Street Network Morphology and Active Mobility to School; Applying Space Syntax Methodology

ABSTRACT

Previous research has found that built environment features (e.g. density, diversity and design) influence children's mode of transportation choice during school excursions. However, little is known about how and to what extent neighbourhood morphology impacts students' commuting patterns. We studied the commuting patterns of children from 18 primary schools in three distinct urban fabric zones (inner, middle, and outer) in Shiraz, Iran. Parents with children in grades 1–6 (n=1503) were chosen to report on their children's school journey diaries. To examine road network layout, five well-known indices based on the Space Syntax methodology were used: Connectivity, Integration, Control, Intelligibility, and Choice. In order to select a local catchment area for each individual student, an inventory GIS model was created. Intelligibility and Integration are found to have a positive association with students' walking distances of 400 and 800 metres among local morphological elements. Students are more likely to stroll when the space's readability, continuity, and coherence improve. Control and Choice, on the other hand, had a detrimental influence on the walking of students.

Key Words: Commuting to School; Active Travel; Walking; Local Morphology; Space Syntax.

1. Background

Many research studies have found that students are increasingly using motorised modes of transport to travel to and from school, rather than traveling by foot or cycling (Sener et al., 2019; Smith et al., 2018; Schlossberg et al. 2006; Duggan et al., 2018). Motivating students and their families to reverse this decline could improve children's well-being (Buttazzoni, Coen, et al., 2018). There have been several studies on the health-related impacts of active commuting on students' physical and mental well-being and fitness (e.g., Chapman et al., 2018; Stark et al., 2018). Physical activity such as walking to school can reduce obesity and overweight (Özbil, Yeşiltepe, et al., 2020) and the chronic diseases associated with it. Accordingly, the benefits of walking to school are significant and widely accepted across the globe.

A growing body of literature examines the relationship between the built environment, socioeconomic characteristics, and school students' commuting patterns (See Pocock et al., 2019; Scheiner et al., 2019). Our study categorizes the determinants of active commuting in school trips into two groups: (1) Non-physical factors (e.g., socio-economic characteristics) and (2) Physical factors (i.e., built-environment characteristics). We aim to synthesize the association between these factors and active commuting to school in this section.

Demographic, social, and economic factors play an important role in facilitating student walk-to-school habits. Students' age and gender are two major determinants of active travel to school. Researchers reported that by the time children reach the age of 14, they achieve a higher level of independence in mobility behaviour (Ikeda et al., 2018) , including walking to school. Additionally, as children grow, their tendency to walk or cycle will increase (Helbich et al., 2016; Wang et al., 2022; Dias et al., 2022Nonetheless, some research has found age to be inversely correlated with children's propensity to walk(E. J. Wilson et al., 2010), and some have found no significant association between age and mode choice of school commuting (e.g., Chen et al., 2018). Some studies have shown that boys are more likely to walk to school (; McDonald, 2008; Soltani & Zamiri, 2011). A New Zealand health survey conducted in 2014-15 revealed that the share of boys walking to school was higher (47%) than the share of girls (41%) (Health, 2015), confirming that boys have more freedom, which leads to more active travel (Murray, 2009). On the other hand, some research has found that girls are more likely to walk to school than boys (Ermagun & Samimi, 2018), while other studies found no association (e.g., Frater et al., 2017).

Several studies have found statistically significant relationships between family's vehicle ownership and the share of children walking to school (e.g., Larsen et al., 2018; Mehdizadeh et al., 2017; Peponis et al., 2007; Stark et al., 2018), while others found no significant association (Schlossberg et al., 2006). There is a correlation between the increased ownership of cars in the family and lower active travel rates in children (Børrestad et al., 2011). The number of children in the household was also found to be associated with the likelihood of active travel among students (Bödeker et al., 2018). When compared with students with no siblings, those with one sibling were less likely to travel actively to school. However, having more children in the household showed no association with school attendance (Ikeda et al., 2018). According to some researchers, there is a direct relationship between the educational level of the parents and the level of walking their children do to school (Rodrigues et al., 2018; DeWeese et al., 2022), although in other studies, no relation was found between the parents' education level and a student's commuting pattern (Fyhri & Hjorthol, 2009).

Furthermore, parents' employment status was discussed as a probable factor affecting students' commute patterns. In comparison to students whose mothers worked full-time, those with part-time jobs were less likely to actively travel to school (Buliung et al., 2017). Some studies suggest that parents with more flexible work schedules encouraged their children to walk to/from school (He & Giuliano, 2015; Sener et al., 2019). According to Larsen et al. (2018), students are driven to school by their mothers if they possess a driving license; meanwhile, fathers with more commitments to their jobs are less likely to drive their children to school (Yarlagadda & Srinivasan, 2008). A number of related studies have found that students living in higher income households are less likely to participate in active travel to school (Ermagun & Samimi, 2018; He & Giuliano, 2015; S. Li & Zhao, 2015; Mitra et al., 2010; Rothman et al., 2018). Conversely, Chen et al. (2018) found no significant correlation between household income and students' walkability. Additionally, some wealthy households or those wishing to send their children to religious, special needs, or elitist schools have to travel far to attend these schools. Specialized schools are seldom found within a locality.

Among several studies, the physical distance between residence and school was found to have a clear and strong correlation with active traveling to school (Javadpoor & Soltani, 2021; Chica-Olmo et al., 2018; Hatamzadeh et al., 2017; Mehdizadeh et al., 2018, 2019; Mehdizadeh & Ermagun, 2018; Mehdizadeh & Mamdoohi, 2020; Rothman et al., 2018; Dias et al., 2022, DeWeese et al., 2022). Studies have found that distance affects the frequency of walking or cycling to school inversely; hence, as the distance between a student's home and school decreases, the likelihood of active travel increases. Distance also correlated with independent travel, as students who need shorter commuting paths are more likely to actively travel to school without requiring supervision from their parents (Larsen et al., 2016). In some studies, the distance ranges from 250 to 1000 metres, which seems suitable as a convenient walking distance for primary school students (e.g., Rodrguez-López et al., 2017; Yang et al., 2016). In addition, several studies examined how walking distance impacts willingness to walk. Reducing commuting distance by 1 km increased walking odds by 0.7 times (Mitra et al., 2010). The perceived walking time to school among students is also shown to influence their tendency to undertake active travel. In a survey, Mehdizadeh et al. (2017) determined that 10 minutes is its threshold.

There are studies that suggest that a more connected local street network may be more supportive of children walking/cycling (Helbich et al., 2016). As a result, more connected streets usually offer more options for routes, therefore, it is more likely to encourage diverse age groups, including children, to walk/cycle to school if it's located just within a reasonable distance (say less than 400 metres)(Javadpoor & Soltani, 2021). In the existing literature, there are relatively few studies that investigate the correlation between street network layout and the travel behavior of children (Lee et al., 2017), in particular, the literature on the potential effect of street spatial form and local morphology represented by space syntax indices on the school students' travel is extremely limited (Ozbil Torun, Göçer, et al., 2020). The two space syntax indices that Ozbil et al. (2016) and (2020b) studied in their research were Integration and Choice, which influenced walking levels negatively or positively, respectively.

According to local morphology, walkable neighbourhoods can promote residents' active commuting, especially for short distances (Mitra & Buliung, 2012). A street network's overall layout and structure that provides route selection (Ozbil et al., 2016), street connectivity (for example, Chen et al., 2018), intersection density (Peiravian et al., 2014), and location of a residential area in relation to a destination (Wilson et al., 2018) all have an impact on citizens' movement patterns. Researchers have looked at the physical structure of street networks to define walk trips in a neighbourhood by creating a distinctive pattern of a grid, which appears to affect residents' walking preferences (Haq & Berhie, 2018; Lage Alvim Serra & Hillier, 2017).

According to what has been reviewed, the conceptual model of this study analyses two main categories of variables:

A) Students' personal characteristics, such as age, gender, number of children, household vehicle ownership, driving license, parents' educational status, and income of the parents; and

B) Morphological factors, including the distance between the school and each student's home, space syntax indices (connectivity, integration, control, intelligibility, and choice) and ped-shed analysis methods in 400- and 800-metre buffers around each student's home. Figure 1 shows a conceptual diagram of the research.

Figure 1. Conceptual model

This study adds to the body of knowledge by exploring the association between neighbourhood morphological features and children's active commuting patterns during school journeys. The novelty of this paper is in developing s a GIS inventory model to determine neighbourhood catchment for each individual student based on his or her home address. Unlike previous studies that assumed students in the same neighbourhood were assigned the same physical characteristics of the neighbourhood (density, diversity, network design, etc.), this study defines a unique neighbourhood for each student with characteristics that differ from those of the other students. In other words, rather than the aggregated (zonal-based) method used in previous studies, the space syntax indices were quantified using a disaggregated (individual-based) method. Furthermore, we compared space syntax indices in 400 and 800 m buffers surrounding each student's dwelling location to examine the impact of proximity on school commuting habits.

The rest of the paper is arranged as follows: Section 2 introduces the study area, the survey design, and the questionnaires used to collect the data. In Section 3, we present the results of the random-utility choice model. At the end of the paper, a discussion of the results, research limitations, and the conclusion is presented.

2. Methods and Materials

2.1. Sampling

Located in the south of Iran, Shiraz metropolitan region has an area of 240 square kilometres and a population density of 8,240 population per square kilometre (The Statistical Center of Iran, 2016). Because of its relatively flat topography, temperate climate and relatively crime-free neighbourhoods, Shiraz, is considered to have great potential for active commuting by students. The region has 155,920 primary students, out of which 128,884 attend 422 public schools and 27,036, attend 197 private schools (Shiraz Municipality, 2016). Local reports indicate that the percentage of active travel in this city is low (TTRC, 2016). The use of personal cars is remarkably high, even among the elderly in this city (Soltani et al., 2018). The "Household Travel Survey" (2016) indicated that about 80 percent of trips in Shiraz are by personal vehicle or fixed car/bus service, indicative of Shiraz's high level of car dependence (TTRC, 2016).

In this study, we selected 18 schools with 1,503 students in three specific urban settings (inner: zone A, middle: zone B, and outer: zone C) (Figure 2). A summary of the selected schools appears in Table 1. The study was based on data collected by the authors in November 2019 from 1503 students. The study's statistical population consisted of students in the first to sixth grades (ages 7- 13 years) of public schools (boys and girls) in Shiraz. First, schools were randomly selected from all three urban fabrics (With different network density and street network configuration) of Shiraz and then the students were randomly selected in each school. Two thousand sixty-four questionnaires were distributed to 18 public schools for boys and girls. A total of 1,736 questionnaires (66% return rate) were returned, of which 1,503 were valid for analysis.

Figure 2. Locations of the 18 school sites across three urban fabrics of Shiraz

Table 1. Summary of selected school's general characteristics

2.2. Questionnaire survey

The questionnaire was divided into three sections: the first requested information about the student as well as their address. The student's parent was asked seven questions in the second part of the questionnaire about their job status (inflexible or flexible), their level of education (illiterate, primary, secondary, and academic), the number of children in their household (one, two, three, or more), the number of cars owned by the household (zero, one, two, three, or more cars), and the number of people who hold driving licenses (one, two, three or more people). A third element of the survey recorded commuting patterns by asking parents, "What mode of transportation do you generally choose for your kid on school trips?" Parents choose their child's travel patterns through active travel: walking, cycling or non-active travel: carpooling, public transportation, school service, private cars, etc. We merged cycling and walking for the concept of active travel because cycling has a relatively low percentage (5%).

2.3. Measuring local morphology

2.3.1. Space Syntax metrics

Space syntax is proposed as a computational language for displaying, quantifying, and describing the spatial geometry and configuration of street networks, as well as comprehending the relationships between spaces and people (Hillier & Hanson, 1989). This notion associates space with unique social dialectics that impact human behaviours, such as travelling from A to B (Hillier & Hanson, 1989). Space syntax indices, as opposed to basic network measurement indices such as intersection density, measure the topological aspects of the street network, such as the direction and number of turns while going from one location to another (Koohsari et al., 2019). The space syntax technique is implemented using two different types of representation: axial analysis and segment analysis. The axial approach considers the longest and shortest lines of sight of people moving through a defined urban space that completely covers that environment (Koohsari, Oka, et al., 2019), whereas the segment approach considers segments formed by dividing the axial lines at intersections into smaller sections (Sharmin et al., 2020). In this study, the UCL Depthmap 10.0 Software was used to extract five space syntax parameters: Connectivity, Integration (R3), Choice (R3), Control, and Intelligibility. We then used Esri ArcGIS 10.5 to determine the averages of each of these variables within a radius of 400m and 800m next to the student's residence. Appendix 1 contains information on the five metrics and how they are measured.

2.3.2. Ped-shed

A Ped-shed, also known as a walkable catchment, is the area of the walking network in relation to the potential area contained within a set buffer based on Euclidean distance (Giles-Corti et al., 2011). It is widely used to describe and characterise the area that is accessible across a roadway network as a proportion of the total area in order to quantify accessibility (Kim et al., 2020), which is computed as follows.

$$Pedshed = (Network\ bufer\ area\ /\ Euclidean\ bufer\ area) \times 100$$

The Ped-shed scale ranges from 0 to 100, with the higher the value, the more walkable the environment. For this study, the ped-shed catchment area was measured using ArcGIS Network Analyst and walking catchment areas were calculated for radii of 400 and 800 metres (5 and 10 minutes) around students' homes.

2.3.3. Distance between home and school

According to Rodrguez-López et al. (2017), the physical distance between home and school is possibly the most crucial component explaining children's proclivity to travel. In this study, the children' parents were requested to provide the exact location of their living locations. The location was determined on the GIS map, and the distance from the student's home to the school was calculated. In ArcGIS, two models were created for each student (see Appendix 2 for the script and more information). Three example students were tested for connection, local integration, local choice, and Ped-shed for radii of 400 and 800 metres, as shown in

Figure 3. A background study (Curtis et al., 2015) explains the rationale behind choosing the radii of 400 and 800 metres.

Figure 3. The street network configuration and Ped-shed analysis of the environment around the home (800 m) of three sample students

2.4. Model specification

A discrete choice model can be used to predict an individual's choice based on perceived benefits (utility) (Ben-Akiva et al., 1985). For the purpose of this paper, which examines commuting by walking or non-walking, binary logit discrete choice models are developed to estimate utility values. Mathematically, for the n-th student, i and j are the two options (Active mode; Non-Active mode) in the choice set:

$$U_{in} = V_{in} + \varepsilon_{in} \quad (1)$$

Where, U_{in} is the utility of the choice i to the $n-th$ student; V_{in} is the observable share of the utility generated by the mix of physical and non-physical variables as explained before. $\varepsilon_{in}$the error term of the portion of the utility not measurable.

$$V_{in} = (X_i, SS_n, SE) \quad (2)$$

Where, X_i is the share of utility associated with the attributes of choice i; SS_n – the share of utility associated with local morphology of the $n-th$ student; and SS_n – the portion of utility associated with socio-economic features of the $n-th$ student.

Based on the random utility maximization theory, the trip-maker selects the alternative i if, and only if $U_{in} > U_{nj}\ \forall\ j\ \_ =\ i$. The likelihood that the $n-th$ student select choice (P_{in}) is presented as follows:

$$P_{in} = \frac{1}{1+e^{-v_n}} = \frac{e^{v_{in}}}{e^{v_{in}} + e^{v_{jn}}} \quad (3)$$

The binary logit model applied for the model estimation can have the following form: School commuting choice = f(x):

$$P_{in} = \frac{1}{1+e^{-\beta X}} \quad (4)$$

By applying (ln) function on both sides of the equation:

$$\ln\frac{f(x)}{1-f(x)} = \beta X = \beta_0 + \beta_1 x_1 + \cdots + \beta_m x_m \quad (5)$$

$$\frac{f(x)}{1-f(x)} = e^{\beta X} \quad (6)$$

Where: X is the vector of chosen independent variables, β_0 is regarded as the constant and $\beta_1, \beta_2, \ldots, \beta_m$ are the coefficients of the explanatory factors.

For fitting purposes, the method of maximum likelihood (MLL) estimation is used. This method comprises selecting values for the coefficients to maximize the probability that the model forecasts the same alternatives selected by the sample students. This approach produces vastly precise estimations.

3. Results

3.1. Descriptive statistics

Table 2 shows the variables utilised in the model. A total of 1,503 pupils were chosen from 18 public elementary schools, with 822 girls (54.7 percent) and 681 boys (45.3 percent). 47.6 percent walked to school, 40.1 percent took public transportation, and 11.6 percent drove to school in a private automobile (Fig 5). The students' average age was 9.92. The majority of mothers (87.8 percent) were able to work flexible hours, whereas barely half of fathers (48.8 percent) were able to do so. Nearly half of the fathers and half of the mothers had no formal schooling. Only 18% of homes had a single kid, while 81% had two or more children. A car is owned by 61 percent of households, whereas 30 percent do not. In nearly 81.3 percent of homes, at least one licensed driver was present, while 18.3 percent did not.

Students walked an average of 602 metres to school, whereas students who used motorised means travelled an average of 2,227 metres (Figure 4). Furthermore, descriptive statistics show that 27.9 percent of pupils reside fewer than 400 metres from their schools and 26.8 percent dwell between 400 and 800 metres.

Figure 4. Space Syntax for each individual students' location of residence

Two different buffer sizes were employed in this study to evaluate and quantify the local morphology around the student's dwelling (400 and 800 metres buffers). Table 2 describes the local morphological characteristics within a radius of 400 to 800 metres. Figure 5-a clearly shows gender disparities in modal choice. According to Figure 5-b, while the majority of individuals within 400 metres of the school decided to walk, the percentage of active travel dropped drastically after the distance crossed 800 metres.

Figure 5. a) Students' modal choice by gender; b) students' modal choice by distance travelled

Table 2. Non-physical and physical variables used in the study

3.2. Modelling results

The estimated model's findings are shown in Table 3. To investigate the relative importance of morphological factors in explaining differences in active travel mode choice, we developed two binary logit models for the radius 400 and 800 metres around the home. The independent factors explain 59.2 percent and 60.7 percent of the variation with the dependent variable in both models. Furthermore, it was discovered that over 83 percent (total percentage) of the predictions produced by the models were correct. Modelling revealed that a student's choice of walking to and from school was related to local morphology. Furthermore, local morphological factors within 400 metres of the student's home were more likely to be associated with school commuting than the 800 metres buffer.

Table 3. Logistic regression estimation results with walking independent as the dependent variable

Students' ages and their preference for active transportation (walking) to school were positively connected; girls were less eager to walk to/from school than boys. There is a link between the number of children in a home and the possibility that youngsters may walk to and from school. As household wealth, automobile ownership, and the number of drivers in the home grew, so did the likelihood of walking.

Space syntactic metrics were connected with students' journey to and from school. Furthermore, we discovered that space syntactic factors with a radius of 400 and 800 metres showed varied relationships with students' commuting times. In both models, there was a clear association between Integration (R3) and walking to and from school. The findings of the odd ratio (EXP(B)) indicated that a rise in Integration (R3) increased the chance of choosing walk mode by 1.348 in the radius of 400 metres, and by 1.378 in the radius of 800 metres, ceteris paribus.

Choice (R3) had a negative connection with commuting to school. For every unit increase in the Choice, the probabilities of walking to school reduced by 1.274 (for a radius of 400m) and 1.695 (for a radius of 800m) (R3). The chance of a student walking from school to home reduced by 1.218 every unit increase in Control in the 400m radius around their dwelling, assuming all other factors remained constant. Within an 800-metre radius, there was no significant link between Control and student travelling to school. The chance of walking to/from school (between 400 and 800 metres of the student's house) was positively connected with intelligence. An increase of one unit in Intelligibility raised the chance of walking by 1.246 and 1.409 in the neighbourhood of 400 and 800 metres around the student house, respectively.

In this study, there was a significant relationship between the distance between home and school and active travel to school, i.e., the distance between home and school was negatively correlated with active travel to school. A one-unit increase in Distance value reduced the number of pupils walking by around 2.38 and 2.47 in the neighbourhood of 400 and 800 metres, respectively. In this model, students' commuting to school was not significantly associated with the Connectivity and Ped-shed variables.

4. Discussion

Active travel to school is connected to local morphological variables such as Integration (R3), Choice (3), Control, and Intelligibility. In contrast, it was determined that student walking was more likely related to the topography of the city at the local level (a radius of 800 metres). As illustrated in Figure 7, increasing space syntax has a major effect on active commuting. In the radius of 800 metres, the extent of change of local morphological variables is larger than in the radius of 400 metres. Due to their near proximity to their site of residence, parents and pupils may obtain a more comprehensive awareness of the environment within a radius of less than 400 metres, which lessens the influence of morphological factors on the way children commute to school (walking). As a result, the street network architecture has less of an impact on how pupils commute to school. The findings corroborate those of Ozbil, Göçer, et al., (2020), who investigated the impact of local integration, as well as those of Helbich et al., (2016) and Ozbil et al., (2016), who investigated the impact of local integration and global choice on children's choice to walk to and from school. Furthermore, this study develops parents' choices of children walking between home and school by emphasising indicators of local urban morphology (integration and choice with three changes of direction) as well as other indicators, such as connectivity, control, and intelligence, and how urban morphology is related in modal choice to and from school in a radius of 400 and 800 metres around the place of residence.

Students that reside in high-integration areas (R3) are more inclined to walk, according to our research. The findings support the natural movement theory (Hillier, 1996), which claims that the more interconnected the streets are, the more probable they are to be more accessible from adjacent streets, attracting more people (Hillier & Hanson, 1989). With fewer disconnected streets, there are more opportunities for interaction and students to meet their classmates on their way to school, which encourages them to walk as their preferred mode of transportation (Giles-Corti et al., 2011). Nevertheless, certain research, such as the one done by Helbich et al., (2016), have suggested that global integration within a 100 metres radius around kids' journeys between home and school negatively affects students' walking. As a result, the idea of natural movement may be said to be more closely followed by the theory of local connection and coherence. Conversely, the high degree of integration, or the overall cohesiveness of the city, indicates the significant importance of that space in the spatial hierarchy and ossification of the city, which, in turn, can increase the movement of motorised vehicles and the presence of strangers in the space, causing parents to be concerned about the security of their children while commuting to school. In contrast, Ozbil et al. (2016) said that there is no significant link revealed between global integration and children's walking between school and home within an 800 metres radius of the school. However, in order to get more notable outcomes, additional study on local and global Integrations is required.

Unlike Ozbil et al., (2016) and Helbich et al., (2016), who found that increasing global choice increased the chance of a kid walking to school, this study found that increasing local choice (R3) decreased the likelihood of pupils travelling to/from school. If the capacity for movement in space is expanded, this may improve the movement of motorised vehicles in such settings, in addition to the potential for route selection for walking. As a result, the great possibility for mobility in the vicinity of a student's residence may enhance the chance of students using that space to travel. Because of the increased risk of a traffic accident, such areas may reduce parents' preference for walking over motorised modes. Furthermore, this study discovered that increasing the movement potential of space within a radius of 800 metres had a bigger influence on a child's capacity to walk than increasing the movement potential of space within a radius of 400 metres. Active commuting increases by 1.3 when

Choice is increased in a radius of 400 metres, and by 1.7 when Choice is increased in a radius of 800 metres (Fig. 6).

It was discovered that at a radius of 400 metres, the higher the control space near a student's residence (the more links in the neighbourhood), the less likely the student was to walk to/from school. According to Koohsari et al., (2012), increased control over open areas and their surrounds reduces the chance that individuals may walk for leisure. In other words, a higher access might make it easier for automobiles to be present in a location. When determining whether to allow their children to utilise such areas, parents may consider safety concerns, making them less likely to let their children to walk to school. Students with higher intellect levels are also more inclined to walk. As a consequence, neighbourhoods with higher intelligibility simplify navigation in local urban areas, making it simpler to grasp and support efficient and direct movements. Therefore, the surroundings will become more readable, and eventually, the sense of direction will improve, perhaps leading to more active school travel. In contrast to our findings, Lamquiz and López-Domnguez (2015) discovered that Intelligibility was adversely connected with the walking preference of Madrid inhabitants. Moreover, our study indicated that the integration (R3), choice (R3), and intelligence of the street network in the radius of 800 metres of students' houses was related with better walking between home and school.

Figure 6. The extent of active commuting change by increasing local morphological factors in a radius of 400 (blue) and 800 metres (red) around the student's residence.

Distance was the most sensitive of the research factors. According to the research, kids who live further away from their school are less likely to actively commute to school (e.g., Chica-Olmo et al., 2018; Ermagun & Samimi, 2018; Rodr*guez-López et al., 2017; Rothman et al., 2018; Yang et al., 2016). Because of the small distance between a student's home and school, less parental supervision was necessary, which increased the possibility of pupils walking to school. According to Ikeda et al., (2018) and Helbich et al., (2016), older kids are more likely than younger students to walk to and from school. According to the survey, females were less likely than boys to actively commute to school, which is likely related to parental worries about female students' safety and security (e.g., Fyhri & Hjorthol, 2009; Health, 2015; Larsen et al., 2012). Furthermore, the number of school students in a household was found to be directly related to the number of school walks (Bödeker et al., 2018; Ikeda et al., 2018). This could be attributed to the increased sense of safety that parents have when their children travel in a group, as well as the ability to gain satisfaction from accompanying their siblings on the school route as a motivation to walk farther.

A substantial link was discovered between home income and the number of students who walked. Similarly to earlier research (Ermagun & Samimi, 2018; S. Li & Zhao, 2015; Rothman et al., 2018; Sener et al., 2019), our findings revealed that a greater household income reduced the chance of walking. There appears to be a rationale for this: as money rises, so does the possibility of a household owning/using a private automobile and accessing school services, but low-income families have few low-cost choices, such as walking to school. Many rich families send their children to specialised schools that are located in remote areas, necessitating the usage of their parents' automobiles to get there. In our research, we discovered that as the number of cars in a home increased, the likelihood of active commuting to school declined (in line with Ermagun & Samimi, 2018; Larsen et al., 2018; Mehdizadeh et al., 2017; Stark et al., 2018). Finally, the findings demonstrated a negative association between the frequency of drivers in the home and children' school commuting (Larsen et al., 2018; Yarlagadda & Srinivasan, 2008).

5. Conclusion

The present research contributes to the literature of active travel (walking to school), and the associations that exist between walking to school and local morphology (street network configuration). In this study, the association between street network configuration and Ped-shed with students walking to school from 18 primary schools in Shiraz, Iran was analysed.

The use of axial street connection measurements through space syntax approach distinguishes this study from others. Unlike many previous studies that grouped the sample students' population into fewer clusters, this study defines the neighbourhood as the catchment area of each student's residence in order to conduct a fine-grained analysis of the urban fabric. Unlike other studies, which code residential addresses at a greater geographical scale (e.g., the nearest street intersection to the child's real residence location or census tracts), this research provides a more detailed measurement of local morphology.

The local morphological variables around the student's house, Integration and Intelligibility, show direct and substantial relationships with pupils walking to school, but Control and Local Choice indicators have a negative association. Integration (R3), Choice (R3), and Intelligibility (R3) were all effective predictors of modal choice for commuting within 400 and 800 metres of a student's house, respectively, but Control only predicted modal choice within 400 metres. There was a discovery that local morphological factors within a 400 metres radius have less effect on children's walking than factors within an 800 metres radius; or, to put it another way, parents and students have a better understanding of their 400 metres environment, which outweighs the access potential of an urban street network. Despite this, it appears that within an 800 metres radius, urban layout characteristics have more influence over a child's commuting to school; however, more research is needed to prove this. Greater cohesiveness and connectedness among routes, as well as intelligibility of the region around a student's accommodation, according to our findings, may affect their decision to walk more frequently. Areas with a greater desire and mobility potential, on the other hand, may improve the accessibility of automobiles to spaces, which then diminishes the impression of safety, resulting in a decreased inclination to walk.

We were unable to ascertain the prevalent pattern of travel for older children with more freedom of movement since the questionnaire was completed by the parents of elementary pupils. Another constraint was the absence of reliable information on the child's walking path from home to school, as well as the quality and breadth of sidewalks and walkways near the student's dwelling. Future study can investigate the causes for the negative correlation between control and selection by including data on the traffic volume of the streets surrounding the student's residence into the space syntax technique. As a result, it is suggested, in addition to measuring and assessing these factors' impact on student commuting to school, environmental characteristics and the design quality of routes leading to school be considered as another factor affecting active travel that should be assessed and analysed.

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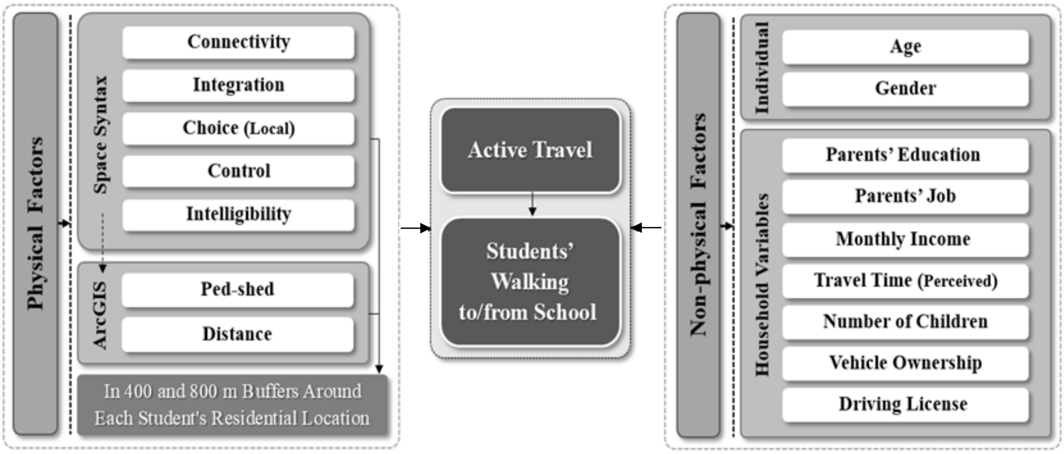


Figure 1. Conceptual model of research

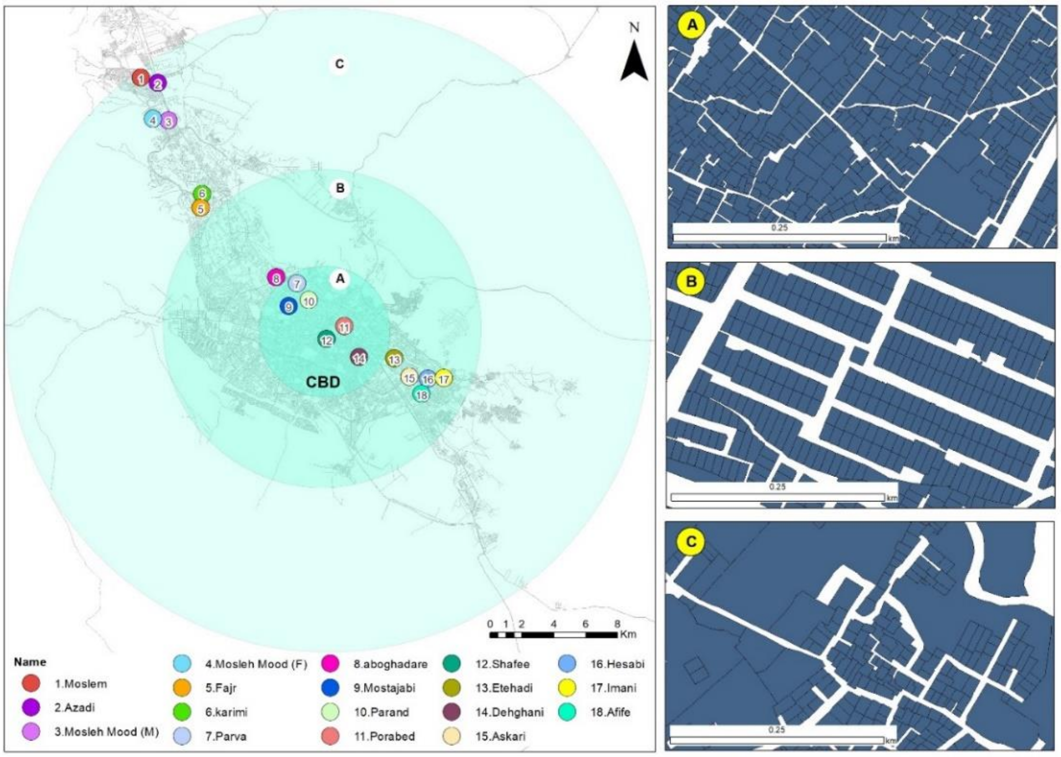


Figure 2. Locations of the 18 school sites across three urban fabrics of Shiraz

Table 1. Summary of selected school's general characteristics

School Zone Number	Zone	Name of School	Gender of Students	Number of Students	Response Rate (%)
1	C	Moslem	M	330	43.1
2	C	Azadi	F	395	57.5
3	C	Mosleh Mood (M)	M	492	37.8
4	C	Mosleh Mood (F)	F	407	47.2
5	C	Fajr	M	581	46.1
6	C	Karimi	F	349	48.1
7	A	Parva	M	434	36.7
8	B	Aboghada	F	519	48.3
9	A	Mostajabi	M	416	25.8
10	A	Parand	F	438	35.0
11	A	Porabed	M	333	65.6
12	A	Shafee	F	373	86.3
13	B	Etehadi	M	658	63.3
14	A	Dehghani	F	194	82.5
15	B	Askari	M	271	56.2
16	B	Hesabi	F	596	28.3
17	B	Imani	M	367	30.6
18	B	Afifeh	F	339	60.6

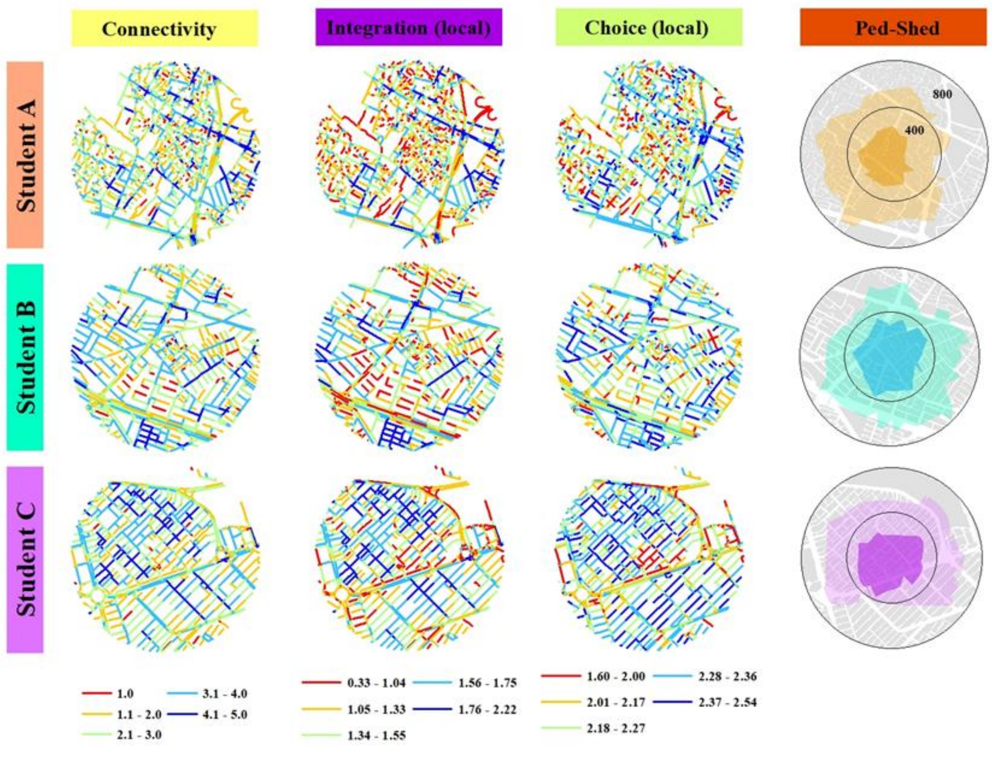


Figure 3. The street network configuration and Ped-shed analysis of the environment around the home (800 m) of three sample students

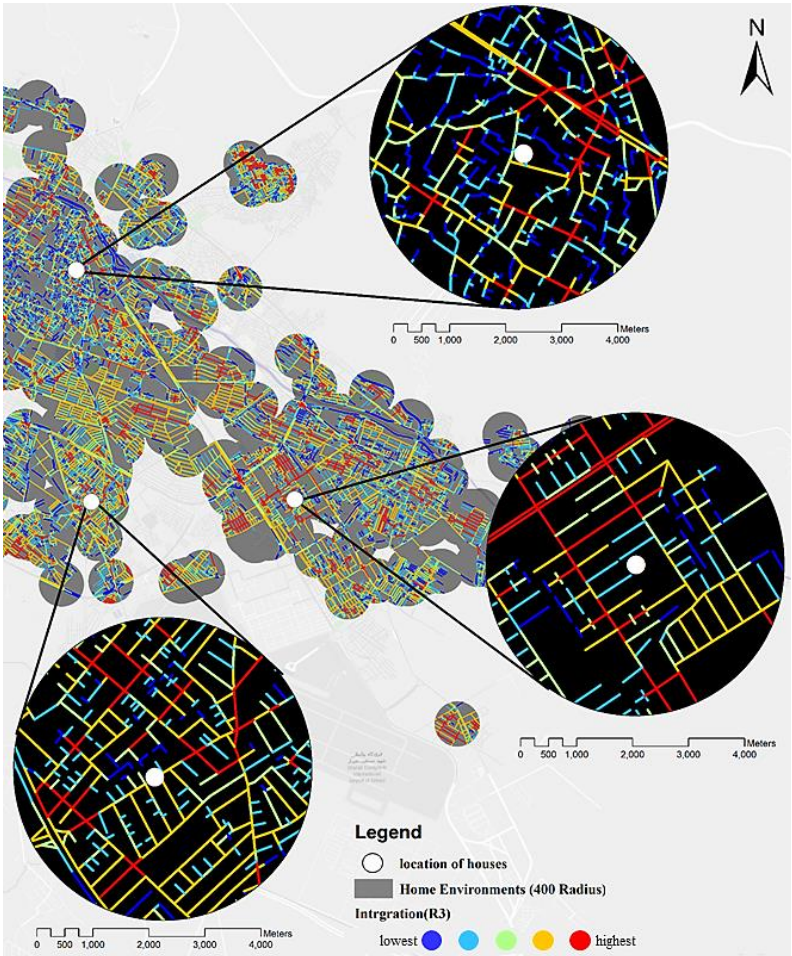


Figure 4. Space Syntax for each individual students' location of residence

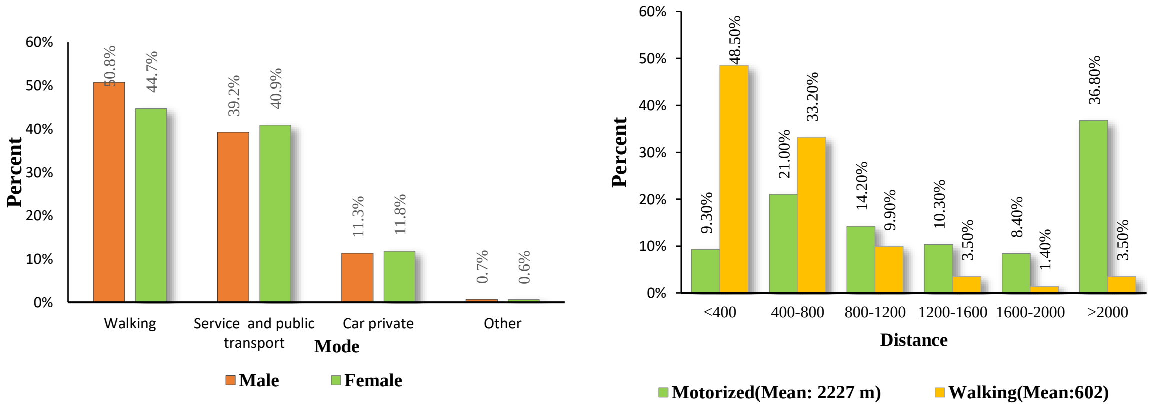


Figure 5. a) Students' modal choice by gender; b) students' modal choice by distance travelled

Table 2. Non-physical and physical variables used in the study

Variable	Frequency (%)	Variable	Frequency (%)
Mode to school, Mean (SD)	0.48 (SD: 0.5)	**Number of children in household**	2.13 (SD: 0.69)
Active Travel(walking)	47.6%	1	18%
Motorized Travel	52.4%	2	50.9%
Age, Mean (SD)	9.92 (SD: 1.75)	3≤	31.1%
7	13.1%	**Income**	1.81 (SD: 0.43)
8	10.9%	≤595$	20.8%
9	13.6%	595-1190	77.8%
10	21.6%	1190$≤	1.4%
11	19.8%	**Number of cars in household**	1.78 (SD: 0.59)
12	15.6%	0	30.2%
13	5.4%	1	61.9%
Gender	1.55 (SD: 0.5)	2	7.4%
male	45.3%	3≤	0.5%
female	54.7%	**Number of driving license holders in household**	2.38 (SD: 0.85)
Father job	0.5 (SD: 0.5)	0	18.4%
inflexible	49.8%	1	30.7%
flexible	50.2%	2	45.1%
Mather job	0.88 (SD: 0.32)	3≤	5.8%
inflexible	11.7%	**Perceived time between home and school**	2.6 (SD: 1.09)
flexible	88.3%	5	18.8%
Father education level	2.71 (SD: 0.88)	5-10	26.8%
illiterate	9%	10-15	34.3%
primary	30.7%	15-20	15.9%
secondary	40.9%	20≤	4.1%
academic	19.4%	**Distance**	2.97 (SD: 1.88)
Mather education level	2.7 (SD: 0.87)	<400	27.9%
illiterate	10.5%	400-800	26.8%
primary	25.9%	800-1200	12.2%
secondary	46.9%	1200-1600	7.1%
academic	16.8%	1600-2000	5.1%
		2000≤	21%

	Radius 400 meter				Radius 800 meter			
	Minimum	**Maximum**	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**	**Mean**	**Standard Deviation**
Connectivity	2.54	4.37	3.17	0.247	2.5	3.64	3.12	0.18
Integration (R3)	1.10	1.80	1.36	0.10	1.08	1.54	1.35	0.07
Choice (R3)	9.75	33.31	18.89	3.338	10.1	25.26	18.34	2.25
Control	0.98	1.02	1.00	0.01	0.99	1.01	1.00	0.00
Intelligibility	0.01	0.04	0.026	0.007	0.01	0.04	0.03	0.01
Ped-shed	17.83	72.13	49.56	9.55	11.57	71.66	45.42	10.19

Table 3. Logistic regression estimation results with walking independent as the dependent variable

variable	Radius 400 meter			Radius 800 meter		
	Coefficient	**p-value**	**EXP (OR)**	**Coefficient**	**p-value**	**EXP (OR)**
Non-physical Variables						
Age	0.188	**0.000*****	1.206	0.188	**0.000*****	1.207
Gender (Referent: Girls)	-0.429	**0.006*****	0.651	-0.461	**0.004*****	0.631
Fathers' worker status (Referent: Flexible)	-0.162	0.304	0.850	-0.181	0.255	0.835
Mather worker status (Referent: Flexible)	0.185	0.447	1.204	0.164	0.515	1.178
Father education level	-0.213	0.087	0.808	-0.159	0.214	0.853
Mother education level	-0.024	0.855	0.976	0.003	0.982	1.003
Number of children in household	0.422	**0.001*****	1.526	0.449	**0.000*****	1.566
Monthly income	-0.569	**0.005*****	0.566	-0.566	**0.006*****	0.568
Number of cars in household	-0.894	**0.000*****	0.409	-0.895	**0.000*****	0.409
Number of driving license holders in household	-0.490	**0.000*****	0.612	-0.474	**0.000*****	0.623
Perceived time between home and school	-0.096	0.274	0.908	-0.057	0.522	0.945
Physical Variables						
Connectivity	0.035	0.652	1.036	0.054	0.496	1.056
Integration (R3)	0.299	**0.000*****	1.348	0.321	**0.001*****	1.378
Choice (R3)	-0.242	**0.005*****	0.785	-0.528	**0.000*****	0.590
Control	-0.197	**0.007*****	0.821	-0.025	0.756	0.975
Intelligibility	0.220	**0.018****	1.246	0.343	**0.001*****	1.409
Ped-shed	0.010	0.213	1.010	0.005	0.524	1.005
Distance	-0.867	**0.000*****	0.420	-0.906	**0.000*****	0.404
Constant	2.088	0.005	8.067	2.243	0.002	9.423
Overall Percentage	83.5			83.1		
-2 Log likelihood	1088.556			1060.816		
Nagelkerke R^2	0.592			0.607		

Note: *, **, Mean significance at 1 percent, 5 percent level.**

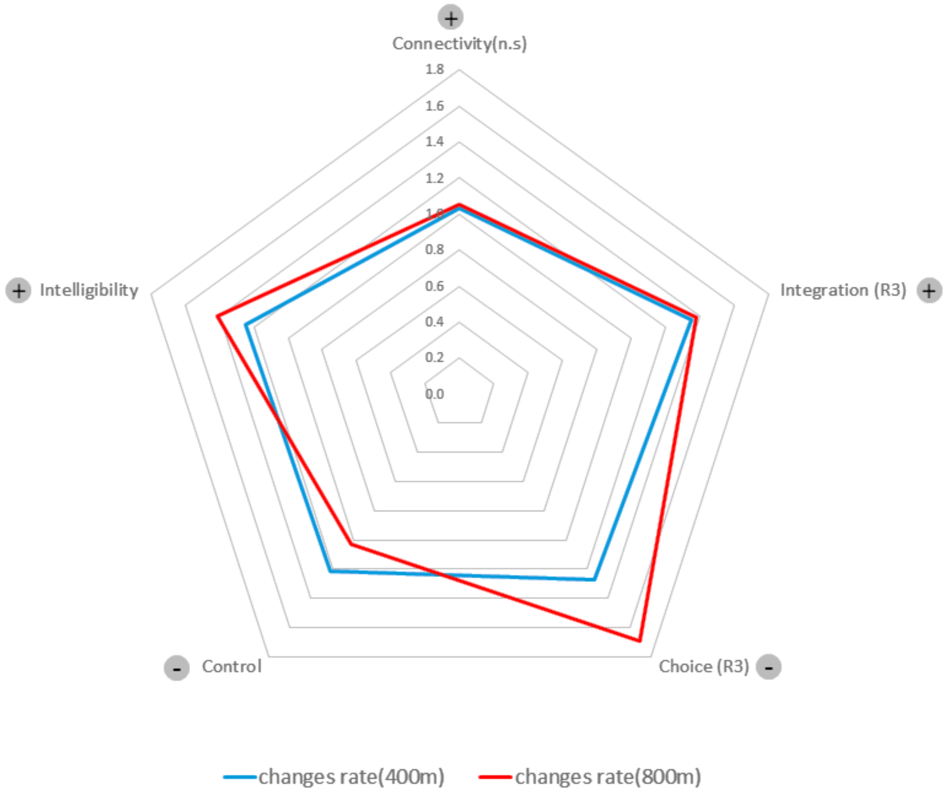


Figure 6. The extent of active commuting change by increasing local morphological factors in a radius of 400 (blue) and 800 metres (red) around the student's residence.

Appendix 1: Details of space syntax calculation

Here a description of space syntax metrics and the way of measuring are detailed.

Connectivity of a line is equal to the number of lines connected directly to it. In other terms, it is the "degree" of a specific node in a graph — that is, the number of edges incident on a node. Therefore, it is calculated as follows:

$\mathrm{C}_i = \sum_{j=1}^{n} a_{ij}$, Where C_i is the connectivity of a line i and a_{ij} is the entry of the i th row and j th column of the connectivity matrix A of the graph of an axial map (D'Acci & Batty, 2019).

Integration is the reciprocal of the real relative asymmetry (RRA) value of an axial line, which is a subordinate of the mean depth (MD) value of the line. The RRA value of a line i is shown as $RRA_i = \frac{RA_i}{D_n}$, where relative asymmetry $RRA_i = \frac{2(MD_i - 1)}{n-2}$, $D_n = \frac{2\left(n\left(log_2\left(\frac{n+2}{3}\right)-1\right)+1\right)}{(n-1)(n-2)}$ and $D_i = \frac{\sum_{j=1}^{n} d_{ji}}{n-1}$where n is the number of lines, d_{ij} is the shortest distance between two lines i and j in a graph G, and $\sum_{j-1}^{n} d_{ij} = 1\ dij$ is the total depth of the ith line (D'Acci & Batty, 2019). Indeed, Integration demonstrates the typical accessibility of the axial lines in a map. Greater integration values demonstrate greater overall accessibility, and lower values demonstrate lower overall accessibility of the map. It describes the amount of easiness one can experience to move within a space.

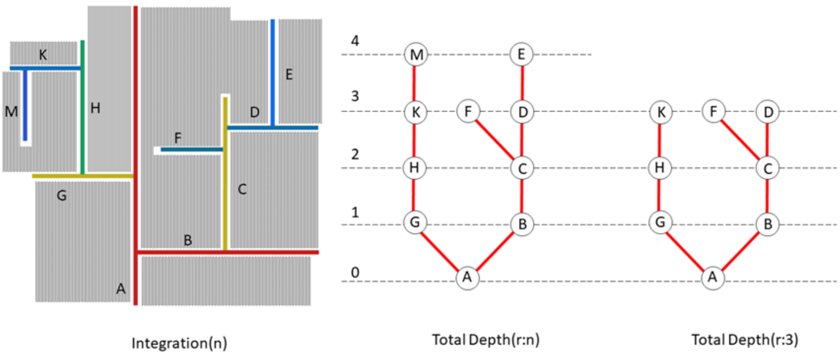
Choice measures the shortest paths between all edges within the network that line on the edge (Roosta et al., 2021). Choice demonstrates the overall potential for the through-movement of the lines in a network. It explains the amount of easiness one seeks while moving from one space to another within an area. Higher average choice values demonstrate the higher overall potential for through-movement, and lower values demonstrate the lower overall potential for through-movement of the network. The following formula is used to calculate the Choice.

$C_i(P_i) = \sum_j \sum_k \frac{g_{jk}(P_i)}{g_{ik}} (j < k)$ where $g_{ik}(P_i)$ is the number of geodesics (the shortest path) between nodes P_j and P_k that contain node P_i , and g_{ik} the number of all geodesics between P_j and Pk (D'Acci & Batty, 2019).

Local Integration (R3) and local Choice (R3) has been used in this study. Local Integration for radius three measures accessibility up to three steps away and in terms of axial line means a topological distance of three turns. There is evidence that local integration is strongly linked to the movement of pedestrians in space, meaning short trips to local destinations (Hillier, 1996).

Control value 'i' ($Ctrl_i$) refers to the reverse sum of other spatial connection values connected to the 'i' spatial node. $Ctrl_i = \sum_{j=1}^{k} \frac{1}{C_i}$ which k is the space number of directly connected spaces with the i space, C_j denotes the connectivity value of the j space (Xu et al., 2020). The greater the Control value of line, the better the street space power. The street spaces have greater control degree, and as well as have better accessibility (D. Li et al., 2016).

Intelligibility, used in the axial line approach, indexes the degree to which the number of quick connections an axial line has is a dependable guide to the importance of that line in the system as a whole (that is, it is a correlation between axial connectivity and axial global integration). A powerful correlation or 'high intelligibility' in a non-orthogonal avenue system indicates that well-connected avenues are also well integrated inside the wider avenue network that may be predictable for the pedestrian motion (Zhang et al., 2013). In this study, to calculate the Intelligibility, global Integration is divided by Connectivity (Sener et al., 2019). Figure below shows a hypothetical example of street networks for which parameters Space Syntax have been calculated.



A

Node(line)	A	B	C	D	E	F	G	H	K	M
Connectivity (All node)	2	2	3	2	1	1	2	2	2	1
Distance A	0	1	2	3	4	3	1	2	3	4
Total Depth for A	23									
Total Depth for A(R:3)	15									
Mean Depth for A	$\text{Mean Depth}_A = \frac{0+1+2+3+4+3+1+2+3+4}{10-1} = 2.56$									
Total Depth for A(R:3)	$\text{Mean Depth}_A = \frac{0+1+2+3+3+1+2+3}{8-1} = 2.14$									
D_n for A	$D_{10} = \frac{2(10(\log_2((10+2)/3)-1)+1)}{(10-1)(10-2)} = 0.306$									
D_n for A(R:3)	$D_8 = \frac{2(8(\log_2((8+2)/3)-1)+1)}{(8-1)(8-2)} = 0.328$									
RA for A	$RA_A = \frac{2(2.56-1)}{10-2} = 0.39$									
RA for A(R:3)	$RA_A = \frac{2(2.14-1)}{8-2} = 0.38$									
RRA for A	$RRA_A = \frac{0.39}{0.306} = 1.2745$									
RRA for A(R:3)	$RRA_A = \frac{0.38}{0.328} = 1.1585$									
Integration for A	$Integration_A = \frac{1}{RRA_A} = 0.7846$									
Integration(R:3) for A	$Integration_A = \frac{1}{RRA_A} = 0.8632$									
Control for A	$Control_A = \frac{1}{2} + \frac{1}{2} = 1$									
Intelligibility for A	$\text{Intelligibility}_A = \frac{0.7846}{2} = 0.3923$									

B

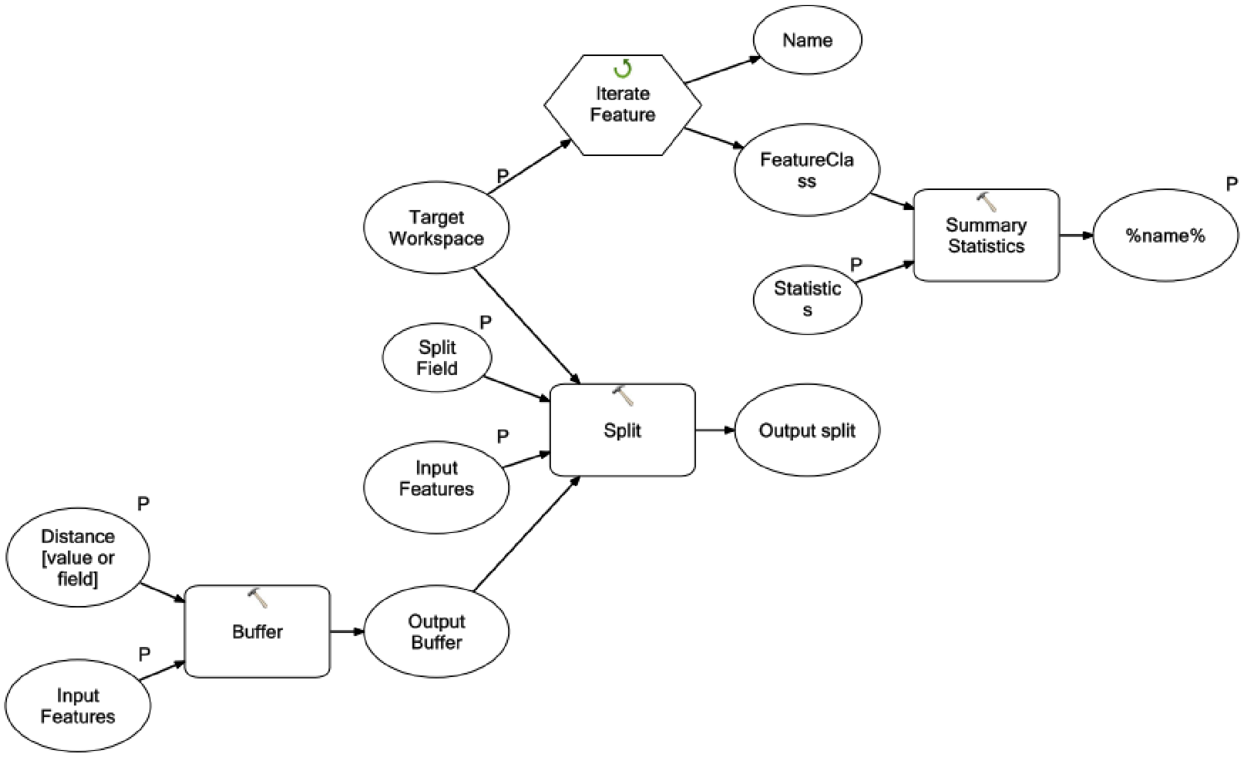
Figure: Calculation of Space Syntax parametres for a hypothetical street network

Appendix 2: ArcGIS model developed for measuring the space syntax of the home location of each individual student

Model 01

```
# -*- coding: utf-8 -*-

# ---------------------------------------------------------------------------

# modelScript.py

# Created on: 2020-08-11 17:47:51.00000

#   (generated by ArcGIS/ModelBuilder)

# Usage: modelScript <Input_Features> <Distance__value_or_field_> <Input_Features_split> <Split_Field> <Target_Workspace> <Statistics_Field_s_> <v_name_>

# Description:

# Active Travel to School

# Set the necessary product code

# import arcinfo

# Import arcpy module

import arcpy

# Load required toolboxes

arcpy.ImportToolbox("Model Functions")

# Script arguments

Input_Features = arcpy.GetParameterAsText(0)

Distance__value_or_field_ = arcpy.GetParameterAsText(1)

Input_Features_split = arcpy.GetParameterAsText(2)

Split_Field = arcpy.GetParameterAsText(3)

Target_Workspace = arcpy.GetParameterAsText(4)

Statistics_Field_s_ = arcpy.GetParameterAsText(5)

v_name_ = arcpy.GetParameterAsText(6)

if v_name_ == '#' or not v_name_:

v_name_ = "F:\\theis\\Article_SJSH\\newMethod\\modeledit\\summary.gdb\\%name%" # provide a default value if unspecified


# Local variables:

Output_Buffer = ""
```

```
Output_split = Target_Workspace

FeatureClass = "\\FeatureClass"

Name = "FeatureClass"

# Process: Buffer

arcpy.Buffer_analysis(Input_Features, Output_Buffer, Distance__value_or_field_, "FULL",
"ROUND", "NONE", "", "PLANAR")

# Process: Split

arcpy.Split_analysis(Input_Features_split, Output_Buffer, Split_Field, Target_Workspace, "")

# Process: Iterate Feature Classes

arcpy.IterateFeatureClasses_mb(Target_Workspace, "", "", "NOT_RECURSIVE")

# Process: Summary Statistics

arcpy.Statistics_analysis(FeatureClass, v_name_, Statistics_Field_s_, "")
```



Model02

```
# -*- coding: utf-8 -*-

# ---------------------------------------------------------------------------

# m2.py

# Created on: 2020-08-11 18:15:53.00000

#   (generated by ArcGIS/ModelBuilder)
```

```
# Usage: m2 <Summary> <Field_Name> <Field_Type> <Field_Length> <Expression> <Table> <File_Name>

# Description:

# Add a field to a feature class and then add the feature class name to that field. This model is useful for merging multiple feature classes and identifying which attribute table records they come from.

#

# ---------------------------------------------------------------------------

# Import arcpy module

import arcpy

# Load required toolboxes

arcpy.ImportToolbox("Model Functions")

# Script arguments

SUMM_400_gdb = arcpy.GetParameterAsText(0)

if SUMM_400_gdb == '#' or not SUMM_400_gdb:

SUMM_400_gdb = "F:\\Article_All\\article_masoud\\article school space syntax\\article_school\\street\\SUMM_400.gdb" # provide a default value if unspecified

Field_Name = arcpy.GetParameterAsText(1)

if Field_Name == '#' or not Field_Name:

Field_Name = "NAME" # provide a default value if unspecified

Field_Type = arcpy.GetParameterAsText(2)

if Field_Type == '#' or not Field_Type:

Field_Type = "TEXT" # provide a default value if unspecified

Field_Length = arcpy.GetParameterAsText(3)

if Field_Length == '#' or not Field_Length:

Field_Length = "70" # provide a default value if unspecified

Expression = arcpy.GetParameterAsText(4)

if Expression == '#' or not Expression:

Expression = "\"%File Name%\"" # provide a default value if unspecified

Table = arcpy.GetParameterAsText(5)

if Table == '#' or not Table:

Table = "F:\\Article_All\\article_masoud\\article school space syntax\\article_school\\street\\SUMM_400.gdb\\SH" # provide a default value if unspecified

File_Name = arcpy.GetParameterAsText(6)
```

```
if File_Name == '#' or not File_Name:

File_Name = "SH" # provide a default value if unspecified

# Local variables:

New_Field_ = Table

Final_Feature_Class = New_Field_

# Process: Iterate Tables

arcpy.IterateTables_mb(SUMM_400_gdb, "", "", "NOT_RECURSIVE")

# Process: Add Field

arcpy.AddField_management(Table, Field_Name, Field_Type, "", "", Field_Length, "",
"NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field

arcpy.CalculateField_management(New_Field_, "NAME", Expression, "VB", "")
```