Examining the relationship between Built Environment and the Mode Choice of Travelers: A Case study of Colombo, Sri Lanka

Rathnayake, H. M. W. T.¹, Kalpana, L. D. C. H. N.¹*, Jayasinghe, A. B.¹

¹ Department of Town and Country Planning, University of Moratuwa

Abstract

The transportation system is an integral component of a modern urban environment. Its drawbacks cause numerous transport-related issues in a majority of cities around the world. Increasing traffic congestion is one of them. Traffic congestion in major roads accounts for an annual loss of approximately 40 billion rupees in Sri Lanka. This system has significantly caused the unbalance of the built environment parameters and the choice of transportation modes, while disrupting the road infrastructure management owing to the growing demand of automobiles. Therefore, it is essential to study the coherence between built environment factors and the transport mode choices and understand their relationship with different mode choices regardless of other critical parameters of mode choice such as income, travel time differential, quality of service. The study was carried out in the Colombo Metropolitan Area. Secondary data was utilized to analyze the mode choice characteristics of the study area. Density, design, and diversity parameters were considered the built-form factors; and centrality measures were utilized to capture the road network parameters. Relationship analysis and Multi-Layer Perceptron analysis were utilized to identify the relationship between the built environment and the choice of mode in transportation. The result revealed that there is a relationship between built environment factors and the choice of mode at origin, destination, and route-wise. The findings of the study would be essential for transport and urban planners to develop more inclusive landuse plans and for better transport management.

Keywords: Built Environment, Mode choice, Transportation planning, Urban Planning, Spatial Analysis

1. Introduction

The transportation system is an integral component in a modern urban environment (Murcio, et al, 2015). The transportation behavior of the community is determined by several factors: i.e., social demographic characteristics, built environment characteristics, available modes (Litman & Burwell, 2006; Klöckner & Blöbaum, 2010; Zailani et al., 2016). In the modern urban context, transportation mode choices are significantly influenced by community transportation by utilizing public and private modes of transportation. Thus, these mode choices are thoroughly depends on the comfort, the quality, and the convenience as well as the safety, cost effectiveness and the efficiency of the transportation modes (Madhuwanthi, et al., 2016; Sayyadi & Awasthi, 2018). Nowadays, people increasingly tend to use private automobiles for to cater their transportation needs. This growth in personalized automobiles leads to numerous transportation related challenges, i.e. traffic congestion, air and noise pollution and disruption of the pedestrian movement

* Corresponding Author:

https://orcid.org/0000-0002-8103-715X
e-mail address: tokalpanahn@gmail.com
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patterns (Litman & Burwell, 2006). Therefore, to mitigate the above issues, transport specialists and planners should be conversant about the relationship between the choice of travel mode and the various factors that lead to such choice.

During the last 28 years in Sri Lanka, the number of persons travelled through Colombo Municipal Council (CMC) area using private modes of transport has increased by more than 2.5 times of the public transport mode users (JICA, 2014). However, only a limited number of studies can be found in the Sri Lankan context, related to the factors affecting the mode choice. According to Madhuwanthi, et al., (2016) around 40 billion rupees are loss annually in Sri Lanka due to the traffic congestion and air pollution on the road. To provide a sustainable solution for that, it is important to identify the factors influencing the mode choice of commuters. Still there is a need of identifying how built environment factors affect the mode choice in the Sri Lankan context.

According to Kumarage (2004) proper town plan, friendly public transport facilities, and a sufficient operational traffic system are required to solve the traffic congestion in the City of Colombo. Analysing the relationship between land use and transportation is more important to build a sustainable transportation system. Transport Policy Reports in Sri Lanka also identified the need of connecting land use plans and the urban transportation system (Kumarage, 2012). For instance, CoMTrans Plan proposed that the integration of urban development with urban transport systems is important (JICA, 2014). It further emphasised the importance of integration between land use and the transport systems. In the spatial planning subject division, built environment consists of two categories of elements: i.e. the built form and road network (Handy, et al., 2002; Jayasinghe, et al., 2019). Thus, these elements determines the transportation options of the community which significantly makes an impact on the choice of their transportation mode (Hillier & Iida, 2005; Jiang & Jia, 2011). On the other hand, in the urban planning context, land use plans and planning policies significantly impact on the change of the built environment which makes a significant influence on the mode choice of travelers (Zhang, 2004; Lu, et al., 2018; Tenzin, et al., 2019). Therefore, studies on the built environment and its influence on the transport mode choices is important for urban and transport planners. Thus, it may be essential for a better arrangement of the built-form and transportation network for a sustainable transportation system (Banister, et al., 2011).

Similarly, identifying the relationship between mode choice and built environment is also important in the spatial planning context, as it answers several frequently asked questions such as, (I) How does a community travel within the transportation network? (II) Why some transport corridors are more attractive than the others? (Zhang, et al., 2012) (III) How and to what extent the built-form parameters and topological and geometric characteristics of a road network impact on travelers’ mode choice decisions. The answers for these questions will depict the relationship between the transportation system and the built environment of cities.

In such context, this study was carried out in the Colombo Metropolitan Area, which is the commercial capital of Sri Lanka. A secondary data source was used to collect
mode choice data of the study area. The literature review enabled to identify the built form characteristics and a novel approach developed following the Network Centrality Approach (NCA) was adopted to decide the road network parameters. The findings of this study will be useful for transport and urban planners to develop more integrated landuse plans and for better management of the transport.

This introduction is followed by the review of literature and finding the research gaps. A brief discussion of built environment characteristics is presented in section three. Methodology and data description of the study are presented in section four. The fifth section provides the analysis and results of the study. The conclusion and recommendations for future studies are presented in the last section.

2. Literature review

According to the Cervero & Kockelman (1997), Studies related to the built environment and mode choice goes back to the early 1950s, where the (Cervero & Kockelman, 1997; Ding & Huapu, 2016) founded an association for built environment and travelers’ attitudes. This had led to examine the significant effects on the built environment from trip generation and the probability of mode choices in the San Francisco-Bay area. Later, Cervero (2002) improved mode choice models by combining land use factors. Lee (2006) found the significance of the attributes of built environment on mode choice in the Dallas Fort Worth Metropolitan Region. Shay & Khattak (2012) identified that the built environment characteristics were positively related with mode choices. According to Ye & Titheridge (2017), who had investigated the effect of built form in Chinese cities, car usage among commuters could be reduced if travel attitudes and aspects on commuter satisfaction were improved, with upgraded accessibility to public transport facilities at residential locations. However, it denied the fact that improving accessibility to public transport facilities at job locations could reduce the travel time among workers. Munshi (2016) explored the relationship between built environment and mode choice in the Indian city of Rajkot (Joshi, et al., 2017). The study revealed that land use diversity had highly influenced the mode choice, while density and design had less influenced the same.

As mentioned above, numerous studies have been carried out to identify the connections between the mode choice and built environment in developed countries. However, those studies have focused more on the built form characteristics, (i.e., density, diversity, design, destination accessibility and distance to transit stops etc.) and not much attention was directed towards road network characteristics. While traffic congestion is constantly increasing in the cities, geographical conditions and network of the existing roads too hinder the vehicle flow (Baig & Rao, 2016). Therefore Hillie & Iida, (2005), Jiang & Jia, (2011) pointed out the importance of considering the road network geometry and topology for modeling traffic flow patterns. However, most studies are focused either on the total traffic flow or merely a single mode of traffic.

Nevertheless, Jayasinghe, et al., (2015) recognized a gap in comparing and contrasting the characteristics of the traffic flow patterns in different types of modes. To address that gap, road network characteristics and how they influence mode choice decisions should be recognized, but studies on those segments
are extremely limited. Considering all the above mentioned studies, it shows that there has been limited attention paid to assessing the built environment in terms of built form characteristics and the road network, and the transport mode choice decisions of commuters. In such a context, studying the relationship between the built environment in terms of built form characteristics and the road network and the transport mode choice decisions of commuters would be the main objective of this study.

3. Characteristics of Built Environment

3.1. Built Form Parameters and Measures

By late 2000, ample studies had been published to manifest the linkages between the built form and mode choice. The studies revealed that employment, population density and land use diversity are significantly associated with people’s choice of mode for shopping trips (Frank & Pivo, 1994). According to McCormack, et al., (2008) mixed destinations are strongly associated with walking trips. Scheiner and Holz-Rau (2007) identified that high density and mixed land use areas provided more destinations and access opportunities for nearby residents. The studies also identified that highly developed dense areas or mixed land use areas had a better effect on the good transit system compared to the other areas. Ewing & Cervero (2010) studied the built form variables that influence vehicle miles traveled (VMT), walking and transit use. They argued that VMT was strongly associated with accessibility to destinations, while walking was associated with the land use diversity and the intersection density.

As mentioned above, there are sufficient parameters proposed to define the built form. Thus, the study selected three (3) built form parameters which have been frequently utilized in recent studies, to investigate the linkages between the built form and mode choices (refer Table 1).

Afterwards, the study identified the respective measures to quantify each of the above mentioned built form characteristics by referring to recent studies (refer Table 2).

Table 1: Built Form Parameters identified by different studies


Table 1: Built Form Parameters identified by different studies
3.2. Road Network Parameters and Measures

As mentioned above, the study used the Network Centrality Approach (NCA) to derive the road network parameters and to investigate the linkages with the built environment in terms of road network and mode choice.

The concept of Network Centrality originated in the 19th century, as a tool in social sciences for the identification of interactions and interrelations (Freeman, 1979). This was developed based on the graph theory, frequently applied to assess the transportation system accessibility, as it delivers the same cognitive result as both terms are often used to define the same concept (Crucitti, et al., 2006; Istrate, 2015; Jayasinghe, et al., 2017). Classic urban geography is concerned with the attraction of each node and its intensity to the overall network, and the significance of each node is based on the topological and geometric properties of urban layouts (Morales, et al., 2017). Currently, network theory has been extremely successful and permeates the methodologies employed for many different urban models (Arcaute, et al., 2016; Kalpana, et al, 2019). In order to access the linkages between road network parameters and mode choice, this study utilized the following NCA measures:

**Closeness Centrality (CC):** CC measures how close the location [link] is to all others along the shortest path (Porta, et al., 2012). The study utilized the following formula to compute the CC of links (Sabidussi, 1966)

\[
CC_{i[r]} = \frac{(N - 1)}{\sum_{j \in N, j \neq i} d_{ij}}
\]

Where;
- \(CC_i\) : Closeness centrality of link ‘i’
- \(N\) : Total number of links in a network
- \(d_{ij}\) : Distance between links ‘i’ and ‘j’ along the shortest path
- \(r\) : Radiuses of influence system considered

**Betweenness Centrality (BC):** BC is referred to the extent a given link belongs to the shortest-path between any pair in a graph (Porta, et al., 2012). The study utilized Freeman’s (1979) formula to compute the BC of links.

\[
BC_{i[r]} = \frac{1}{(N - 1)(N - 2)} \sum_{j,k \in N; j \neq k; k \neq i} \frac{P_{jk}}{P_j}
\]

Where;
- \(BC_i\) : Betweenness centrality of link ‘i’
- \(N\) : Total number of links in a network
- \(P_{jk}\) : Number of geodesics between link ‘j’ and ‘k’
- \(P_{jk(l)}\) : Number of geodesics between link ‘j’ and ‘k’ that pass-through link ‘i’
- \(r\) : Radiuses of influence system considered

**Connectivity centrality (Cn):** Cn computes the number of links directly connected to a particular link in a graph. The study utilized the following formula to compute the Cn of links (Hillie & Iida, 2005)
$Cn_i = k$ \hspace{1cm} (3)

Where;

$Cn_i$ : Connectivity centrality of link ‘i’,
$k$ : Number of links directly connected to link ‘i’

In order to assess the above mentioned NCA measures, the study used the GIS Environment. The detailed methodology of examining the relationship between the built environment and mode choice will be discussed in the methodology section.

4. Method and Materials

4.1. Study Area

The study is based in Colombo Metropolitan Area (CMA) of Sri Lanka (refer Figure 2). CMA accounts for more than 50% of the country’s GDP and 700,000 trip accumulations per day. Out of that, 38% trips are generated by private vehicles and 40% are by the public transport modes while rest of the other trips, (i.e., 22%) are generated from the walking and cycling. The area characterises gross trip production rate of 1.87 per person.

4.1 Study Framework

The framework of the study is depicted in Figure 1. The study is divided into three main stages: the first stage includes the data preparations for building the indexes for each specific variable in both the built environment and mode choice parameters. The second stage includes the preparation of each specific index. Finally, it assesses the relationship between the built environment characteristics and mode choice parameters using regression and multilayer perceptron analysis.
4.2. Data Collection Methods

The study predominantly depended on secondary sources to acquire the data. Thus, Japan International Cooperation Agency (JICA) Home Visit Survey 2013 data for the Western Province of Sri Lanka (JICA, 2014) was utilized for this purpose. Accordingly, CMA is divided into 306 traffic analysis zones (TAZ), and the built environment and mode choice data were collected with the base of each TAZ.

In this instance, mode choice data for each specific transportation mode was collected according to the origin, destination, and route selection of the transportation mode of each TAZ in the CMA. In such a context, origin trips of vehicles denote the types of transportation modes that have originated from each particular TAZ. Destination trips denote the types of transportation modes of vehicles utilized to reach each TAZ. Similarly, route mode choices denote the types of transportation modes of vehicles which are frequently used in each TAZ.

The study considered the relationship of built environment parameters and road network characteristics to the origin, destination, and route selection as separate entities. This was mainly for two reasons. The first is that the primary data collections were carried out according to the origin, destination, and route selection of the transportation mode of each TAZ in the CMA as separate entities. Thus, investigating them together derived some inconsistencies in the data as some vehicular mode choices had not been considered in each mode choice category. The second is that there was no noticeable difference in the quality of the transportation conditions, transportation accessibility and mobility conditions, of the CMA, which is the study area. Therefore, there wouldn’t be a significant impact on the quality of the findings of the study regardless they were investigated together for a complete picture. Unlike the other studies, this study used route selection data zone wise, owing to the form of availability. Car, Motor-Cycle, Three-wheeler, Bus, Railway and Non-Motorized Transport (NMT) were the different transportation modes considered. Thereafter, the study assessed the built environment parameters for each TAZ.
Examining the relationship between Built Environment and the Mode Choice of Travelers: A Case study of Colombo, Sri Lanka

Table 3. Built Environment Parameters, (i.e., built form and road network) and the Method of Assessment

<table>
<thead>
<tr>
<th>Factor</th>
<th>Method of Computation</th>
<th>Required Data</th>
<th>Used tool or technique</th>
</tr>
</thead>
</table>
| Density | Population Density  
Number of people in a TAZ/Area of TAZ | Population data of each TAZ, Area of each TAZ | ArcGIS Field Calculator |
| Employment Density  
Number of Employers/employees coming to the TAZ/Area of TAZ | Employment data of each TAZ, Area of each TAZ | ArcGIS Field Calculator |
| Design | Junction Density  
Number of junctions in each TAZ/Area of TAZ | Number of junctions in each Area of TAZ | ArcGIS Field Calculator |
|  | Street Density  
Number of Streets in TAZ/Area of TAZ | Number of Streets, Area of TAZ | ArcGIS Field Calculator |
| Diversity | Land use Balance Entropy Index  
$Entropy = \left\{ -\sum_{k} \left( p_{j} \ln p_{j} \right) \right\} / (\ln k)$ | Land use Data of each zone | Entropy Index |
| Centrality Parameters | Betweenness, Closeness and Connectivity | Road Network | Spatial Network Analysis Tool (sDNA) |

Required data, computation method and used technics are given in Table 3. In order to calculate the NCA parameters, the method previously adopted in Jayasinghe, et al. (2015) was followed. Thus, it prepared the road segment graph by clipping the original road lines at each intersection into minor parts.

The study utilized the sDNA Tool in QGIS environment to compute the NCA measures. Afterwards, the study prepared two spatial indexes, which included the attributes of Built Environment and Mode Choice indexes for all TAZ (refer Tables 4 and 5).

Table 4. Mode Choice Indexes for the each TAZ

<table>
<thead>
<tr>
<th>TAZ</th>
<th>Origin</th>
<th>Destination</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Car</td>
<td>Motorcycle</td>
<td>3wheeler</td>
</tr>
<tr>
<td>1</td>
<td>0%</td>
<td>5%</td>
<td>17%</td>
</tr>
<tr>
<td>2</td>
<td>9%</td>
<td>5%</td>
<td>19%</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>306</td>
<td>8%</td>
<td>15%</td>
<td>4%</td>
</tr>
</tbody>
</table>
Table 5. Built Environment Indexes for each TAZ

<table>
<thead>
<tr>
<th>TAZ</th>
<th>Area (Ha)</th>
<th>Population Density</th>
<th>Employment Density</th>
<th>Junction Density</th>
<th>Street Density</th>
<th>Diversity</th>
<th>Average of Connectivity</th>
<th>Average of Closeness</th>
<th>Average of Betweenness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22.58</td>
<td>187.99</td>
<td>7.65</td>
<td>0.04</td>
<td>0.04</td>
<td>0.49</td>
<td>4.00</td>
<td>0.18</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>208.15</td>
<td>128.98</td>
<td>29.94</td>
<td>0.01</td>
<td>0.00</td>
<td>0.67</td>
<td>4.50</td>
<td>0.19</td>
<td>9.30</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>306</td>
<td>782.12</td>
<td>22.00</td>
<td>0.26</td>
<td>0.01</td>
<td>0.00</td>
<td>0.67</td>
<td>4.60</td>
<td>0.10</td>
<td>27.42</td>
</tr>
</tbody>
</table>

4.3. Data Analysis Method

After preparing the two spatial indexes, the study assessed the relationship of built environment characteristics and the mode choice using Regression analysis and Multi-Layer Perceptron (MLP) analysis, with EXCEL and SPSS Software. First, the study plotted both indexes in a scatter plot graph according to origin, destination, and route, in order to identify the relationship of each parameter to mode choice. Thus, it considered each mode choice as an independent variable (Y) and all the built environment parameters as dependent variables (X), which allowed to visually interpret the relationships among datasets. The Best-fit-line was added to the plot, to determine the most appropriate relationship between each corresponding variable. Afterwards, the coefficient of determination \( R^2 \) was calculated to determine the proportion of variance in the built environment parameters that can be explained by each mode choice decision of travelers. Hence, the study derived the regression equation with the basis of the most appropriate relationship which was determined by the best-fit-line. Thereafter, the study utilized the MLP Analysis to identify the most significant factors to the mode choice among all the built environment parameters. MLP is a fundamental Neural Network Analytical method which comprises the SPSS Toolkit. Since the study includes both linear and non-linear parameters, MLP analysis can equally evaluate the significance of each parameter.

It is important to note that the analysis of the study has not encountered all the transportation modes consistently in the mode choice indexes since the data has been acquired from secondary data sources. Therefore, a corresponding relationship analysis was carried out with the available secondary data. In the following section, the results of the analysis are discussed.

5. Analysis and Results

5.1. Relationship Analysis

The study plotted each built environment parameter according to origin, destination,
and route and the coefficient of determination of each relationship was evaluated to determine the proportion of variance. The results and status of the relationships with the original mode choices are presented in the table 6.

Accordingly, the population density in the density parameter depicts a negative correlation with car and motorcycle modes. This indicates that a higher population density discourages people to utilize private transportation modes and they tend to use public transportation instead. This is clearly distinguished by the increasing demand for the three-wheelers ($R^2=0.5311$, $p<.01$) and the NMT ($R^2=0.5382$, $p<.01$). Among them, three-wheelers have a higher positive correlation ($R^2=0.5068$, $p<.01$). This clearly reflects the actual transportation behavior, as with higher transportation density areas, there is potential to generate demand for the three-wheelers due to easy accessibility convenience, and affordability. Meanwhile, street density and origin of NMT have a higher positive correlation ($R^2=0.5032$, $p<.01$). This leads to understand that the higher street density areas have more tendency for a pedestrian friendly transportation system.

The study also identified a negative relationship between the car origins and employment density. This indicates that, within the high employment density areas, people tend to use public transportation modes, (i.e., three-wheelers ($R^2=0.3597$, $p<.01$) and public transportation ($R^2=0.3342$, $p<.01$) and NMT ($R^2=0.3378$, $p<.01$). This is mainly caused by the vibrant land use activities which encourage NMT and increase the demand for public transportation modes, including three-wheelers.

Considering the relationship between transportation parameters and origin, mode choices, none of the transportation modes depict a significant relationship with the connectivity parameter. Therefore, it can be understood that the connectivity factor has less influence on the origin of transport modes. On the other hand, landuse diversity significantly impacts on the origin of three-wheelers ($R^2=0.3521$, $p<.01$), public transport ($R^2=0.3342$, $p<.01$) and NMT ($R^2=0.3378$, $p<.01$). This clearly illustrates that the origins of travel trips of these transportation modes are significantly influenced by the potentials of the shortest path distance of the transportation segments with the highest accessibility to a particular destination. As an example, the public transportation system usually follows the highest accessible transportation network where the majority of people can receive the benefit of the service.

Meanwhile, the origin of public transportation ($R^2=0.4267$, $p<.01$) mode depicts a linear positive correlation with the betweenness parameter as the corresponding transportation mode is profoundly dependent on pass by road segments. As an example, public transportation usually follows the shortest
road segment between two identified locations, (i.e., these road segments denote the major arteries). Thus, it can provide a convenient service by covering the road segments which are highly used for various travel trips.

Next, the study presents the results and status for the destination mode choice in Table 7. According to the density parameters in Table 7, population density and destination of three-wheelers ($R^2=0.6173$, $p<.01$) and public transportation ($R^2=0.5054$, $p<.01$) modes have a higher positive correlation, as both modes are predominantly utilized for passenger transportation purposes. Meanwhile, employment density and destination choice of cars have a higher positive correlation, as both modes are predominantly used for passenger transportation purposes. Considering the density parameter; none of the destination modes show a significant positive correlation with the junction density, but car and public transportation modes depict a week positive correlation. On the other hand, street density and destination of car mode choices denote a negative relationship ($R^2=0.406$, $p<.01$). This could be owing to higher densities in the street where people tend to use public transportation modes and NMT for their travel purposes, due to the higher mobility of the transportation system. However, distinct reasons for this relationship cannot be assessed due to the non-availability of data for other mode choice decisions.

Table 6. Summary of Relationship and Coefficient of Determination of Origin Mode Choice vs. Built Environment Parameters

<table>
<thead>
<tr>
<th>Built Environment Parameters</th>
<th>Density</th>
<th>Design</th>
<th>Diversity</th>
<th>Road Network Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Population Density</td>
<td>Employment Density</td>
<td>Junction Density</td>
<td>Street Density</td>
</tr>
<tr>
<td>Car</td>
<td>Linear - Negative</td>
<td>Linear - Negative</td>
<td>Logarithmic - Negative</td>
<td>Logarithmic - Positive</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.1331$</td>
<td>$R^2 = 0.1608$</td>
<td>$R^2 = 0.1449$</td>
<td>$R^2 = 0.0678$</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>Exponential - Negative</td>
<td>Logarithmic - Positive</td>
<td>Logarithmic - Negative</td>
<td>Linear - Positive</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.1094$</td>
<td>$R^2 = 0.1157$</td>
<td>$R^2 = 0.1732$</td>
<td>$R^2 = 0.1221$</td>
</tr>
<tr>
<td>Three-wheelers</td>
<td>Linear - Positive</td>
<td>Linear - Positive</td>
<td>Linear - Positive</td>
<td>Linear - Positive</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.5311$</td>
<td>$R^2 = 0.3597$</td>
<td>$R^2 = 0.5068$</td>
<td>$R^2 = 0.3716$</td>
</tr>
<tr>
<td>Public Transportation</td>
<td>Linear - Positive</td>
<td>Linear - Positive</td>
<td>Linear - Positive</td>
<td>Linear - Positive</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.4152$</td>
<td>$R^2 = 0.4685$</td>
<td>$R^2 = 0.2372$</td>
<td>$R^2 = 0.3272$</td>
</tr>
<tr>
<td>NMT</td>
<td>Linear - Positive</td>
<td>Logarithmic - Positive</td>
<td>Linear - Positive</td>
<td>Linear - Positive</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.5382$</td>
<td>$R^2 = 0.0333$</td>
<td>$R^2 = 0.2828$</td>
<td>$R^2 = 0.5032$</td>
</tr>
</tbody>
</table>

Rathnayake et al.
On the other hand, landuse diversity significantly discourages the destination mode of car \((R^2=0.5221, p<.01)\) and three-wheelers \((R^2=0.5458, p<.01)\) as the rich landuse diversity encourages the demand for public transportation modes \((R^2=0.5266, p<.01)\). Therefore, in the areas of high landuse diversity, people tend to use more public transport modes. However, further studies are required to clearly identify the relationship of landuse diversity and public transportation modes as this study does not include the impact of several major transportation modes, such as the NMT, Motorcycle and Railway.

Considering the relationship between transportation parameters and destination mode choices, none of the transportation modes depict a significant relationship with the connectivity parameter. However, a moderate positive correlation was identified between the public transportation mode and connectivity parameter, \((R^2=0.406, p<.01)\). This may be caused by the higher concentration of economic and service potentials for these decidedly connected areas, making these areas major destinations for the public transportation modes. Moreover, the closeness parameter and all the destination modes, (i.e., car \((R^2=0.3803)\), three-wheeler \((R^2=0.4099, p<.01)\) and public transport \((R^2=0.3671, p<.01)\) showed significant positive correlations. This clearly depicts attraction to origin – destination (O-D) trips of all the transportation modes. Meanwhile, the destination of public transportation \((R^2=0.3344, p<.01)\) mode depicts a positive correlation with the betweenness parameter, as it reveals attraction to pass by trips.

Table 7. Summary of Relationship and Coefficient of Determination of Destination Mode Choice vs. Built Environment Factors

<table>
<thead>
<tr>
<th>Built Environment Parameters</th>
<th>Density</th>
<th>Design</th>
<th>Diversity</th>
<th>Road Network Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>Population Density</td>
<td>Employment Density</td>
<td>Junction Density</td>
<td>Street Density</td>
</tr>
<tr>
<td>Car</td>
<td>Linear Negative</td>
<td>Linear Positive</td>
<td>Linear Positive</td>
<td>Logarithmic Negative</td>
</tr>
<tr>
<td>Three-wheelers</td>
<td>Linear Positive</td>
<td>Linear - Negative</td>
<td>Logarithmic Positive</td>
<td>Linear Negative</td>
</tr>
<tr>
<td>Public Transportation</td>
<td>Linear Positive</td>
<td>Linear Positive</td>
<td>Linear Positive</td>
<td>Linear Negative</td>
</tr>
</tbody>
</table>
 Accordingly, none of the route mode choices show a significant relationship with population density, but three-wheelers ($R^2=0.2202$, $p<.01$) and public transport ($R^2=0.2665$, $p<.01$) modes depict a positive correlation with the high population density areas. This clearly signifies the increasing demand for public transportation modes in areas with a high population density. Similarly, employment density also denotes an insignificant relationship with the route mode choice. However, car, motorcycle, three-wheeler, and public transportation route mode choices denote a fairly positive relationship due to the high employment density of these areas.

On the other hand, none of the route mode choices depict a significant correlation with the junction density. Street density received a weekly positive correlation with the car ($R^2=0.2065$, $p<.01$), motorcycle ($R^2=0.3099$, $p<.01$), three-wheeler ($R^2=0.3225$, $p<.01$) and public transportation ($R^2=0.2408$, $p<.01$). This clearly denotes greater transportation mobility potentials for both private and public transportation and is explicit in the three-wheel and motorcycle mode choices.

Meanwhile, landuse density significantly encourages the route choices of car ($R^2=0.4881$), three-wheeler ($R^2=0.3994$, $p<.01$), public transportation ($R^2=0.3773$, $p<.01$) and NMT ($R^2=0.3449$, $p<.01$). This is mainly caused by the diversity of landuse features of the area as it generates multiple route mode choices according to the accessibility of the traveler/passenger. However, it discourages motorcycle route choices ($R^2=0.0048$, $p<.01$) as these choices predominantly occur based on transportation accessibility.

Table 8. Summary of Relationship and Coefficient of Determination of Route Mode Choice vs. Built Environment Factors

<table>
<thead>
<tr>
<th>Built Environment Parameters</th>
<th>Density</th>
<th>Design</th>
<th>Diversity</th>
<th>Road Network Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Populati on Density</td>
<td>Employment Density</td>
<td>Junction Density</td>
<td>Street Density</td>
</tr>
<tr>
<td>Car</td>
<td>Linear Negative - Linear Positive</td>
<td>Linear Negative - Linear Positive</td>
<td>Linear Negative - Linear Positive</td>
<td>Linear Negative - Linear Positive</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.0534$</td>
<td>$R^2 = 0.2472$</td>
<td>$R^2 = 0.2091$</td>
<td>$R^2 = 0.2065$</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>Exponential Negative - Exponential Positive</td>
<td>Linear Positive - Linear Positive</td>
<td>Linear Positive - Linear Positive</td>
<td>Linear Positive - Linear Positive</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.224$</td>
<td>$R^2 = 0.2884$</td>
<td>$R^2 = 0.2148$</td>
<td>$R^2 = 0.3099$</td>
</tr>
<tr>
<td>Three-wheelers</td>
<td>Exponential Positive - Exponential Negative</td>
<td>Linear Positive - Linear Positive</td>
<td>Linear Positive - Linear Positive</td>
<td>Linear Positive - Linear Positive</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.2202$</td>
<td>$R^2 = 0.2992$</td>
<td>$R^2 = 0.24$</td>
<td>$R^2 = 0.3225$</td>
</tr>
<tr>
<td>Public Transportation</td>
<td>Linear Positive - Linear Negative</td>
<td>Linear Positive - Linear Negative</td>
<td>Linear Positive - Linear Negative</td>
<td>Linear Positive - Linear Negative</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.2665$</td>
<td>$R^2 = 0.239$</td>
<td>$R^2 = 0.2318$</td>
<td>$R^2 = 0.2468$</td>
</tr>
<tr>
<td>NMT</td>
<td>Linear Positive - Linear Negative</td>
<td>Linear Positive - Linear Negative</td>
<td>Linear Positive - Linear Negative</td>
<td>Linear Positive - Linear Negative</td>
</tr>
<tr>
<td></td>
<td>$R^2 = 0.2678$</td>
<td>$R^2 = 0.2905$</td>
<td>$R^2 = 0.1923$</td>
<td>$R^2 = 0.2646$</td>
</tr>
</tbody>
</table>
Considering the transport parameter relationship to the route mode choices, the connectivity parameter depicts a very significant correlation with all the considered transportation modes i.e., car ($R^2=0.7281$, $p<.01$), motorcycle ($R^2=0.7364$, $p<.01$), three-wheeler ($R^2=0.7178$, $p<.01$), public transport ($R^2=0.7436$, $p<.01$) and NMT ($R^2=0.7515$, $p<.01$). This clearly indicates that higher connectivity areas have more potential for any transportation mode's route mode choices as they are highly interlinked with other transportation segments.

Closeness parameter also depicts a very significant relationship with route selection. This clearly denotes that transportation route selection decisions are highly influenced by the accessibility of the transportation network. Thus, higher accessible road networks have the potential to be selected by any transportation mode as their route mode choice.

Similarly, the betweenness parameters also denoted a significant relationship with the transportation route selection; i.e., car ($R^2=.7764$, $p<.01$), motorcycle ($R^2=0.6292$, $p<.01$) and public transport ($R^2=0.7646$, $p<.01$). The betweenness parameter usually denotes distinctly connected road segments in the transportation network; thus, it is obvious that any of the transportation modes have potential to select these road segments as their route mode choice, as these road segments consist of the shortest path distance between two identified locations. This is clearly distinguished by the NMT ($R^2=0.8357$, $p<.01$) and three-wheeler ($R^2=0.7662$, $p<.01$) mode choices which usually select the shortest distance for transportation purposes. Thus, it denotes a negative relationship.

Afterwards, the study utilized MLP Analysis to identify the most significant parameters to the choice of mode among all the built environment parameters.

5.2. Multi-Layer Perceptron Analysis

In order to initiate the MLP analysis, first it was required to divide the dataset into two parts as trained dataset and test dataset, as depicted in Table 9. Hidden layers were created for each transportation mode choice according to origin, destination, and route. Afterwards, the model derived highly significant parameters for each transportation mode choice according to the model assigned built environment parameters.

<table>
<thead>
<tr>
<th>Sample</th>
<th>T</th>
<th>N</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Training</td>
<td>210</td>
<td>68.6%</td>
</tr>
<tr>
<td></td>
<td>Testing</td>
<td>96</td>
<td>31.4%</td>
</tr>
<tr>
<td>Valid</td>
<td></td>
<td>306</td>
<td>100.0%</td>
</tr>
<tr>
<td>Excluded</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>307</td>
<td></td>
</tr>
</tbody>
</table>

The MLP model derived highly significant built environment parameters for each selected mode choice according to the origin, destination, and route, which are presented in Table 10.

The study illustrates the most significant parameters for each respective mode choice in Table 10. The results revealed that Street Density, and Connectivity of the transportation system parameters did not significantly impact on the mode choice decisions. However, Population Density, Landuse Diversity and Centrality parameters i.e., CC and BC make a significant impact on all types of transportation mode choices.

6. Conclusion

The main intention of the study was to examine the relationship between the built environment and the mode choice of travelers. In such terms, the study used two
analytical approaches - i.e., Regression analysis and MLP analysis to examine this relationship. Under the Regression analysis, the study detected how each built environment characteristic influenced each mode choice at the origin, the destination and the route. The MLP analysis denotes the most significant among all the built environment factors that can affect the mode choice. According to the results, there is a significant relationship between mode choice and built environment parameters – especially the road network parameters. The key findings of the paper are summarized as follows:

- There is a less significant influence of built environment characteristics on the origin mode choice decisions of all the considered transportation modes. However, some of the transportation origin mode choices such as the three-wheelers, public transportation and NMT, depict a relatively positive relationship with built environment parameters, such as the population density, landuse diversity and the centrality. The study notes that if the area has a high population density, people are inclined to use public transportation and NMT modes significantly for their travel purposes.

In addition, if the number of junctions of the area is high, it may originate more three wheeler rides due to the mobility and convenience of the area. The study also identified that higher street density has the potential to originate more NMT modes, as it encourages walkability and a pedestrian friendly environment.

Table 10. Summary of Significant Parameters for Each Transportation Mode Choice

<table>
<thead>
<tr>
<th>Type of Mode</th>
<th>Mode Choice</th>
<th>Significant Parameter/s</th>
<th>Normalized Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Origin</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td>Population Density</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Junction Density</td>
<td>97.4%</td>
</tr>
<tr>
<td>Motorcycle</td>
<td></td>
<td>Closeness</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Junction Density</td>
<td>99.2%</td>
</tr>
<tr>
<td>Three-Wheelers</td>
<td></td>
<td>Employment Density</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Population Density</td>
<td>90.2%</td>
</tr>
<tr>
<td>Public</td>
<td></td>
<td>Diversity</td>
<td>100.0%</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td>Population Density</td>
<td>93.1%</td>
</tr>
<tr>
<td>NMT</td>
<td></td>
<td>Diversity</td>
<td>100.0%</td>
</tr>
<tr>
<td><strong>Destination</strong></td>
<td>Car</td>
<td>Diversity</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>Three-wheel</td>
<td>Diversity</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>Public Transportation</td>
<td>Population Density</td>
<td>100.0%</td>
</tr>
<tr>
<td><strong>Route</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td>Closeness</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Betweenness</td>
<td>99.0%</td>
</tr>
<tr>
<td>Motorcycle</td>
<td></td>
<td>Closeness</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Betweenness</td>
<td>82.7%</td>
</tr>
<tr>
<td>Three-Wheelers</td>
<td></td>
<td>Betweenness</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Closeness</td>
<td>63.1%</td>
</tr>
<tr>
<td>Public</td>
<td></td>
<td>Closeness</td>
<td>100.0%</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td>Betweenness</td>
<td>72.6%</td>
</tr>
<tr>
<td>NMT</td>
<td></td>
<td>Betweenness</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Note: The Table exclusively depicts the most significant parameters and their normalized importance, thus the least important parameters are not displayed

- It was identified that the Diversity and the Density are influential in attracting more destination mode choices. Thus, if an area has higher land use diversity,
people are likely to use public transportation systems more to reach the area owing to the excessive transportation demand, traffic congestion and convenience. Therefore, diversity and public transportation has a high linear positive relationship. It seems to have discouraged car users of the area. In addition to that, the population density and attraction to public transportation depicts a linear positive relationship. Thus, if the area has a high population density, people tend to use public transportation and three wheelers significantly, to reach their destination.

The study recognized road network parameters, derived through the NCA approach, and that depict significant influence on the route mode choice. Thus, the closeness parameter portrays a positive relationship with the route choices of car, motorcycle, three-wheel, public transport and NMT. This clearly depicts that all route choices are extremely sensitive to the accessibility of the transportation system, as with higher accessibility, the potential is more for any transportation mode choice. However, the betweenness parameter received a negative relationship on the three-wheeler and NMT mode choices as the higher intervening road segments (i.e., arterial roads) discourage pedestrians and short distance travel trips.

The study identified that NCA approach derived road network parameters denote a significant relationship with the mode choice of travelers. This clearly distinguishes that the mode choice decision are made not only by considering the built form parameters, but it is also impacted by the topological and geometric characteristics of the transportation system. Therefore, it is equally important to consider both built-form and road network characteristics when evaluating travelers’ behavior on the transportation system. On the other hand, closeness and betweenness centrality parameters denote that mode choice decisions are significantly impacted by the accessibility and shortest path road segments which highly intervene in-between the origin-destination trips.

Meanwhile, the origin of public transportation modes depicts a linear positive relationship with the betweenness parameter as the corresponding transportation mode is profoundly dependent on passing by road segments. As an example, public transportation usually follows the shortest road segment between two identified locations (i.e., these road segments denote the major arteries). Thus, it can provide a convenient service by covering the road segments that are highly utilized for various travel trips. Moreover, the closeness parameter and the destination mode of public transport have significant positive relationships. This clearly depicts the origin-to-destination (O-D) trips of all the transportation modes. This is essential finding for the future transportation development purposes.

In the urban planning and transportation planning context, understanding of built environment parameters and their influence on the transportation mode choice renders vital knowledge in many aspects. It helps increase the integration of both subjects and effects to better transportation management, landuse planning, and policy formulation. Moreover, the study highlights the significant parameters that affect each mode choice decision, which
helps to enhance the transportation accessibility and promotes specific transportation modes. For instance, The study denotes that if the area has a high population density, people are inclined to use public transportation and NMT modes significantly for their travel purposes, thus improving the walkability and public transportation services would be an ideal solution for such areas. Also, it helps transport and urban planners to identify the potential mode choices that are particularly attractive with the area-specific built environment characteristics.

The study was predominantly based on secondary data to identify mode choices and hence all the transportation modes are not consistently included in every mode choice category. The study used zone-wise route selection data, owing to the availability, but the result would have been precised if the road segment-wise data had been collected. On the other hand, since the study mainly focused on examining the relationship between the built environment characteristics and transport mode choices, this study did not consider the influence of socio-economic factors such as the household income, age, and the education level; and other critical parameters of mode choice such as travel time differential and quality of service, regardless of their significant influence on the mode choice decisions.

Finally, the proposed methodology needs to be tested for its validity by applying it in different urban areas, which is left for future researchers.

References


