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The impact of topological properties of built environment on children independent mobility: A comparative study between discretionary vs. nondiscretionary trips in Dhaka

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Abstract

Researchers broadly represented the built environment (BE) using geographic and topological indicators. Despite studies have shown that the geographic BE affects children independent mobility (CIM), little is known about the effects of topological BE on CIM. Less so, how the effects vary between discretionary and nondiscretionary CIM trips. The study addresses these gaps using self-reported two-day mobility data of 151 children aged 10-14 years from Dhaka, Bangladesh. Geographic BE data (e.g. land uses, street width, building height) were collected through a virtual BE audit following each route. Topological BE data (e.g. step-depth, integration, choice) were derived in Depthmap X. CIM was measured in a binary scale by checking whether the reported trips were taken independently or not. Three binary logistic regression models (an overall model, a discretionary trip model, and a nondiscretionary trip model) were estimated to determine the effects of geographic and topological BE on CIM, controlling for other confounding effects. The findings demonstrate that both geographic and topological BE affect CIM. However, they affect discretionary and non-discretionary CIM differently – e.g. step-depth, angular connectivity and presence of institutional land use affect only non-discretionary CIM, whereas integration, recreational land use and traffic composition affect only discretionary CIM. The findings highlight that geographical features need to be considered in tandem with topological features of the BE, stratified by destination types, to maximise CIM.

Keywords: Independent mobility; built environment; space syntax; discretionary trip; nondiscretionary trip; virtual BE audit

1. Introduction

Children's independent mobility (CIM) is defined as the freedom of children to travel around their neighbourhood without adult supervision (Tranter and Whitelegg, 1994). CIM is beneficial for children's physical, cognitive, emotional, communicational, navigational, analytical and social development (Christensen and O'Brien, 2003; Hüttenmoser, 1995; Prezza and Pacilli, 2007; Rissotto and Tonucci, 2002). It also reduces car dependency, and consequently, lowers air pollution, urban traffic congestion, greenhouse gas emissions and childhood obesity (Lopes et al., 2014; U.S. Environmental Protection, 2003; Whitzman et al., 2010).

Despite the widely acknowledged benefits, CIM has declined sharply over the last few decades (Carver et al., 2013; Lopes et al., 2014). For example, in Australia, unaccompanied children walking to school dropped from 68% to 31% between 1991 and 2012, and in the United Kingdom, the drop was 40% between 1971 and 1990 (Schoeppe et al., 2015). On the other hand, the number of Australian children with obesity increased from 21% to 26% between 1995 and 2012 (Australian National Preventive Health Agency (ANPHA), 2014).

There is clear evidence in the literature that built environmental and socio-cultural transformations caused by the growing pressure of urbanization have altered children's mobility patterns worldwide (Fyhri et al., 2011; Lopes et al., 2014; Malone and Rudner, 2011). Studies spanning decades have identified various built environment (BE) variables that influence CIM (Broberg and Sarjala, 2015; Islam et al., 2014; Lin and Chang, 2009; Loebach and Gilliland, 2016; Loebach and Gilliland, 2014; Lopes et al., 2014; Mackett et al., 2007; Monsur et al., 2017; Villanueva et al., 2013). The BE is broadly represented using geographic (e.g. distance, land uses) and topological indicators (e.g. depth, integration) in the literature. However, existing CIM studies applied only the geographic indicators of the BE following the 5D principles (i.e. Density, Design, Diversity, Distance and Destination accessibility) of Ewing and Cervero (2010). As a result, this large body of the literature mostly ignores the other representation of the BE measured using topological indicators as conceptualised in the space syntax literature (Hillier and Hanson, 1984).

Geographic indicators of BE are based on the assumption that human movement is shaped by the metric distance between spaces and functional aspects of land-uses. Topological indicators, on the other hand, are based on the consideration that human movement is shaped by the configuration of road networks alone (Hillier and Hanson, 1984). In case of pedestrian movement, while the latter is conceptualised on the notion of visual distance/ number of turn from origin to destination (named as 'depth') as the key determinant, the former is conceptualised on the notion of metric distance (Hillier et al., 1993). Such deterministic approaches have been much critiqued in contemporary social theories, and also specifically in relation to space syntax and walking (Dovey and Pafka, 2019; Netto, 2016). These researchers expressed their concern about the determinism embodied in the space syntax literature and not incorporating the entire social context while assessing the impact of configurational impact on walking. Despite the criticism, space syntax has been identified as a powerful tool to measure walkability in urban environment.

The use of space syntax to explain CIM is rare. On the other hand, few studies used space syntax to explain child's active travel behaviour (Argin and Torun, 2015; Helbich et al., 2016; Zdrahalova and Boumova, 2016). Nevertheless, these studies have reported inconsistent results. For example, while Zdrahalova and Boumova (2016) found no correlation between space syntax measures (i.e. integration and choice) and child's walking, Argin and Torun (2015) and Helbich et al. (2016) respectively found that child's walking to school is negatively associated with integration and positively associated with choice. Importantly, the direction and magnitude of space syntax impact on children active travel show contrasting results to that found on adult behaviour. For instance, unlike Argin and Torun (2015), Baran et al. (2008) found a strong positive association between utilitarian walking of adults and integration. These inconsistencies also mean that the effects of space syntax measures on adult/child walking cannot be entirely applicable to CIM. This raises the need for CIM studies to apply space syntax measures to inform BE interventions (Cutumisu and Spence 2009).

Existing studies on the BE-CIM link are largely focused on travelling to school, which is a mandatory activity of school children to attend. Earlier research, however, suggested that children make more discretionary trips than mandatory/nondiscretionary trips and they prefer to visit a wide range of destinations in their local environment (Badland et al., 2015; Loebach and Gilliland, 2016). In Finland, for example, only one-third of children's daily trips are to and from school, while 52% of the trips are made to leisure activities, and the remaining 15% are to other local destinations (Finish Transport Agency, 2012). More importantly, research on adult walking behaviour identified that BE factors affecting discretionary and nondiscretionary walking are substantially different (Koohsari et al., 2013; Koohsari et al., 2016). The topological BE also impacts discretionary and nondiscretionary walking differently. In the space syntax literature, discretionary movement is regarded as natural movement which is more exploratory in nature such as visiting a park, gallery, and city (Baran et al., 2008; Hillier et al., 1993; Turner and Penn, 2002). On the other hand, nondiscretionary type of movement is more wayfinding in nature with a specific destination in mind (Helbich et al., 2016). These findings indicate the need for research studies identifying the effects of BE on both discretionary CIM and nondiscretionary CIM in order to enhance children's overall IM. This study aims to contribute to these gaps in the CIM literature. The two interrelated objectives of this study are: first, to identify different geographic and topological factors that significantly affect CIM, and their strength of association controlling for a wide range of socio-economic and individual factors; and second, to test whether the effects of these factors vary between discretionary and nondiscretionary CIM.

2. Literature review

2.1 Space Syntax theory, method and measures in the context of pedestrian movement

Space Syntax theory and analytical methods were developed based on the spatial configuration of road networks to understand the interdependency between spaces and people. This theory conceptualises that space has its own social logic that affects human behaviour, such as pedestrian mobility from one place to another (Hillier and Hanson, 1984). Space syntax is defined as 'a model of representation, analysis and interpretation', which argues that the configuration of street network itself is the main generator of patterns of movement (Hillier et al., 1993). Hillier et al. (1993) called the movement as natural movement, which explains that the spatial configuration of urban grid itself yields attraction inequalities and privileges some urban spaces over others for movement and activities without the consideration of land-use attractors.

Space syntax concept has been operationalised using two types of representations of urban spaces: axial and segment. Axial method analyses spatial network by the longest and least set of axial (straight) lines for the representation of urban spaces, whereas segment method uses segments formed by chopping the original axial lines at the junctions into smaller individual parts. Axial method is based on the topological distance between an origin and a destination, which refers to the number of directional changes required to reach a destination. This is why Axial method is also called the fewest turn concept (Hillier and Iida, 2005). Unlike axial method, segment method is based on angular, metric and topological distances. The angular and metric distances are respectively defined as the sum of directional changes in degrees and the sum of segment lengths in metre between an origin and a destination (Hillier and Iida, 2005; Turner, 2007).

The three distance concepts (topological, angular and metric) in space syntax are used to derive various indicators in order to explain pedestrian movements such as integration, connectivity, choice and control (Baran et al., 2008; Koohsari et al., 2013; Özer and Kubat, 2014; Wineman et al., 2014). Integration is considered as a key indicator of space syntax. It measures how far a given street is from all other streets, calculated by the average number of turns between streets. Connectivity is measured in two ways in the BE literature: non-angular connectivity and angular connectivity. Non-angular connectivity denotes the number of streets or neighbouring spaces that are directly connected to a given street whereas angular connectivity measures cumulative turn angle of a segment to other segments. Control measures the degree to which a space controls access to its immediate neighbours by taking into account the number of alternative connections that each of these neighbours has (Hillier and Hanson, 1984). Choice measures the extent to which a given street belongs to the shortest path between any pairs of two streets (Hillier et al., 1986).

The application of other indicators, such as intelligibility (measures the relationship between integration and connectivity of a space) by Wang et al. (2012), step-depth (a measure of movement efficiency given the distance one must travel in the network) and intensity (measures the rate of change of entropy relative to total depth) by Lerman et al. (2014), and synergy (the correlation between local and global integrations) by Li et al. (2015), to explain pedestrian movement is fairly limited in the literature.

Despite the effectiveness of space syntax indicators in explaining pedestrian movement, studies have also identified several limitations of space syntax technique including discontinuous nature of axial map transformation, uncertainty appears in production of axial map from a piece of real urban texture, inability to take into account the land use and building height, its sensitivity to boundary conditions and axial analysis's privilege on visibility over accessibility (Batty, 2013; Pafka et al., 2018; Ratti, 2004).

2.2 Geographic BE factors affecting CIM

2.2.1 Distance to destination

Distance to destination measures how far (feet, metre, kilometre) one must travel to reach destination. It is one of the most frequently examined BE variables in connection with CIM. Both 'crow fly' distance (the straight-line distance between two points) (Broberg and Sarjala, 2015) and 'network distance' (actual path distance between origin and destination) (Loebach and Gilliland, 2014) were applied in CIM research. Studies repeatedly found that distance from home to school has a strong negative association with CIM (Loebach and Gilliland, 2014; Monsur and Islam, 2011). The result is similar for park as a local destination. In the UK and in Italy, living near a park has been found to have a positive association with CIM (Mackett et al., 2007; Prezza et al., 2001).

2.2.2 Diversity of land-uses

Different types of land-uses have been found to influence children's IM and active travel, including residential, commercial, retail, recreational, and institutional land-uses (Broberg and Sarjala, 2015; Kyttä, 2004; Loebach and Gilliland, 2014). A study on 9-13 years old children shows that the proportion of residential and industrial land-uses within an 800m of child's home are positive predictors of children's independent time spent outside (Loebach and Gilliland, 2014). Predominantly CIM was assessed against diversity as well as land-use mix. The land use mix is defined as "the evenness of distribution of square footage of development across four types of land uses within a 1 kilometer distance from each participants house" (Frank et al., 2004, p. 90). The four land uses used in this study to calculate the land-use mix were residential, commercial, office, and institutional. However, different CIM studies measured land use mix differently. For example, Islam et al. (2014) measured the summation of all mix-use building footprint area within a zone, whereas Carver et al. (2014, p. 27) measured land use mix by the "proportion of each land use squared and summed".

In general, mixed-use is believed to decrease trip distance, thereby increases the potential of CIM to close destinations (Carver et al., 2014b). However, the CIM literature reported a mixed result. For example, Broberg and Sarjala (2015) and Islam et al. (2014) reported a negative correlation between CIM and land-use mix in Finland and Bangladesh respectively, whereas the relationship was positive for girls travelling to school independently in the UK (Carver et al., 2014a).

2.2.3 Design of street

Design of street includes both walking/cycling environment and traffic environment of an area as discussed below:

- Walking environment

A growing number of studies have investigated the associations between different street design variables that foster the walking/cycling environment and CIM. These studies found that a neighbourhood characterized by well-connected streets has a positive influence on girls' IM (Villanueva et al., 2012; Villanueva et al., 2013). Well-connected street networks are believed to increase proximity to destinations and provide multiple route options. In contrast, in the context of Dhaka- a highly urbanized city in Bangladesh, research has shown that dead-ends (opposite to connected street) promote CIM range and independent outdoor time. Perhaps dead ends are considered as the last resorts of children to play as formal open spaces are limited (Islam et al., 2014; Monsur et al., 2017). In addition to connectivity, a higher number of crossing/ intersection on a route from home to school is found to reduce IM in Bangladesh (Monsur and Islam, 2011) and Taipei (Lin and Chang, 2009).

Other street design features, for example, presence and better physical condition of sidewalks, lower number of pedestrian crossings, wider sidewalk, a higher density of trees along footpath are found to provide ease and comfort in movement. These can also create a better perception of neighbourhood among children and consequently promote CIM (Boarnet et al., 2003; Lin and Chang, 2009; Loebach and Gilliland, 2016; Monsur et al., 2017; Van Oel, 2009). Safe sidewalk also relaxes parental mobility restriction for children (Loebach and Gilliland, 2016; Santos et al., 2013). Although several features of the street environment such as building height, obstruction of walking environment etc. have been found to affect adult walking, they are yet to assess for CIM.

- Traffic environment

Traffic environment of neighbourhoods including traffic volume and speed, vehicular street width and number of vehicle lanes have been examined in a number of studies due to their importance in explaining CIM behaviour. Heavy traffic on neighbourhood streets is found to reduce IM among children and youth (Tranter and Doyle, 1996). This finding is further supported by other studies (Villanueva et al., 2012; Villanueva et al., 2013), which claim that low-speed vehicles and low-traffic streets encourage girls' IM. Furthermore, a wider vehicular street that caters more traffic and consequently increases the chance of accidents has a negative impact on CIM (Monsur and Islam, 2011). A frequent exploration of the relationship between parental perception of traffic and CIM confirmed that a higher level of traffic speed and volume, unsafe crossing, and poor physical condition of roads have negative influence on CIM regardless of the age and gender of child and the locational variations (Villanueva et al., 2012; Villanueva et al., 2013).

2.3 Socio-demographics and personal-level factors affecting CIM

The literature is mostly unanimous on the significance of socio-demographic variables on CIM. Studies have shown that older children have greater CIM than younger ones (Prezza et al., 2001; Rissotto and Giuliani, 2006), and boys are more independently mobile with greater granted mobility licences than girls (Islam et al., 2014; Lopes et al., 2014; Prezza et al., 2001). However, mobility restriction is flexible if a child is accompanied by siblings or peers (O'Brien et al., 2000). In addition, the company of peers or siblings is more beneficial for the increment of CIM journey among girls than boys. For example, Mackett et al. (2007) found that similar proportions of boys (85%) and girls (81%) were allowed to travel with other children whereas a larger difference was evident when boys (63%) and girls (48%) reported travelling alone. Aside from child's demography, it is evident that children from higher-income families are less likely to travel actively, independently and by public transport (Tranter and Pawson, 2001).

3. Data and methods

3.1 Study context

This research collects data from Dhaka, Bangladesh. Dhaka was selected for two reasons. First, there is a scarcity of CIM studies in the context of developing nations compared to developed nations (Sharmin and Kamruzzaman, 2017), which often leads BE professionals of developing countries to rely on findings from developed countries. This practice raises the question of validity and appropriateness of their applications due to the contextual variations (Kyttä, 2004). Second, Dhaka, characterised by one of the world's highest annual growth rate of population (3.8%) as reported in (BBS, 2011), possesses a unique setting for CIM research because a higher degree of urbanization has been identified as a barrier to CIM all over the world (Islam, 2008; Lopes et al., 2014).

3.2 Data

This research required three types of data to address the research objectives: a) activity-travel data of children; b) geographic and topological BE data that could potentially affect CIM behaviour, and c) socio-demographic data of children and parents that might impact CIM decision.

3.2.1 Questionnaire survey to collect child-reported activity-travel data and parent-reported socio-demographic data

A questionnaire survey was conducted between September and November in 2017 with children and parents from randomly selected seven schools in Dhaka, Bangladesh (Figure 1). This study included children from the early adolescent period (10 to 14 years) since this age group is less studied compared to middle childhood (approx. 9-12 years) (Lopes et al., 2014). The initial sample included a total of 336 participants (n=168 children, n=168 parents). Due to some missing data of children and parents, 17 sample unit (1 child and 1 parent per unit) were consequently eliminated from statistical analysis which resulted in an analytical sample of 151 students.

School-based sampling strategy was adopted in this research. This method has been widely applied in CIM research worldwide (Islam et al., 2014; Loebach and Gilliland, 2014; Villanueva et al., 2012). The sampling strategy in this research followed 2 steps: random sampling of schools, and random sampling of children. Random sampling of schools was done from a list of all schools in Dhaka retrieved from the website of Bangladesh Bureau of Educational Information and Statistics (BANBEIS). Since the BANBIES list has complete information about public schools only, initially, 4 public schools were selected randomly based on clustered random sampling method. These four schools were located in Azimpur, Magbazar, Manikdi, and Uttara referred as study area 1, 2, 3 and 4 respectively in this study. From these areas, eight private schools were selected randomly, two from each area. The principals of the selected schools were then requested for their voluntary participation in this research. Upon their acceptance (8 out of 12 schools accepted to participate), the school officials were asked to arrange classes with students. One of the authors of this paper provided a short presentation about this research to the students, also explaining how students can participate in the research. The students who have shown inclination, an information sheet and a consent form were given to them to deliver to their parents. They were also asked to return the consent form upon receiving approval from their parents. Respondents living within 1.6 km (crow-fly distance) of the schools were included in this study. The 1.6 km buffer was selected based on the literature as it represents the walkable distance for children aged 10-14 years (McDonald and Aalborg, 2009).

Parents who provided consent (16% of the total forms distributed) were then contacted over the phone to seek an appointment for data collection. To ensure the comfort of children, they were surveyed in their home environment. However, in some cases with the help of school officials, presentations were arranged in coaching/ private tuition after school where both children and parents were available. This process accelerated getting parents' consents. This is a context-specific solution. In Dhaka, coaching is run by mostly school teachers and acts as an extended school in some cases. This approach facilitated a snowball technique to further include some school-going children in this study (9%) from outside of the selected schools.

Data from children were collected following a four-step process. First, a questionnaire survey was conducted to collect data regarding child's age, gender, and other personal-level information (i.e. ownership of cycle, number of friends, number of siblings aged ≤18 years, and number of known people in the neighbourhood). Second, a travel diary was employed to collect child's activity-travel data including the type of destination visited (e.g. school, park mosque), mode of travel (walk, cycle, car, bus, local vehicles etc.), and accompaniment of each trip taken (alone, with friends/ siblings aged ≤18 years, parents/guardians). Students were asked to report a two-day travel diary. The included days were the last school day and the last school off day/ weekend. The children who didn't attend school in the survey week and in the previous week were excluded from the survey to minimise recall biases. Third, children were asked to draw their travel routes and activity points (origin and destination) on a Google Earth image. Fourth, questionnaire survey of respective parents was then conducted to collect socio-demographic data (i.e. household income, duration of residency in current neighbourhood, parent's education level, parent's age and gender)

Descriptive characteristics of the sample and their extent to CIM trips are shown in Table 1. Of the children, 53% were girls. The mean age of children is 12.5 years. 38.4% of children were from Area 1, whereas 27.2%, 21.2% and 13.2% were from area 2, 3 and 4 respectively. The majority of children reported that they did not own a bicycle (62.9%) and belonged to relatively small families having only one sibling (55%). However, at the neighbourhood level, participants reported that a majority of them have many friends (70%) and lots of known residents (74.2%) as they have been living in the same neighbourhood for a long time (Mean= 8.97 years).

The majority of survey respondents (43%) are from a family with a monthly household income of tk.26000-50000 (approx. $325- $625 USD) which is considered as lower-middle to middle-income group in the local context (Power and Participation Research Centre, 2016). A higher representation of mothers was evident in this survey (62.3% cases) with aged between 30-45 years (84.8% cases). A majority of fathers are also from the same age bracket (57.6%).

The 151 child participants reported 466 trips in total which destined to 14 different activity types over the two days surveyed. Almost an equal number of trips were made to both nondiscretionary (53.2%) and discretionary destinations (46.8%). Overall, 86.1% of the children reported having at least one independent travel. 70.3% of the 466 trips were found to be made independently. Children made more independent trips on weekdays (70.6%) compared to weekends (29.4%). One reason for this high rate of independent trips on weekdays could be the school-based nondiscretionary trips. The analysis shows that a majority of nondiscretionary independent trips were made on a weekday (87.7%).

Figure 2 shows children's status of independent mobility to different locations. A further subcategory of discretionary and nondiscretionary destinations displays that school is the most frequently visited destination for CIM (26%) followed by coaching (20.8%). On the other hand, among all discretionary destinations, park is the most popular discretionary destination to visit independently both on weekdays and weekends (18.3%) followed by shop (14.1%) and Mosque (7.6%).

3.2.2 Geographic and topological BE data collection and measurement of route-level BE

Table 2 presents a description of all BE variables (n=28) included in this study. These BE data were collected by applying different techniques. The geographic BE data were collected through a virtual BE audit. This technique is reported to be reliable in the literature (Kelly et al., 2012).

For virtual BE audit, an audit tool was developed by: listing BE variables based on a systematic review of BE-CIM link, reviewing existing walkability tools for children and adults, and reviewing local urban development regulation (BCA 2008; Lee et al., 2013; Sallis et al., 2015; Sharmin and Kamruzzaman, 2017; Shatu and Yigitcanlar, 2018). Briefly, this tool captured information about 24 attributes of the BE under 4 categories: land-use, walking environment, traffic environment and, aesthetic and comfort (See Table 2). Note that context played an important role in the selection of these variables; irrelevant variables were excluded while some context-specific variables were included (e.g. traffic composition).

Geographic BE data were collected virtually by a co-author of the paper using Google Street View in December 2017. Data were collected for each segment on child-reported routes. Photographs and videos were captured for street segments where Google Street View data were not available during the time of the data collection. Data for about 11% of the total of 681 segments were extracted from videos and photographs. Google Street View based BE data collection methods were adopted in this study because this technique is gaining popularity in the public health literature (Badland et al., 2010).

The space syntax indicators (e.g. step-depth, integration, choice and connectivity) were derived in Depthmap, version X 0.50 using a 4–step process: a) preparation of existing road network maps in ArcGIS. Given that the original base network was dated, these were updated following Google Street Map and site visit where necessary. The study area was determined based on a 1km buffer from the furthest activity location of children in order to minimise the edge effect in spatial analysis (Ratti, 2004); b) construction of axial maps in Depthmap based on the prepared road network maps; c) preparation of segment maps from the axial maps to run segment analysis; and d) running segment based angular indicator generation processes in Depthmap. This research used segment analysis over axial analysis, because a segment based representation of the BE is more precise and able to capture minor variations in directional change over axial map (Hillier and Iida, 2005). Moreover, the recent space syntax literature reveals that segment based analysis can explain travel behaviour better than axial analysis (Sharmin and Kamruzzaman, 2018a).

Angular method was selected for the derivation of space syntax measures because existing literature, comparing the three types of distance measures (angular, topological and metric) available for segment based analysis, indicates that angular measures are the strongest predictor of travel behaviour (Sharmin and Kamruzzaman, 2018b; Xia, 2013). Angular step-depth was measured separately for each reported route. It calculates total directional changes in angle between an origin and a destination, and represented by 1 for a 90-degree change. Unlike angular step-depth, angular integration, angular choice and angular connectivity indicators were derived for each segment of all routes at r=n level.

Geographic distance of each reported route was derived in ArcGIS. Given that the BE data were collected for each segment (except distance and step-depth), they were aggregated for each reported route. The values of respective segment level attributes were averaged based on the number of segments forming a route. Table 3 presents the summary statistics (mean, standard deviation) of all BE variables for the reported routes.

3.3 Measurement of CIM

This study considered only self-reported CIM to different local destinations as this is the most widely applied CIM measures in the literature (Foster et al., 2014; Sharmin and Kamruzzaman, 2017). CIM can also be conceptualised in other ways, e.g. CIM licence (parent's granted permission for their child) (O'Brien et al., 2000), CIM range (longest distance travelled independently) (Loebach and Gilliland, 2014) and CIM time outside (maximum time spent outside independently) (Monsur et al., 2017) which were not included in this study.

CIM in this research was measured for each trip reported by each child. Children indicated the destinations they visited in their travel diary and the accompaniment of their trips. At first, all trips taken by a child to different destinations over the two days of survey period were scored; each independent (alone/ with friends/ with siblings ≤18 years old) trip was coded as 1 and otherwise 0. The independent trips were then subdivided into two groups based on the types of destinations visited: discretionary and nondiscretionary. Discretionary CIM trips represent independent visit to any local discretionary destinations, e.g. park, playground, shop, café, friend's home, relatives home, religious centre, club, library etc. On the other hand, nondiscretionary CIM trips refer to an independent visit to any nondiscretionary destinations such as school, coaching and extra-curricular classes over survey days.

3.4 Statistical analysis

A step-by-step analytical strategy was applied in this research. First, correlation among the 28 BE variables was tested by conducting a bivariate correlation analysis, and variables with high correlation (>0.7) were identified. The explanatory power of the correlated variables was tested individually and the variables with larger explanatory power were retained for further analysis (Zainodin et al., 2011). Table 4 represents the correlation coefficient values among the variables. As reported in Table 4, six variables (i.e. setback, footpath width, footpath continuity, stopover activities, pedestrian volume and physical access) were excluded from the analysis. Second, the purposeful selection method of variables as applied by Hosmer Jr et al. (2013) was adopted in this research. This method has the ability to avoid the over-specification problem caused by a large number of explanatory variables with a relatively small sample size (Carver et al., 2014a; Freund, 2006). As part of the purposeful selection, a series of binary simple (unadjusted) logistic regression models were estimated separately for each of the remaining 22 BE variables to identify factors having an association with CIM (See Appendix A). A categorical variable 'study-area' was also included in this step to check whether the contextual variations among the areas have any impact on CIM behaviour or not. A study has reported that the extent of CIM differs between neighbourhoods with different socio-demographics and morphological variations (Stark et al., 2018). Third, BE variables with significant associations with CIM at the 0.1 level in the unadjusted models were entered into an adjusted multiple logistic regression model. Fourth, a step-wise exclusion of variables with statistical insignificance was conducted to keep only the statistically significant factors in the final model. Cluster-robust (CR) inference was considered for all logistic regression models as multiple trips (observations) were reported by each child (cluster). By allowing the correlation between observations, this inference has the aptitude to correct Standard Error (SE) estimation of the model by increasing precision of parameter estimate, *B* and the Confidence Interval (CI) of *Bs* (Cameron and Miller, 2015). Failure to control for within-cluster error correlation can lead to very misleadingly small errors and consequent misleadingly narrow confidence intervals, large t-statistics and low p values. Step 2, 3 and 4 were repeated to identify BE variables significantly associated with Discretionary and nondiscretionary CIM. All statistical models were run in Stata/SE 15.1.

4. Results

4.1 The extent of overall CIM in relation to geographic and topological BE

Table 5 shows the estimated parameters of the binary logistic regression model for overall CIM. The *Wald* Chi^2 statistic for the overall CIM model is 55.8 with 8 df, which are well above the critical value for the statistical significance at the 5% level of significance. The *pseudo-*R^2 value of 0.169 for this model also indicates a reasonable level of fit with an explanation of 16.9% variance of the response data. As reported in Table 5, four BE variables are significant predictors of CIM: two of them are topological BE indicators including angular step-depth and angular integration, and the rest are geographic BE indicators including recreational land-use and traffic composition on the way to destinations. While space syntax indicators have negative associations with CIM, the relationship is positive for geographic variables. In terms of the magnitude of these associations, angular integration and recreational land-use along the route show the strongest negative and positive impact on CIM, respectively. The odds ratio for the angular step-depth suggests that one unit increase of angular step-depth (i.e. a 90° change in direction/1 turn) is associated with a 10.4% decrease in the likelihood of making a CIM trip. Similarly, a one unit increase of angular integration reduces the odds of making an independent trip by 1%. Results of geographic variables, on the other hand, shows that the odds of making an independent trip is 12.1 times higher if recreational land-uses are present along walking routes. In a similar way, low traffic speed along the route has been found to increase the odds of making a CIM trip by 2.4 times.

For overall CIM, girls are 52.5% less likely to take an independent trip than boys, however, with the increase of child's age by one year, CIM is likely to increase by 39.3%. Increase of number of siblings less than 18 years old also increases the likelihood of a CIM trip by 87.5%. In contrast, overall CIM is likely to drop by 44.1% with an increased number of motorised vehicle owned by family.

4.2 BE factors affecting CIM trips to discretionary and nondiscretionary destinations

This section articulates results on the comparative analysis between discretionary and nondiscretionary CIM. As reported in Table 5, the predictors of CIM are different for discretionary and nondiscretionary trips. The *Wald Chi2* values of the discretionary CIM and nondiscretionary CIM models are respectively 20.78 and 45.63. Both of the *Chi2* statistics are well above the critical values for statistical significance at the 5% level of significance, suggesting that both models have sufficient explanatory power.

The statistically significant predictors of discretionary CIM trips include angular integration, recreational land-use and traffic composition along the route. While the angular integration has a negative association, the other two BE variables have positive associations with discretionary CIM. Results suggest that a one unit increase of angular integration decreases the odds of CIM to discretionary destinations by 1%. In contrast, the presence of recreational land-use along the route increases the odds by 18.4 times for a discretionary trip to be independent. The increase in low-speed non-motorised traffic by one unit increases the odds of discretionary CIM trip by 3.3 times. Among the sociodemographic variables, the odds of discretionary CIM trip increases by 75.1% for a child having an additional sibling ≤ 18 years old.

As reported in Table 5, the significant predictors for nondiscretionary CIM trips include three BE variables and four sociodemographic variables. Three significant BE variables are angular depth, institutional land-use and angular connectivity. An additional unit of step-depth between origin and destination is associated with a 21.8% reduction in the odds of taking a nondiscretionary CIM trip. The increase in angular connectivity and presence of institutional land-use along the route decreases the odds of nondiscretionary CIM trips by 83.2% and 99.9%, respectively. Four significant sociodemographic variables are gender, age, number of siblings ≤ 18 years old and family's ownership of motorised vehicles. Results suggest that girls are 55.7% less likely to take an independent nondiscretionary trip. The odds of independent nondiscretionary trip increases by 72.7% for a one year increase in child's age. Interestingly, the odds of independent nondiscretionary trip increases by 2.14 times for a child having an additional sibling ≤ 18 years old. On the other hand, one unit increase in the number of motorised vehicle owned by a child's family decreases the odds of independent nondiscretionary trip by 55%.

5. Discussion and Conclusions

While the empirical evidence base on BE characteristics influencing CIM is expanding, the focus has often been only on the geographic dimension of the BE. Less attention has been given to the topological dimension of the BE. This study attempted to examine the effects of a wide range of topological and geographic BE indicators on CIM. Another goal of this investigation was to broaden the knowledge beyond school trips and distinguish the effects between discretionary and nondiscretionary CIM trips. This knowledge is needed for effective BE interventions aiming to encourage children to be more independent. The following sub-sections discuss the key findings from this study in policy terms.

5.1 Topological BE is an important factor for CIM

A number of observations can be made from the empirical results on the BE-CIM link. First, the topological dimension was found to be as important as the geographic dimension. For instance, the significant negative association of step-depth confirms that children are more likely to avoid the visually longest routes in the street network. This clearly indicates that an increased degree of directional changes in a route, regardless of its metric distance, acts as a barrier to CIM. This could be attributed to the decreased sense of safety and comfort along with increased perceived risk among children and parents when the visual connection is interrupted. Perceived risk of children and parents has already been identified by Carver et al. (2010) as a barrier to children's active travel. The high correlation between depth and distance indicates that they are both important in explaining CIM. The importance of step-depth as found in this research and distance to destinations as found in previous research, for example in Loebach and Gilliland (2014), has significant policy bearings and should both be considered in designing the street networks in an area.

The negative association between integration and CIM reaffirms that children's travel choices are different from adults. While integrated streets are more attractive and accessible to adult pedestrians, the same streets are less appealing to children to walk independently. This is an interesting finding that contradicts the general assumption that pedestrian movement potentials and exploratory natural movement are likely to increase on highly integrated streets (Hillier et al., 1993; Turner and Penn, 2002), characterised by lower crime rates and antisocial behaviours as reported in Hillier and Shu (2000). One explanation of this could be that more integrated streets mean more connected streets, which are in turn linked with increased traffic volume. Heavy traffic and traffic safety have always been a major concern for children and parents for CIM (Carver et al., 2014a; Tranter and Doyle, 1996; Villanueva et al., 2012; Villanueva et al., 2013). Aligned with the above literature, this study confirmed children's preferences for routes, which cater predominantly to low-speed non-motorized traffic and are less connected to other streets. This finding reconfirms previous findings that more connected roads reduce CIM, whereas dead ends (opposite to connected street) increase CIM in Dhaka (Islam et al., 2014; Monsur et al., 2017). The negative association with angular connectivity is in contrast with adults' active travel behaviour as found by Wineman et al. (2014), highlighting that some configurational properties of streets act as a barrier for CIM.

Integrated streets, furthermore, increase the opportunities for commercial growth along the street, which consequently attracts further pedestrians and transform the street to more crowded (Can and Heath, 2016; Peponis et al., 1996). The increased crowd could be associated with an increased level of stranger danger among children. If children perceive stranger danger, their CIM drops in the context of both developed and developing countries (Bwire, 2011; Foster et al., 2014). This explains why children of current study avoided the routes with more integration and institutional facilities. However, unlike institutional land-uses, the presence of recreational land-uses such as water body, park and playgrounds along the route were found to promote CIM. This aligns with previous findings that children living near a park tend to make more CIM trips (Mackett et al., 2007; Prezza et al., 2001).

These findings further raise two major policy concerns: a) how to design street networks that would be beneficial for active movement for both children and adults, or in other words, how should the city planners and urban designers balance between highly integrated/connected street and less traffic volume?; and b) how should the BE professionals negotiate between child-friendly land-uses and adult-friendly land-uses in a neighbourhood?

5.2 BE influences discretionary and nondiscretionary CIM differently

This study found that the geographic and topological BE variables correlating with discretionary and nondiscretionary CIM are different. For instance, as a topological factor, step-depth and angular connectivity were found to have statistically significant associations with nondiscretionary CIM. In contrast, it was integration for discretionary CIM. Similarly, some geographic BE factors such as presence of recreational land-use along the route, and traffic composition are only associated with discretionary CIM whereas presence of institutional land-use is only associated with nondiscretionary CIM. A plausible interpretation could be that children prefer direct, less-connected and safe routes to nondiscretionary destinations (e.g. school). This behaviour is expected given the repeated and mandatory nature of this activity type. On the other hand, for discretionary CIM (e.g. park, shop, friend's home etc.), children tend to go through less crowded and more relaxing areas (where park or waterbody exist along the routes). These findings clearly indicate the policy bearing that BE interventions should be customised according to the destination type to promote CIM.

Other than BE variables, socio-demographic and personal factors were found consistently important for children's overall, discretionary and nondiscretionary trips. Consistent with previous studies, older children and children having siblings were found more likely to make independent trips whereas, girls compared to boys and children having motorised vehicle at home are less independent (Lopes et al., 2014; Prezza and Pacilli, 2007; Rissotto and Giuliani, 2006). However, depending on the purpose of trips, the significance of these factors varies. For example, for discretionary trips, only having siblings can make a positive difference whereas, for nondiscretionary trips, where school has a major share, boys and older children enjoy more independence.

5.3 Limitation and Strength of the study

This study has several limitations. CIM was measured by self-reported children's independent visits to different destinations as this is the most commonly conceptualised form of CIM. However, CIM can be conceptualised in different ways (e.g. CIM range, CIM licence). Future studies should focus on these CIM measures and improve the understanding presented in this study. Moreover, this study measured distance quantitatively (both geographic and topological). Research has shown that cognitive distance also affects travel behaviour (Montello, 1997). Further research is warranted to investigate the effects of cognitive distance on CIM and how this differs between children and adults. Furthermore, it would be worth investigating how an increased level of entropy/information of locations that offer more than one route for movement choice impact CIM. An inclusion of the perception of local environment would also help to understand the effects of BE more robustly. This research combined all kind of independent travel modes reported by the participants. However, a separation of active vs non-active CIM as well as independent walking vs independent cycling could provide detailed knowledge about transport mode-specific CIM behaviour. This will also help policymakers to make effective interventions in promoting CIM. This is worth noting that the findings are based on the case study of Dhaka, and may relate to some of its morphological and cultural specificity. Despite the above limitations, the evidence from this comparative study adds to the current body of knowledge documenting the importance of topological BE on CIM and the most influential geographic and topological BE variables for discretionary and nondiscretionary trips. The findings serve as a guide for local as well as global policymakers and other BE professionals to design and deliver children friendly environments across the city where children can enjoy the freedom of movement, exploration and play, and can get an active and healthy life.

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The impact of topological properties of built environment on children independent mobility: A comparative study between discretionary vs. nondiscretionary trips in Dhaka

Table 1: Summary statistics of variables included in the model

Variable Name	Frequency	%	Mean	St.Dv
Child demography and individual factors				
Gender				
Male	71	47.0	-	-
Female	80	53.0	-	-
Age (years)	-	-	12.25	1.47
Number of sibling ≤ 18 years old	-	-	0.89	0.70
Number of car/ motorbike in family	-	-	0.30	0.52
I have lots of friends in neighbourhood				
Yes	105	70	-	-
No	46	30.5	-	-
I know a lot of people in my neighbourhood				
Yes	112	74.2	-	-
No	39	25.8	-	-
Ownership of cycle				
Yes	56	37.1	-	-
No	95	62.9	-	-
Case study area				
Area 1 (Azimpur)	58	38.4	-	-
Area 2 (Madhubag)	32	21.2	-	-
Area 3 (Manikdi)	41	27.2	-	-
Area 4 (Uttara)	20	13.2	-	-
Family demography				
Length of stay (year) in current neighbourhood	-	-	8.97	7.44
Family income				
less than 25000 taka ($324 USD)	45	29.8	-	-
26000-50000 ($325-$625)	64	43.0	-	-
51000-100000 ($626-$1250)	34	22.5	-	-
100000-200000 ($1251-$2500 USD)	6	4.0	-	-
more than 200000($2500 USD)	1	0.7	-	-
Age of Mom (year)				
<30	15	9.9	-	-
30-45	128.0	84.8	-	-
>45	8.0	5.3	-	-
Age of Dad (year)				
<30	0	0.0	-	-
30-45	87.0	57.60	-	-
>45	64.0	42.40	-	-
Relationship with participating child				
Mother	94	62.3	-	-
Father	52	34.4	-	-
Other	5	3.3	-	-
Trip Information				
Total trip	466	100.0	-	-
Independent	327	70.2	-	-
Discretionary independent trip	173	52.9	-	-
Non-Discretionary independent trip	154	47.1	-	-
Weekday independent trip	231	70.6	-	-
Weekend independent trip	96	29.4	-	-
Discretionary independent trip on weekday	96	55.5	-	-
Discretionary independent trip on weekend	77	44.5	-	-
Non-Discretionary independent trip on weekday	135	77.7	-	-
Non-Discretionary independent trip on weekend	19	11	-	-

Dependent	139	29.7	-	-

Table 2: Categories and description of explanatory variables used to collect BE data

BE Type	BE Categories	Variable Name	Level	Explanation	Measuring Scale
Geographic BE	**Distance**	Distance		Network distance (m) to destination	Continuous
	Land Use	Residential land use	None	If there is no residential use in the ground floor along a segment	1
			Few	If there are a few residential uses in the ground floor along a segment	2
			A lot	If there are a lot of residential uses in the ground floor along a segment	3
		Commercial and retail land use	None	If there is no commercial/ retail use in the ground floor along a segment	1
			Few	If there are a few commercial/ retail and business use in the ground floor along a segment	2
			A lot	If there are a lot of commercial/ retail and business use in the ground floor along a segment	3
		Institutional land use	None	If there is no institutional use in the ground floor along the segment	1
			Few	If there are a few institutional uses in the ground floor along the segment	2
			A lot	If there are a lot of institutional uses in the ground floor along the segment	3
		Recreational land use	Yes	If recreational use (e.g. park, waterbody) is present along the segment	1
			No	If no recreational use is present along the segment	0
		Religious land use	Yes	If religious use (e.g. mosque, church, temple) is present along the segment	1
			No	If no religious use (e.g. mosque, church, temple) is present along the segment	0
		Vacant land	Yes	If there is a vacant lot present along the segment	1
			No	If there is no vacant lot present along the segment	0
		Under-construction land use	Yes	If there is an under-construction land use present along the segment	1
			No	If there is no under-construction land use lot present along the segment	0
		Setback	No building	If there is no building along the segment	1
			>1.5m	If building at >1.5m from the segment	2
			< 1.5m	If building at < 1.5m from the segment	3
			At edge	If building at the edge of the segment	4
	Walking Environment	Footpath availability	Yes	If footpath is present	1
			No	If footpath is absent	0
		Footpath width	None	If footpath is absent	0
			<1m	If footpath width is <1m	1
			1m-2m	If footpath width is between 1m-2m	2
			>2m	If footpath width is >2m	3
		Footpath continuity	None	If footpath is absent	1
			Incomplete	If footpath is incomplete	2
			Complete	If footpath is complete	3
		Walking environment condition	Poor	If many bumps/cracks/holes/ dirty objects are present on the segment	1
			Moderate	If some bumps/cracks/holes/ dirty objects are present on the segment	2
			Good	If very few bumps/cracks/holes/dirty objects are present on the segment	3
		Walking environment obstruction	Yes	If poles/ parked vehicles/ garbage cans/ vendors/ temporary structures/construction materials are present on the segment	1
			No	If poles/ parked vehicles/ garbage cans/ vendors/ temporary structures/construction materials are absent on the segment	0
		Stopover activities	Yes	If food cart, vendor/shops with children's kinds of stuff are present along the segment	1
			No	If food cart, vendor/shops with children's kinds of stuff are present along the segment	0
	Traffic Environment	Street width	Primary	If the street width is >9m	1
			Secondary	If the street width is between 6m-9m	2
			Tertiary	If the street width is between 3m-6m	3
			Feeder	If the street width is <3m	4
		Street connectivity		Number of intersecting axial lines at the end of the road segment	Continuous
		Intersection with traffic control measure	Yes	If there is traffic light/traffic police/zebra crossing at the intersection of a segment	1
			No	If there no traffic light or traffic police at the intersection at the end of a segment	0
		Pedestrian volume	Low	If 0-5 pedestrians are visible on a segment at a time	1
			Moderate	If 6-30 people are visible on a segment at a time	2

			High	If >30 people are visible on a segment at a time	3
		Traffic composition	High speed motorised traffic	If only high-speed motorised traffic (e.g. car, bus, truck etc.) are present on a segment	1
			Moderate speed motorised traffic	If a mixture of high and moderate speed motorised traffic (e.g. car, bike, cng etc.) is present on a segment	2
			Moderate speed motorised and non-motorised traffic	If a mixture of moderate speed motorised and non-motorised traffic (e.g. rickshaw, bike, cng, private car etc.) is present on a segment	3
			Low-speed non-motorised traffic	If only non-motorised traffic (e.g. rickshaw, cycle, school van etc.) is present on a segment	4
	Aesthetic, Comfort and Safety	Number of tree shades	None/ very few	If no/very few trees are present along a segment	1
			Some	If some trees are present along a segment	2
			Many/ dense	If many/dense trees are present along a segment	3
		Building height	No building	If no building is present along a segment	0
			Short	If average building height along a segment is 1-2 stories	1
			Medium	If average building height along a segment is 3-6 stories	2
			Tall	If average building height along a segment is more than 6 stories	3
		Physical access	Low/None	If low/no level of physical access to adjacent land use is present	1
			Moderate	If a moderate level of physical access to adjacent land use is present	2
			High	If a high level of physical access to adjacent land use is present	3
		Visual access	Low/None	If a low level/no visual connection to adjacent land use is present	1
			Moderate	If a moderate level of visual connection to adjacent land use is present	2
			High	If a high level of visual connection to adjacent land use is present	3
Topological BE	**Topological properties of street**	Angular step-depth		Angular change between origin and destination of a taken route where 90º angle change is equivalent to 1 step depth	Continuous
		Angular integration		The closeness of each segment to all others in terms of the sum of angular changes that are made on each route where integration = Node count/ Mean depth	Continuous
		Angular choice		Chance of a segment to fall on the shortest angular path between origin and destination. Choice = $\sum_j \sum_k \frac{djk(i)}{djk}$, where d_{jk} refers to the shortest-path between line j and k; d_{jk} (i) refers to the shortest-path containing line I between line j and line k.	Continuous
		Angular connectivity		Cumulitive turn angle of a segment to other segments where 45º angle change is equivalent to 0.5 cumulative weight	Continuous

Table 3: Summary statistics of geographic and topological BE variables included in the model

Variable Name	Mean	Std. Dev.
Distance (m)	539.35	465.99
Presence of residential land use	1.89	0.42
Presence of commercial and retail land use	1.67	0.48
Presence of religious land use	0.08	0.09
Presence of recreational land use	0.14	0.16
Presence of other land use	1.11	0.08
Presence of vacant land	0.29	0.25
Presence of under-construction land use	0.11	0.17
Footpath availability	0.15	0.18
Footpath condition	2.33	0.40
Footpath obstruction	0.47	0.24
Street width	3.11	0.54
Street connectivity	2.00	0.18
Intersection with traffic measure	0.01	0.03
Traffic composition along the route	3.28	0.52
Number of trees	1.82	0.49
Building height	1.68	0.38
Visual access	2.04	0.30

Angular step depth	3.35	2.47
Angular integration	356.811	92.90
Angular choice	199058.90	172253.50
Angular connectivity	2.56	0.37

Table 4: Correlations coefficient among BE variables

Sl	Variable Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Angular connectivity	1																											
2	Angular choice	-0.229	1																										
3	Angular integration	0.409	0.348	1																									
4	Angular step-depth	-0.141	-0.082	-0.131	1																								
5	Distance	-0.104	-0.071	-0.209	0.638	1																							
6	Presence of residential land use	0.344	-0.443	0.124	-0.138	-0.192	1																						
7	Presence of commercial and retail land use	-0.370	0.442	-0.109	0.171	-0.064	-0.478	1																					
8	Presence of religious land use	-0.051	0.019	0.105	-0.162	-0.109	-0.201	0.259	1																				
9	Presence of recreational land use	0.029	-0.317	-0.106	-0.222	-0.093	0.132	-0.473	0.092	1																			
10	Presence of institutional land use	-0.132	0.049	0.002	0.068	0.277	-0.359	0.090	0.235	-0.228	1																		
11	Presence of vacant land	0.133	-0.406	-0.313	-0.106	0.254	0.116	-0.671	-0.178	0.358	-0.076	1																	
12	Presence of under construction land use	-0.097	-0.158	-0.188	0.081	0.142	0.229	0.062	-0.075	-0.103	-0.022	0.151	1																
13	Setback of building	-0.201	0.359	0.090	0.141	-0.137	-0.093	*0.749*	0.094	-0.484	-0.083	*-0.729*	0.178	1															
14	Footpath availability	0.217	0.313	0.653	0.052	-0.001	-0.124	-0.071	0.018	-0.046	0.141	-0.270	-0.190	0.061	1														
15	Footpath width	0.059	0.461	0.483	0.072	0.011	-0.102	-0.086	0.015	0.023	0.130	-0.259	-0.199	0.031	*0.967*	1													
16	Footpath continuity	0.198	0.599	0.512	0.047	-0.017	-0.150	-0.030	0.076	-0.038	0.138	-0.312	-0.250	0.066	*0.969*	*0.960*	1												
17	Footpath condition	0.072	-0.072	-0.456	0.156	0.259	-0.030	-0.014	-0.068	0.021	0.008	0.175	-0.076	-0.190	-0.345	-0.324	-0.304	1											
18	Footpath obstruction	-0.146	0.174	0.053	0.278	0.063	-0.273	0.589	0.010	-0.352	0.105	-0.370	0.415	0.529	0.112	0.117	0.099	-0.020	1										
19	Street width	0.022	-0.256	-0.160	-0.148	-0.436	0.302	-0.026	-0.112	0.038	-0.390	-0.114	-0.053	0.005	-0.378	-0.386	-0.379	-0.225	-0.265	1									
20	Street connectivity	0.204	-0.116	0.174	0.001	0.114	-0.036	-0.091	0.067	-0.073	0.176	-0.009	0.092	-0.001	0.160	0.133	0.105	-0.168	0.019	-0.115	1								
21	Stopover activities	-0.374	0.466	-0.061	0.125	-0.127	-0.279	*0.861*	0.327	-0.444	0.170	-0.663	0.160	*0.731*	-0.023	-0.032	0.023	-0.086	0.534	0.037	-0.154	1							
22	Intersection with traffic control	0.274	0.173	0.083	0.029	-0.049	-0.003	-0.107	0.079	-0.025	0.197	-0.053	-0.178	-0.223	0.227	0.242	0.291	0.009	-0.070	0.034	0.128	-0.003	1						
23	Pedestrian volume	-0.312	0.603	0.126	0.116	-0.017	-0.635	*0.704*	0.286	-0.298	0.406	-0.585	-0.202	0.457	0.245	0.208	0.270	-0.120	0.391	-0.146	-0.047	0.670	0.099	1					
24	Traffic composition	-0.146	-0.127	-0.064	-0.027	-0.291	0.138	0.005	-0.306	-0.116	-0.444	-0.087	-0.037	0.175	-0.217	-0.250	-0.253	-0.319	-0.068	0.612	-0.174	-0.036	-0.290	-0.106	1				
25	Number of trees	0.271	-0.275	-0.194	-0.070	0.229	-0.110	-0.619	0.025	0.471	-0.012	0.655	-0.247	*-0.814*	0.041	0.076	0.049	0.303	-0.411	-0.197	0.028	-0.663	0.104	-0.370	-0.182	1			
26	Building height	0.606	-0.365	0.264	-0.100	-0.232	0.574	-0.156	-0.048	-0.087	-0.121	-0.058	-0.005	-0.048	-0.014	0.019	0.019	0.051	-0.081	0.097	-0.042	-0.069	0.276	-0.335	-0.227	-0.171	1		
27	Physical access	0.217	-0.048	0.052	0.006	-0.173	-0.101	0.419	0.082	-0.151	-0.035	-0.210	-0.079	0.224	-0.318	-0.303	-0.299	0.047	0.249	0.162	-0.075	0.229	-0.119	0.197	0.030	-0.244	0.296	1	
28	Visual access	0.236	0.046	0.046	-0.009	-0.114	-0.247	0.321	0.075	-0.140	-0.002	-0.085	-0.146	0.076	-0.176	-0.183	-0.149	0.042	0.223	0.052	-0.001	0.107	-0.036	0.198	0.022	-0.051	0.229	*0.907*	1

*Column numbers represents the corresponding variable serial as shown in the Sl column
*Italic and highlighted indicate a stronger correlation (value ≥ 0.7)

Table 5: Binary logistic regression analysis results of overall CIM, discretionary CIM and non-discretionary CIM

Variable Name	Overall CIM					Discretionary CIM					Non-discretionary CIM				
	Odds Ratio	**Std. Err.**	**z**	**P>|z|**	**95% CI**	**Odds Ratio**	**Std. Err.**	**z**	**P>|z|**	**95% CI**	**Odds Ratio**	**Std. Err.**	**z**	**P>|z|**	**95% CI**
Angular step-depth	0.896	0.043	-2.28	0.023	0.816 0.985	-	-	-	-	-	0.786	0.061	-3.08	0.002	0.675 0.916
Angular integration	0.996	0.001	-2.66	0.008	0.994 0.999	0.995	0.002	-2.65	0.008	0.991 0.999	-	-	-	-	-
Angular connectivity	-	-	-	-	-	-	-	-	-	-	0.168	0.086	-3.47	0.001	0.062 0.460
Presence of recreational land use	12.153	12.057	2.52	0.012	1.739 84.946	18.451	22.775	2.36	0.018	1.642 207.343	-	-	-	-	-
Presence of institutional land use	-	-	-	-	-	-	-	-	-	-	0.001	0.001	-3.74	0.001	0.000 0.017
Traffic composition along the route	2.462	0.581	3.82	0.001	1.551 1.909	3.349	1.157	3.5	0.001	1.702 6.593	-	-	-	-	-
Gender (Female=1, Male= 0)	0.475	0.121	-2.92	0.003	0.288 0.782	-	-	-	-	-	0.443	0.148	-2.43	0.015	0.230 0.854
Age	1.393	0.120	3.84	0.001	1.176 1.649	-	-	-	-	-	1.727	0.224	4.22	0.001	1.340 2.226
Number of sibling ≤ 18 years old	1.875	0.370	3.19	0.001	1.274 2.759	1.751	0.451	2.17	0.030	1.056 2.901	2.147	0.605	2.71	0.007	1.235 3.731
Number of Motorised vehicle	0.559	0.148	-2.19	0.028	0.332 0.940	-	-	-	-	-	0.450	0.150	-2.4	0.016	0.235 0.864
Cons	0.005	0.008	-3.32	0.001	0.000 0.111	0.114	0.157	-1.57	0.116	0.008 1.705	5385.166	19064	2.43	0.015	5.222 5553080
Log pseudo- likelihood				*-235.751*					*-96.678*					*-124.152*	
Prob > chi2				*0.001*					*0.0001*					*0.001*	
Wald chi2				*55.8*					*20.78*					*45.63*	
Pseudo R2				*0.169*					*0.127*					*0.245*	
N				*466*					*217*					*248*	

Appendix A

Table A: Odds of explanatory variables in bivariate unadjusted model for overall CIM, Discretionary CIM and Nondiscretionary CIM

Variables	**Overall CIM**		**Discretionary CIM**		**Nondiscre**	
	Odds Ratio	**95% CI**	**Odds Ratio**	**95% CI**	**Odds Ratio**	**9**
Angular step depth	0.877***	.801 .959	0.927	.817 1.051	0.897**	[illegible]
Angular integration	0.996***	.995 .999	0.996**	.981 .999	0.998	[illegible]
Angular choice	1.000	.999 1.000	1.000	.999 1.000	1.000	[illegible]
Angular connectivity	0.364***	.204 .694	0.518	.240 1.18	0.233***	[illegible]
Distance	0.998***	.998 .999	0.999**	.998 1.000	0.998***	[illegible]
Presence of residential land use	1.089	.638 1.859	1.346	.632 2.867	0.694	[illegible]
Presence of commercial and retail land use	1.027	.655 1.609	0.603*	.332 1.095	1.521*	[illegible]
Presence of institutional land use	0.011***	.001 .1871	0.051*	.001 2.284	0.015**	[illegible]
Presence of religious land use	0.211	.019 2.334	0.118*	.006 2.217	0.224	[illegible]
Presence of recreational land use	12.055***	2.382 61.014	13.564**	1.190 154.502	5.307	[illegible]
Presence of vacant land	1.111	.453 2.725	3.140*	.803 12.271	0.512	[illegible]
Presence of under construction land use	0.679	.198 2.330	0.286*	.050 1.619	1.258	[illegible]
Footpath availability	0.274**	.090 .828	0.221*	.035 1.386	0.575	[illegible]
Footpath condition	0.986	.587 1.656	1.164	.631 2.146	0.881	[illegible]
Footpath obstruction	0.573	.222 1.477	0.162***	.041 .636	2.391	[illegible]
Street width	1.859***	1.22 2.834	1.980**	1.093 3.586	1.507	[illegible]
Street connectivity	0.095**	.015 .597	0.267***	.120 .594	0.001***	[illegible]
Intersection with traffic control measure	0.034	.000 80.105	0.003	.000 78.838	1.289	[illegible]
Traffic composition along the route	1.971***	1.23 3.135	1.940**	1.083 3.473	2.005**	[illegible]
Number of tree	0.906	.557 1.472	1.570*	.834 2.955	0.636*	[illegible]
Building height	0.524**	.295 .929	0.403	.160 1.014	0.493**	[illegible]
Visual access	0.682	.333 1.398	0.811	.284 2.318	0.368**	[illegible]
Study area						
1	Ref	-	Ref	-	Ref	
2	1.849**	.927 3.688	1.770	.624 5.021	2.135**	[illegible]
3	2.107**	1.178 3.767	2.318	.823 6.528	2.057**	[illegible]
4	0.521**	.260 1.044	0.317**	.119 .844	0.740	[illegible]

* Significant at the 0.10 level
** Significant at the 0.05 level
*** Significant at the 0.01 level

Article Title:

The impact of topological properties of built environment on children independent mobility: A comparative study between discretionary vs. nondiscretionary trips in Dhaka

Figure 1: Study areas and the location of selected schools in wider geographic context of Dhaka, Bangladesh

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