relationship with the number of pedestrians ([Hankey et al., 2012](#); [Sung, Go, & Choi, 2013](#)).

The latter studies suggested an ideal quantity of pedestrian space. ([FURUIN, 1971](#)) described the characteristics of five levels of pedestrian density using space per person and flow rate. There are some studies on enhanced methods for evaluating the level of service (LOS) considering pedestrian behavior and walking condition ([Gallin, 2001](#); [Talavera-Garcia & Soria-Lara, 2015](#)). While these studies have focused on the evaluation of individual pedestrian level and street level, [Puškarev \(1975\)](#) analysed the relationship between building floor space and pedestrian circulation space and evaluated pedestrian space of the Midtown Manhattan area based on their LOS. However, it is difficult to say that sufficient pedestrian spaces have been made to satisfy pedestrian space demands following suggested LOS of these studies due to space limitation and lack of attention paid to the pedestrian.

In order to incorporate the results and suggestions of these studies into spatial planning, it is essential to quantify the current situation of pedestrian spaces and understand how they have been built until now. However, there is a lack of quantitative data and analysis for pedestrian space. There are few published statistics about pedestrian space. For example, the length of roadway that walkway was installed on in the Annual Report of Road Statistics has only published data in Japan. Furthermore, there is no clear guideline on how spaces have to be built for the safety and comfort of pedestrians.

In this regard, the objective of the present study is to clarify how much pedestrian space exists and to explain how they have been made related to urban structure and public transportation such as building density, railway stations, and urban renewal projects in central Tokyo. It was hoped that the study would contribute a comprehensive understanding of pedestrian space and provide performance measures for pedestrian space which can be used to monitor the current usage, and act as a benchmark and a reference point for future improvement plans.

The remainder of this study is organized as follows. The second section, then, describes the target areas and the method of data construction. The third section illustrates the distributional characteristics of pedestrian space regarding not only building density but also public transportation and urban renewal projects which can influence the quantity of pedestrian space. The fourth section constructs the regression models using the walkway ratio as a dependent variable and attempts to investigate a quantitative relationship among pedestrian space, building, transportation infrastructure, and urban renewal projects. Lastly, the fifth section summarizes the results and provides suggestions for accomplishing walkable pedestrian spaces.

2. STUDY AREA AND DATA CONSTRUCTION

2.1 Case study area

Central Tokyo is composed of 14 wards and covers an area of 217.8 square kilometers. This area has a population of 3,433,144 ([Statistics Bureau, Japan, 2010](#)) and 5,920,219 employees ([Statistics Bureau, Japan, 2009](#)).

Central Tokyo was selected for the following reasons. First, Tokyo is the largest metropolitan area in the world with a well-developed public transportation system ([Kawabata & Shen, 2006](#); [Kenworthy & Laube, 1999](#)). It is thus expected that these cities have relatively well-designed pedestrian space related to public transportation. Results from this case study are expected to give suggestions to not only cities in Japan, but also Asian cities which are trying to make their cities walkable. Second, sufficient spatial data has been accumulated to make it possible to construct pedestrian space data and examine relationships with other spatial factors such as building density, traffic systems and urban policies. Third, the Tokyo 2020 Olympic and Paralympic Games will be held and many developments including pedestrian space improvements, such as stadiums and other infrastructure, are being conducted. Thus, this study may contribute to these projects by suggesting the current optimal level of pedestrian space.

2.2 Data construction

In this study, land use was classified into building area, unbuilt area, and road space. Road spaces include roadways for automobiles, walkways for pedestrians, and other road spaces that do not separate roadway and walkway areas. Off-ground level (OGL) road spaces such as pedestrian bridges, underground passages, and viaducts were also considered. This is shown schematically in *Figure 1*.

Figure 1. Land use classification

This classification reflects how cities have grown increasingly dense. New spaces have been created using three-dimensional approaches (e.g., the development of high-rise buildings and underground spaces) to compensate for limited ground space. This strategy has been applied to both roadway spaces and buildings. At Tokyo Station and Shinjuku Station, for example, pedestrian spaces were constructed three-dimensionally using pedestrian bridges and underground passages to promote smooth pedestrian flows.

As an informational database on pedestrian spaces currently does not exist, it was necessary to compile and merge data from different sources into one spatial database. For ground-level (GL) road spaces (roadways and walkways) and OGL walkways, layers related to road spaces and buildings were extracted from Zmap-TOWN II (2006, ZENRIN CO., LTD). For OGL roadways, network data from MAPPLE Digital Map Data 10000 (2006, Shobunsha Publication, Inc.) were used.

Figure 2. Pedestrian spaces in front of the west entrance of Shinjuku Station

All road spaces in central Tokyo were constructed as polygon data in ArcGIS. Because underground space polygons from Zmap-TOWN II data do not provide distinctions between passageways and stores in underground

spaces, underground areas of pedestrian space were estimated assuming that 30% of the total underground area is pedestrian space based on information provided by the Tokyo regional disaster management plans ([Tokyo Disaster Management Council, 2015](#)). The mesh in front of the west entrance of Shinjuku Station shown in *Figure 2* illustrates how OGL walkways are being utilized. This mesh exhibits the highest walkway ratio including OGL structures (GL roadways account for 27.9%, GL walkways account for 11.0%, and OGL walkways account for 4.0%). In this mesh, OGL walkways account for 26.6% of the entire walkway area.

3. DISTRIBUTION OF PEDESTRIAN SPACE IN CENTRAL TOKYO

In this section, the quantity of road area including GL and OGL area was investigated based on constructed data to figure out how much space is allocated for pedestrians, and the relationships with buildings, public transportation, and urban renewal projects that determine the main orientation and destination of pedestrian flows and have effects on urban infrastructure, were examined.

3.1 Composition of land uses

In order to examine how much space is allocated for road area, especially for pedestrians, a composition of each land use is calculated. *Figure 3* shows the composition of land use of the 14 wards. The total ground level area is converted to the percentage of the total 100%. In the 14 wards, road area accounts for 21.8%; this is composed of 18.1% GL roadway, 2.7% GL walkway, 0.7% OGL roadway and 0.3% OGL walkway. OGL spaces were used more frequently for pedestrians than for automobiles. OGL roadways accounted for 3.5% of the entire roadway area. On the other hand, OGL walkways accounted for 8.8% of all walkways.

To obtain an understanding of the spatial distribution of pedestrian spaces, a map of the walkway ratio over a 500 meter mesh was made. This is shown in *Figure 4*. First, central and sub-central areas such as neighbouring areas of Tokyo, Shinjuku, Shibuya, and Ikebukuro station showed a high walkway ratio. The walkway ratios including OGL space of the meshes in front of Tokyo station and Shinjuku station were 12.6% and 15.0% respectively. Second, coastal areas such as Shinbashi station and Odaiba district indicate a high walkway ratio due to high density and large-scale development projects. Third, eastern areas show higher value compared to western areas because large-scale land readjustment projects were undertaken after the Great Kanto Earthquake (GKE) of 1923.

Figure 3. Land use classification ratios

Figure 4. Distribution of walkway ratios (GL+OGL)

3.2 Relationship between the pedestrian space and building density

The common goal of transportation planning is to satisfy derived transportation demands by supporting mobility (Rodrigue, Comtois, & Slack, 2016). For the same reason, central and sub-central areas where many people congregate show high walkway ratios in Figure 4. In this context, the relationship between pedestrian space and building density were investigated in order to examine whether the quantity of walkway varies according to building density which is closely related to pedestrian generation.

Figure 5 illustrates the average walkway ratio and walkway area per hectare of building floor area for each class of floor area ratio (FAR) using 500 meter mesh. 45 meshes with less than 50% of FAR were excluded because they, for the most part, are composed of park and water area. FAR was calculated by multiplying polygon area and a storey of each building based on Zmap-TOWN II 2006.

Figure 5. Walkway ratio and walkway area per hectare of building floor area

As FAR increases, average walkway ratio also increases. On the other hand, walkway area per hectare of building floor area does not increase (WAF). Areas with higher FAR tend to include more commercial uses which entice more pedestrians compared to residential or industrial uses. Hence, it can be assumed that the greater the building density and the more pedestrian travel it generates, the less walkway space there is available to it.

[Puškarev \(1975\)](#) also pointed out the same relationship in Midtown Manhattan (38th to 61st streets, Second to Eighth avenues). In order to compare the results of this study to Midtown Manhattan, Chuo ward was selected as a case study area because all parts of this ward are commercial zones like Midtown Manhattan, and walkway ratios and FAR are calculated for each block in *Figure 6*. *Table 1* compares the relationship between walkway space and building floor area in Chuo Ward and Midtown Manhattan. The values of Midtown Manhattan are retrieved from [Puškarev \(1975\)](#). WAF decreases as FAR increases in both results. [Puškarev \(1975\)](#) argued that such misallocation of pedestrian space can be connected to pedestrian congestion in high-density areas. Even though calculation methods of the two results are different, Chuo Ward shows a lower level of pedestrian space compared to Midtown Manhattan especially in low FAR blocks because there are many narrow roads without walkways.

Figure 6. FAR and walkway in Ginza district in Chuo Ward

Table 1. Walkway space related to building floor area in Chuo Ward and Midtown Manhattan

FAR	Chuo Ward of Tokyo			Midtown Manhattan*		
	% of total floor area	% of total walkway space	WAF (m ² /ha)	% of total floor area	% of total walkway space	WAF (m ² /ha)
0-5	35.60	42.68	24.81	8.60	27.00	80.30
5-10	60.25	55.08	18.92	19.90	23.00	29.20
10-15	4.03	2.20	11.30	24.50	18.90	19.50
15-20	0.12	0.05	8.17	29.50	21.40	18.40
20-25				14.10	8.20	14.70
25-30				3.40	1.50	10.80
Total	100.00	100.00	20.70	100.00	100.00	25.70

3.3 Relationship between the pedestrian space and railway station

A railway station is a representative facility where many people congregate. It can be assumed that the requirement of pedestrian space increases with the increase in the number of passengers to channel pedestrian flows. In order to examine this hypothesis, the relationship between the walkway ratio and the number of passengers was analysed. 266 stations in the target area were grouped into low-use (the number of passengers per day with fewer than 50,000, 168 stations), mid-use (the number of passengers per day with between 50,000 and 100,000, 59 stations), and high-use stations (the number of passengers per day with more than 100,000, 39 stations) based on the number of passengers using data from Tokyo metropolitan area Personal Trip (PT) survey 2008. Then, average walkway ratio within a 500 meter radius from each station was calculated separately in *Figure 7*.

Figure 7. Average walkway ratio by the number of passengers

The average road space ratio of 25.1% was found within a 500 meter radius from 266 railway stations in the areas studied. Of these areas, 20.3% are GL roadways, 3.4% are GL walkways, 0.9% are OGL roadways and 0.5% are OGL walkways. Average walkway ratio for all stations showed a

higher value (3.9%) than the average walkway ratio of the entire target area (3.0%). The walkway ratio increased as the number of passengers increased in order to channel pedestrian flows. The walkway ratio of high-use stations was about 1.8 times higher than that of low-use stations. Walkways account for 6.1% of the area within 500 meters from railway stations in high-use stations. Walkways account for 4.0% of the area within 500 meters from railway stations in mid-use railway stations. In low-use stations, walkways account for 3.4% and did not show much difference to the entire walkway ratio (3.0%). Three-dimensional walkways are more proactively used in high-use stations to channel pedestrian flows.

3.4 Relationship between the pedestrian space and urban renewal project

Urban districts have been updated continuously through individual developments and renewal projects such as large-scale redevelopments and land readjustment projects. Recent urban renewal projects tend to make pedestrian-friendly space. In order to analyse their influence on pedestrian space, (1) land readjustment projects and (2) redevelopment projects were studied due to their large effects on the urban structure.

3.4.1 Land readjustment projects

Land readjustment projects can alter the form of a district and construct new public facilities in promoting land utilization. The strategy is frequently used to facilitate urban renewal ([Bureau of Urban Development, Tokyo Metropolitan Government, 2013](#)). Numerous land readjustment projects have been conducted in Tokyo. However, here only two types of land readjustment projects were examined: projects designed to rebuild Tokyo after GKE (districts after GKE), and projects that targeted districts damaged in the Bombing of Tokyo during the Second World War (districts after WWII). A database for districts was constructed based on the land readjustment map produced by the Bureau of Construction, Tokyo Metropolitan Government.

Of the 14 wards examined, 17.2% of target areas were rebuilt by these two land readjustment projects (13.3% of the districts after GKE and 3.9% of districts after WWII). As expected, the average walkway ratio of land readjustment project districts was 5.2% higher than the average walkway ratio of the entire area. Districts after WWII exhibited a higher ratio (6.2%) than districts after GKE because these areas are located close to major transit stations such as Shinjuku, Shibuya, and Ikebukuro.

3.4.2 Redevelopment projects

The redevelopment project is a comprehensive renewal strategy that is designed to improve public facilities such as roads and parks while also creating safe and comfortable living spaces ([Bureau of Urban Development, Tokyo Metropolitan Government, 2013](#)). From 1971 to 2013, 111 districts within the 14 wards of Tokyo have been upgraded through redevelopment projects. In this study, redevelopment district data was constructed based on the list from the Urban Renewal Association of Japan. Among them, 36 districts for which whole processes from plan to completion were undertaken between 1997 and 2008 were employed to compare the change of pedestrian

space by the relevant redevelopment project. Walkway ratios before and after projects were calculated based on Zmap-TOWN II 1997 and 2008.

It became evident that pedestrian spaces have been improved by redevelopment projects in *Figure 8*. The average walkway ratio of 36 districts increased from 5.4% to 11.2% after the projects. In order to examine the effects of 76 redevelopment projects on neighbouring areas as well as the project area, the neighbouring areas within 500 meters from the project area were divided into five parts by the distance from project boundary, and the walkway ratio of each part was calculated in *Figure 9*. Even though the walkway ratio increased after projects, the large gap in walkway ratio between redevelopment districts and surrounding districts indicates that effects on pedestrian space may be limited in its scope. This can cause traffic jams in neighbouring areas due to increased traffic volume caused by recent large-scale mixed-use projects.

There is an example which demonstrates enhancement not only to pedestrian spaces but also to the city's overall transportation infrastructure by expanding the scope of the project area and creating a three-dimensional road system. *Figure 10* illustrates the change of walkway between before and after the project based on the planning map in the Loop Road No. 2 Shimbashi-Toranomon Redevelopment District. GL walkways account for 28.6% of all GL area. This ratio is four times higher compared to before the project (6.7%).

Figure 8. Comparison of walkway ratio before and after redevelopment project

Figure 9. Walkway ratio of redevelopment districts and neighbouring area

Figure 10. Loop Road No. 2 Shimbashi-Toranomon Redevelopment District
(Source: modified from the planning map produced by the Tokyo Metropolitan Government Urban Redevelopment Office, 2013)

4. REGRESSION ANALYSIS AMONG PEDESTRIAN SPACE, URBAN STRUCTURE AND PUBLIC TRANSPORTATION

In transportation planning, satisfying a derived transportation demand by supporting mobility is the common goal of transportation. Transportation infrastructure provides transport supply in which mobility can occur

(Rodrigue, Comtois, & Slack, 2016). This would also be true in pedestrian space planning.

However, pedestrian spaces have not necessarily been built with consensus guidelines. In order to monitor current usage and suggest reference points for future improvement, it is necessary to quantify how pedestrian spaces have been built until now. Based on results from the previous section, it can be assumed that buildings, public transportation and urban renewal projects have relationships with pedestrian space.

In this regard, investigating these relationships make it possible to understand how pedestrian spaces have been built, such as whether the relationships are significant and how much factors are related to the walkway area. It can give information to make a benchmark or a reference point to tell planners how much space exists and has to be made for walkable space related to other factors. In this section, the relationship among the quantity of pedestrian space, building, public transportation and urban renewal projects was analyzed via multiple regression models to give quantitative information.

4.1 Description of the variables

As dependent variables, walkway ratio (*WWR*) for each mesh (500m) was used to measure the quantity of pedestrian space. *WWR* represents how much space is allocated to pedestrian space.

Table 2. Summary statistics for the variables

Variables		Description	Mean	SD
<i>WWR</i> (%)		Walkway to mesh area ratio	2.97	2.18
Building	<i>FAR</i> (%)	Ratio of total floor area of building to the mesh area	157.11	81.74
	<i>ZR</i> (%)	Proportion of residential zone	42.14	35.13
	<i>ZC</i> (%)	Proportion of commercial zone	32.89	30.82
	<i>ZI</i> (%)	Proportion of industrial zone	21.07	29.75
Transportation	<i>RR</i> (%)	Proportion of roadway area	17.85	6.39
	<i>NP</i> (%)	Number of passengers distributed to each zone according to area ratio within 200 meters from each station per the zone area	2.3	5.54
Urban Renewal	<i>PLR_GKE</i> (%)	Proportion of the readjustment project district (GKE) area to the zone area	15.25	31.96
	<i>PLR_WW</i> (%)	Proportion of the readjustment project district (WW) area to the zone area	4.2	14.15
	<i>PRD</i> (%)	Proportion of the land redevelopment project districts area to the zone area	0.83	3.9

Independent variables were classified into (1) building density, (2) public transportation, and (3) urban renewal project. First, the ratio of total floor area to mesh area (*FAR*) and proportion of land use zone (*ZR*, *ZC*, *ZI*) were selected to illustrate building density and uses. Proportions of land use zone for each mesh were calculated using the zoning data (2013) from the National Land Numerical Information of Japan. Zoning in Japan has 12 zones and they have been classified into three categories: residential (7

zones), commercial (2 zones), and industrial zones (3 zones). Second, the roadway ratio (*RR*) and the number of passengers have been used to consider the transportation condition. Third, the proportion of urban renewal projects area to mesh area (*PLR_GKE*, *PLR_WW*, and *PRD*) has been employed to consider the effects of urban renewal projects. *Table 2* shows the definitions and statistics summaries for each variable.

Policies and regulations for making public space including walkways vary according to zoning regulations. For example, redevelopment projects in the commercial zone are required to make more public spaces to accommodate traffic flows and to improve the cityscape. In this regard, target areas were divided into three groups according to proportion of the land use zones: Residential (the proportion of residential zone with more than 50%, 339 meshes), commercial (the proportion of commercial type zone with more than 50%, 166 meshes), and industrial groups (the proportion of both residential and commercial zone with lower than 50%, 213 meshes). *Figure 11* illustrates the distribution of the three groups and *Table 3* shows the summary statistics of the three groups.

Figure 11. Distribution of three groups

Table 3. Summary statistics for three groups

Variables	Residential group		Commercial group		Industrial group	
	Mean	SD	Mean	SD	Mean	SD
<i>WWR</i> (%)	1.96	1.34	5.39	2.47	2.70	1.51
<i>FAR</i> (%)	128.88	50.92	251.66	92.65	129.51	53.59
<i>ZR</i> (%)	76.24	13.82	11.84	15.56	12.71	15.39
<i>ZC</i> (%)	19.29	13.37	82.38	17.44	16.64	15.23
<i>ZI</i> (%)	3.76	8.35	4.30	9.85	60.03	23.10
<i>RR</i> (%)	15.44	4.12	25.08	5.77	16.13	5.67
<i>NP</i> (%)	1.16	2.01	6.29	9.72	1.05	2.92
<i>PLR_GKE</i> (%)	1.31	8.74	44.97	41.75	14.30	31.24
<i>PLR_WW</i> (%)	2.54	9.79	9.85	22.39	2.50	10.27
<i>PRD</i> (%)	0.90	3.90	0.86	3.40	0.72	4.25

4.2 Estimation model

An important estimation problem is spatial dependence in the data. Ordinary least squares does not account for the interplay between spatially close observations, which may lead to biased estimation (LeSage & Pace, 2009). There are two basic modelling options to consider spatial autocorrelation: the spatial error (SEM) and the spatial lag (or spatial autoregressive, SAR) functional forms.

The definition of neighbours used in the weights matrix was based on the first order queen contiguity. The Lagrange multiplier tests confirmed significant spatial error auto-correlation while no significant spatial lag dependence was detected by the robust LM-test. Three models were estimated using SEM:

$$Y = \beta X + u$$

$$u = \lambda W u + \epsilon$$

where n is the number of observations, m is the number of independent variables, Y is an $n \times 1$ vector of dependent variables, X is an $n \times m$ vector of independent variables, β is an $m \times 1$ vector of regression coefficients, λ is a spatial error coefficient, W is an $n \times n$ vector from the spatial weight matrix, and ϵ is an $n \times 1$ vector of idiosyncratic errors. Models are estimated with the statistical software GeoDaSpace using ML method.

4.3 Results of regression model

Table 4 reports the result of the three regression models. In order to consider non-linear effects of independent variables, quadric terms of *FAR*, *NP* and *RR* were employed. Only the quadric term of *FAR* showed a significant relationship and was employed in models. The Pseudo R-squared for the three groups is 0.383, 0.675, and 0.387 respectively. High pseudo R-squared of the commercial group indicates that pedestrian spaces have been built with a close relationship to the characteristics of building and transportation that influence pedestrian traffic flows. On the other hand, pedestrian spaces in the residential and industrial group tend to have been built with less consideration of these factors compared to the commercial group. The results should be interpreted as being associative rather than causal because pedestrian spaces have not been necessarily made corresponding to building density and the number of passengers.

Table 4. Results of regression model

	Residential group			Commercial group			Industrial group		
	Coef.	Beta	z-Statistic	Coef.	Beta	z-Statistic	Coef.	Beta	z-Statistic
Constant	0.078		0.263	1.257		1.568	-1.184 ***		-3.775
<i>FAR</i>	-0.009 *	-0.349	-2.528				0.007 ***	0.246	4.506
<i>FAR</i> ²	3.32×10^{-5} **	0.387	2.975	2.31×10^{-5} ***	0.506	9.983			
<i>Z_R</i>				-0.020	-0.127	-1.902	0.002	0.017	0.354
<i>Z_C</i>	0.010 *	0.102	2.035				-0.002	-0.025	-0.403
<i>Z_I</i>	0.005	0.033	0.779	-0.016	-0.066	-1.279			
<i>RR</i>	0.137 ***	0.422	9.779	0.096 **	0.225	3.222	0.182 ***	0.683	11.592
<i>NP</i>	0.120 ***	0.180	4.513	0.080 ***	0.314	6.393	0.074 **	0.143	3.211
<i>PLR_WW</i>	0.024 **	0.156	2.850	-0.005	-0.078	-1.052	-0.005	-0.095	-1.127
<i>PLR_GKE</i>	0.006	0.044	1.090	0.009	0.080	1.432	-0.005	-0.034	-0.716
<i>PRD</i>	-0.012	-0.036	-1.006	-0.015	-0.020	-0.451	0.011	0.030	0.726
lambda	0.552 ***	0.000	10.366	0.083	0.000	0.760	0.639 ***	0.000	11.640
No. mesh	339			166			213		
PseudoR ²	0.383			0.675			0.387		
AIC	927.8			601.5			636.0		

Sig. codes: * $p < 0.05$; ** $p < 0.01$, *** $p < 0.001$

4.3.1 Building density

All groups show the tendency that *WWR* increases as *FAR* increases. In the commercial group especially, a positive coefficient of the quadric term means that there have been great efforts for making more pedestrian space in high-density areas with commercial uses. However, this result does not mean that there are enough spaces for pedestrians because walkway area per hectare of building floor area in the previous section does not increase as *FAR* increases.

In the residential group, however, *WWR* decreases as *FAR* increases when *FAR* is lower than 137.7%. On the other hand, when *RR* was employed as the dependent variable, *FAR* shows a positive relationship with *RR*. It indicates that pedestrian space has been built with less priority than spaces for automobiles in residential groups. In the industrial groups, *FAR* shows a positive relationship. This is because that pedestrian space has been secured to ensure the safety of pedestrians from vehicles that are generated from industrial buildings.

4.3.2 Transportation

With regard to the relationship between the pedestrian space and railway station distribution, it became clear that the *WWR* increases as the number of passengers increases. The commercial group shows the highest beta coefficient of *NP*. It indicates that there was a further consideration in pedestrian traffic from stations compared to residential and industrial groups.

RR shows a positive effect in all three group. Residential and industrial groups show a higher beta coefficient compared to the commercial group. It indicates that pedestrian spaces have been built as not the independent part, but the additional parts of roadway space. This result can have two different interpretations. First, pedestrian spaces have been made by the construction of roadways even though building density and the number of passengers were not high. Second, the areas with poor infrastructure condition may suffer from a shortage of pedestrian spaces even though building density is high. The peripheral part of the target area tends to have a poor infrastructure condition and relatively high building density.

4.3.3 Urban renewal project

Even though urban renewal project areas show high *WWR* in the previous section, only *PLR_WW* for the residential group shows a significant relationship with *WWR*. This suggests that high *WWR* in urban renewal project districts is not the result of the priority on pedestrian space, but the result of well-planned roadways.

5. DISCUSSION AND CONCLUSION

This study clarified how much pedestrian space exists, and investigated how they have been related to building, transportation and urban renewal projects in central Tokyo.

The findings from this study showed that road area accounts for 21.8% on average in central Tokyo, this is composed of 18.8% roadway and 3.0% walkway, and pedestrian spaces are accumulated in central and sub-central areas which have high building density, and in urban renewal projects areas.

Three-dimensional walkways are more proactively used to channel pedestrian flows that congregate around stations compared to a roadway. However, it should be noted that segregation of pedestrians and vehicles by three-dimensional space can cause public dissatisfaction with streets (Hamilton-Baillie & Ben, 2008). Considering accessibility and connectivity for all users of space is necessary to make walkable environments.

Even though there is no consensus guideline for making pedestrian spaces, the higher correlation between walkway ratio with building density and the number of railway passengers in commercial areas suggests that pedestrian spaces have been built with the consideration of pedestrian traffic flow from buildings and stations. On the other hand, pedestrian spaces have been built mainly by the construction of the roadway in other areas. Furthermore, there was less priority to walkway than spaces for automobiles in residential areas with mid building density. This result suggests that areas with poor infrastructure condition and high density have a possibility of a shortage of pedestrian space to secure safety. However, it may be difficult to make more pedestrian space due to the limited space and poor road network. Soft approaches such as allocating street furniture and changing road design to drop vehicle speed should also be considered to secure safety and comfort of pedestrians.

Areas with urban renewal projects such as redevelopment and land readjustments show high walkway ratios. However, urban renewal projects did not necessarily give more consideration to pedestrians, all other things being equal. This study introduced the case of a redevelopment project that gave priority to spaces for pedestrians. Extending the scope of these projects is a way to make a more walkable city.

This study clarified how pedestrian space has been distributed related to urban structure and public transportation, and the results showed the degree of relationship with the quantity of pedestrian space. Even though the result of this study cannot be generalized because the results have come from a case study of the Tokyo ward area, the quantitative results of this study can be used to provide a performance measure and benchmark for planners wanting to investigate the current level of pedestrian space.

International comparative studies based on the suggested method can contribute to clarifying the necessary level of pedestrian space to make a more walkable city. Further study is necessary consider both quantitative information of pedestrian space and pedestrian flow using location information data such as individual mobile data and GPS which is being accumulated with the development of technology.

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