Comparison and Evaluation of Built Environment Factors for Developing Pedestrian Urban Travels

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ABSTRACT

Summary: This study examines the impacts of the built environment on pedestrian urban travels using a fuzzy AHP approach, by taking into account fifteen different variables based on three criteria: network design, environment, and safety. We gathered data from academic and industry experts using a fuzzy-based pairwise comparative survey.

Advantage: We adopt two methods for selecting high-priority variables. The average value of cumulative weights, which prioritise variables with a weight greater than the average value, and a variation weights values analysis that divides variables into three groups as high, medium, and low priority depending on the weight pattern slope's breaking points. The findings indicate that the weights variation approach is more effective.

Limit: Because the survey statistical population comprised both academic and industrial experts, a significant amount of effort was spent identifying qualified candidates and gathering the necessary data.

Results: The results prioritise effective variables including level of stress, lighting, obstacles on sidewalks, width of sidewalk, sidewalk surface quality, pedestrian bridges, cleanliness and density of green areas, access to public transportation, intersection traffic controls, and walking utilities. Furthermore, the findings show that by growing policies on the variables of high and medium priority, up to 68 percent of the objective function can be achieved pedestrian urban commuting will significantly improve.

1. Introduction

Walking is not only an environmentally sustainable mode of transportation but it has also been found in several reports to have favourable impacts on public health [1–3]. Many studies have been conducted on the influences of active travels on air quality, traffic congestion, obesity, and detrimental effects of motorised vehicles [4–7]. Mode choice investigation for
several developed countries revealed that long-term intervention policies in active travel contributed to a decline in vehicle ownership and an increase in walking, bicycling, and public transport [8–11].

The relation between urban built environment (BE) factors (land use mix, street connectivity, access to public transport, and safety strategies) and the decision to walk for transportation is considered in various studies [12–22]. Zhao and Wan indicated that for promoting walking, a dense street design with land use complexities and a viable environment is one of the best scenarios [23]. Zhao et al. indicated that a higher density of mixed land use grows active transport modes [24]. Chen et al. suggested that neighbourhood form, land use mixture, street networks, and green environment have significant impacts on walking choices [25]. Kang et al. indicated that BE factors and trip purpose influence individuals’ walking frequency, pace, distance, and location [26]. Zhang et al. indicated that for developing shopping active travels, neighbourhood built environments should be socio-economic. They proposed that a policy based on the completed commercial infrastructure and public transit links in the communities would be appropriate [27]. Park et al. found that besides socio-demographic factors and car ownership, BE amenities, including sidewalks quality, have a significant effect on active school trips [28]. Boulange et al. presented that network design and BE characteristics such as land use combination, street connectivity, residential density, and access to retail centres are positively correlated with active travels and negatively associated with car use [29]. Gaglione et al. indicated that physical characteristics (slope, sidewalk width, and sidewalk pavement), urban characteristics (green areas, and non-main roads), and safety characteristics (lighting, traffic volume) are influenced elderly accessibility [30]. Lin et al. demonstrated that pedestrian injury frequency and severity are attributed not only to demographic characteristics but also to road environment factors such as intersection controls, public transit access, vehicle speed, and land use mix diversities [31]. Osama and Sayed found that BE features such as public transit stop location, traffic signals, commercial centres density are positively correlated with pedestrian safety [32]. Hong and Chen indicated that individuals who live in neighbourhoods with decent accessibility and good walking infrastructure tend to perceive their environments safer and are more likely to commute long distances through walking [33]. Clifton et al. suggested that apart from the behavioural attributes, BE factors such as lighting, marked crosswalk, access to public transit, and sidewalks connectivity are negatively correlated with accident severity [34].

As shown above, it is clear that several studies have been conducted on the impacts of the BE on active travel. However, in order to determine the best policies for walking improvement, a necessity of evaluation, comparison, and prioritising of these variables is evident from the literature. Our study seeks to reduce the shortcomings of past literature through a fuzzy analytical technique. The purpose of this study is twofold: (a) Identifying BE factors affecting the walking frequency and tendency; (b) Comparing and prioritising these variables depending on their importance, through fuzzy set theories.

The remainder of this study is organised as follows. The methodology is introduced in Section 2. In Section 4 data analysis is presented. Discussion and results are presented in Section 5. Finally, Section 6 concludes the paper and provides suggestions for future research.
2. Methodology

2.1. Multi-criteria Decision Analysis (MCDA)

The MCDA employs analytical and mathematical methods to assist in the evaluation of a variety of options based on a variety of goals and criteria [35]. In areas such as sustainable development, supply chain management, and logistics and transportation, the MCDA has been broadly used to aid decision-making [36–46]. The conventional MCDA processing stages are: (1) Determining the relevant criteria and alternatives; (2) Assigning numerical values to the relative significance of the criteria and the effects of the alternatives on them; and (3) Analysing the numerical values that will be used to prioritise each alternative [47].

The most widely used MCDA approach in transportation is Saaty’s analytical hierarchy process (AHP) [48]. AHP framework uses a pairwise comparison to evaluate the criteria weights [49]. Generally, experts are invited to participate in the weight evaluation. Any pairwise comparison yields a numerical value, which represents the weight ratio of the two decision parameters. To assign numerical values, the Saaty preference scale is used, which ranges from one to nine, and represents the significance of one alternative over another [50].

The comparisons of variables through the AHP technique are not only inaccurate because of the arbitrary essence of linguistic judgments, as seen in Saaty’s scales, but also is extremely difficult to determine uncertain decisions by these exact static scale values [51]. However, determining an unpredictable conclusion based on these particular static scale values is extremely difficult. When dealing with ambiguous decisions to express the relative value of parameters, it’s possible to use fuzzy sets or fuzzy numbers, which take into account the fuzziness of human thought. One of the most common techniques to integrate fuzziness into MCDM is the fuzzy AHP.

2.2. Fuzzy AHP

The fuzzy AHP (FAHP) is an extension of the AHP technique for MCDM in pairwise-based comparisons that deal with uncertain real-world decision problems [52]. According to Chen and Hsieh [53], FAHP consists of the following steps in deployment: (1) Establishing a hierarchy of levels for decision-making; (2) prioritisation based on fuzzy pairwise comparisons; (3) Searching for accuracy of the experts’ priority decisions; (4) Combination of pairwise preferences; and (5) Defuzzification of the priorities. Since fuzzy numerical means are not crisp values and therefore cannot be ranked explicitly, defuzzification is required [54].

In a FAHP decision problem, there is a collection of alternatives \([M_i (i = 1, 2, \ldots, m)]\), a set of evaluation criteria \([C_j (j = 1, 2, \ldots, n)]\), a linguistic judgment \((r_{ij})\) expressing the relative value for every pair of criteria, and a weighting vector \([W = (W_1, W_2, \ldots, W_n)]\). The FAHP, like the conventional AHP, has a decision matrix. However, this method employs triangle fuzzy numbers (TFNs) instead of fixed pairwise values [55]. A fuzzy number \(\tilde{F}\) is a triangular fuzzy number if it is defined according to Equation (1) and illustrated as in Figure 1 [56].

\[
\tilde{\mu}_A(x) = \begin{cases} 
(x - \frac{l}{m} - l), & l \leq x \leq m, \\
(u - x) - m, & m \leq x \leq u, \\
0, & \text{otherwise}
\end{cases}
\]  

(1)
Figure 1. Demonstration of a triangular fuzzy number $\tilde{A}$ [55].

Table 1. Fuzzy linguistic variables and corresponding fuzzy numbers [55].

| Linguistic variable        | Fuzzy number | Membership function |
|----------------------------|--------------|---------------------|
| Equally important         | $\tilde{1}$  | (1,1,3)             |
| Moderately important      | $\tilde{3}$  | (1,3,5)             |
| More important             | $\tilde{5}$  | (3,5,7)             |
| Strongly important         | $\tilde{7}$  | (5,7,9)             |
| Extremely important        | $\tilde{9}$  | (7,9,9)             |
| Intermediate values in judgments | $\tilde{2, 4, 6, 8}$ | |

As shown in Equation (1) and Figure 1, the comparative ratios between the factors $i$ and $j$ are described by TFN, which defines the judgment regarding $a_{ij}$, and are represented by $\tilde{a}_{ij}$ which is denoted by $(l, m, u)$. In a TFN, parameters $l$, $m$, $u$ indicate the smallest possible value, the most optimistic value, and the largest possible value, respectively [56].

As represented in Equation (2), matrix $\tilde{A}$ reflects an $(n \times n)$ decision matrix consisting TFNs ($\tilde{a}_{ij}$) for all $i, j \in \{1, 2, \ldots , n\}$.

$$\tilde{A} = \tilde{a}_{ij} = \begin{bmatrix}
(1, 1, 1) & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\
\tilde{a}_{21} & (1, 1, 1) & \cdots & \tilde{a}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & (1, 1, 1)
\end{bmatrix}$$

Table 1 presents fuzzy linguistic variables to depict the fundamental fuzzy numbers used in factor calculations. These definitions are used to make pairwise comparisons easier to utilise in fuzzy-based decision-making systems so that they can be applied to determine which TFN is superior to another.

The prioritisation process is the most essential phase in the FAHP. The basic procedure is summarised as follows.

1. Constructing and organising the decision-making hierarchy. At the first step, we restructure the intricate decision-making problem into a hierarchical framework. The resulting structural context is useful in explaining the relationships between the parameters of each decision level, as well as assisting decision-makers in investigating the effects of various decision criteria on the analysis process [57].

2. Developing the fuzzy pairwise comparison matrices. Pairwise comparison is used to assess the relative significance of the criteria. The relative value is converted into TFNs after expert analysis [54].
(3) Consistency test and prioritising fuzzy weights. A fuzzy comparison matrix $\tilde{A} = \{\tilde{a}_{ij}\}$ is consistent if $\tilde{a}_{ik} \otimes \tilde{a}_{ki} \approx \tilde{a}_{ij}$, where $i, j, k = 1, 2, \ldots, n$ [58]. After that, the fuzzy priorities $\tilde{w}_i$ are estimated, from which the priority vectors $(w_1, w_2, \ldots, w_n)^T$ are derived from the comparison matrix, using a prioritisation hierarchy methodology [59].

To estimate the weight values for decision criteria and alternatives, the synthetic extent values can be calculated from Equation (3).

$$S_i = \sum_{j=1}^{m} M_{ij} \otimes \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij} \right]^{-1}$$

where $M_{ij}, j = 1, 2, 3 \ldots, n$ are TFN values. The degree of possibility of $M_1 \geq M_2$ is presented in Equation (4).

$$V(M_2 \geq M_1) = hgr(M_1 \cap M_2) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases}$$

(4) Defuzzification. The graded mean integration representation approach can be used to overcome conversion of fuzzy weights to crisp weights, as shown in Equations (5) and (6) [60]:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \ldots \otimes \tilde{a}_{ij} \otimes \ldots \otimes \tilde{a}_{in})^{1/n}$$

$$\tilde{w}_i = \tilde{r}_i \otimes \left[ \tilde{r}_1 \oplus \ldots \oplus \tilde{r}_j \oplus \ldots \oplus \tilde{r}_n \right]^{-1}$$

where $\tilde{a}_{ij}$ is fuzzy comparison value of dimension $i$ to criterion $j$, $\tilde{r}_i$ is a geometric mean of fuzzy comparison value of criterion $i$ to each criterion, and $\tilde{w}_i$ is the fuzzy weight of the $i$th criterion, which can be indicated by a TFN $\tilde{w}_i = (l_{wi}, m_{wi}, u_{wi})$ [60].

(5) Weight vector estimation and normalisation, and alternatives ranking. Finally, the local priorities extracted at various levels of the decision structure hierarchy are combined to produce composite priorities for the alternatives based on the weighted sum $A_i = \sum_{j=1}^{n} w_j a_{ij}$, where $w_j$ represents the weight of criterion $j$. The option that has a higher value of $A_i$ is preferred [61].

3. Modelling Approach and Results

Different variables must be identified in order to assess and compare the built environment influences on pedestrian commuting. Furthermore, data collection through an MCDM survey, as well as filtering and deletion of incompatible responses, are needed. Then, in sequence, the steps of fuzzy analysis should be performed. The model structure in Figure 2 demonstrates a summary of the modelling and data analysis process for this research.
3.1. Variables and Data Collection

The first step is to classify and evaluate the most important criteria and sub-factors. The variables were chosen based on their effects on walking patterns. The final variables were defined after obtaining a vast number of variables for each category from the literature review and a questionnaire from fifteen academic experts. There were three classes of BE variables: (1) network design, (3) safety factors, and (3) environment characteristics. Some of the most important variables based on the literature are as follows:

Network design variables: Physical circumstances such as sidewalk features, access to public transportation, topographic condition, street network connectivity, and level of traffic stress [16,19,23–25]. The level of traffic stress indicates the interaction between the traffic flow of the urban road network and the design conditions of the pedestrian network. This variable considers the collision level between pedestrians and vehicles under the parameters of speed limits, sidewalk characteristics, and road type [30].

Environment factors: Amenities, and aesthetic facilities including cleanliness and density of green areas, sidewalk surface quality, the existence of obstacles on sidewalks, lighting, and walking utilities such as frequency and quality of sitting places and scenic views [12,15,17].

Safety factors: Intersection traffic control (such as traffic lights, pedestrian traffic signs, and traffic calming), pedestrian crossing features (such as raised crosswalks, and distanced coloured crosswalks at intersections) [12,31–32], and crime security conditions (surveillance security systems, Security service centres, police and guard stations, and vitality) [33–34].

Figure 3 illustrates the hierarchical structure of the selected walking BE criteria and alternatives, as well as their codes.

For data collection, we produced a pairwise comparative survey based on TFNs that focused on all the criteria and selected BE variables shown in Figure 3 and was undertaken by 50 experts from academia and industry. The study was limited to 43 correct answer sheets after incompatible responses were eliminated. The statistical population is summarised in Figure 4 in terms of experience and areas of expertise.

3.2. Results of Data Analysis

The first step in the FAHP process is to develop a combined group decision pairwise comparison matrix for criteria and alternatives using data gathered from experts. Tables 2–5 demonstrate these matrices. Then, using Equation (3), synthetic extent values can be produced, with the results shown in Table 6. Tables 7–10 then indicates the outcomes of
Equation (4), the degree of possibilities for each criterion, and the estimation of raw and normalised weights for both criteria and alternatives.

It is now possible to calculate the priority of BE alternatives and criteria using the results of the normalised weight from the above tables. Figure 5 demonstrates the priority of the judgment factors depending on their weight. As can be shown, the environmental group has gained the most significance. Following that, the network design and safety categories were found to be important, respectively. Alternatives are prioritised by combining their weights and the related criteria. Table 11 shows the results of the cumulative weight estimation for the alternatives, as well as their prioritisation (Figure 6).
### Table 3. Pairwise comparison matrix for network design factors based on group decision-making.

|                  | Level of stress | Width of Sidewalk | Access to public transportation | Topographic condition | Network connectivity |
|------------------|-----------------|-------------------|---------------------------------|-----------------------|----------------------|
| Level of stress  | (1, 1, 1)       | (0.2, 1.15, 4)    | (0.13, 2.8, 5)                  | (0.13, 4.85, 7)       | (0.13, 3.65, 6)      |
| Width of Sidewalk| (0.2, 0.87, 4)  | (1, 1, 1)         | (0.2, 2.35, 6)                  | (0.16, 4.22, 6)       | (0.16, 3.22, 7)      |
| Access to public transportation | (0.2, 0.36, 5)  | (0.17, 0.43, 5)   | (1, 1)                          | (0.13, 2.15, 6)       | (0.16, 1.61, 6)      |
| Topographic condition | (0.14, 0.21, 4) | (0.13, 0.24, 4)   | (0.16, 0.47, 5)                | (1, 1)                | (0.16, 0.61, 5)      |
| Network connectivity | (0.17, 0.27, 4) | (0.13, 0.31, 5)   | (0.14, 0.62, 6)                | (0.13, 1.64, 5)       | (1, 1)               |

### Table 4. Pairwise comparison matrix for safety factors based on group decision-making.

|                     | Intersection traffic controls | Marked crosswalks | pedestrian bridges | Presence of police officers | Presence of security cameras |
|---------------------|-------------------------------|-------------------|--------------------|----------------------------|----------------------------|
| Intersection traffic controls | (1, 1, 1)                     | (0.25, 1.45, 6)  | (0.2, 0.77, 5)    | (0.33, 1.83, 5)            | (0.25, 0.85, 6)            |
| Marked crosswalks   | (0.17, 0.69, 4)               | (1, 1, 1)        | (0.16, 0.72, 4)   | (0.25, 1.42, 5)            | (0.33, 0.57, 5)            |
| pedestrian bridges  | (0.2, 1.3, 5)                 | (0.25, 1.39, 6)  | (1, 1, 1)         | (0.2, 3.25, 7)             | (0.16, 1.2, 4)             |
| Presence of police officers | (0.2, 0.54, 3)               | (0.2, 0.7, 4)    | (0.14, 0.31, 5)   | (1, 1)                     | (0.14, 0.35, 4)            |
| Presence of security cameras | (0.17, 1.15, 4)             | (0.2, 1.75, 3)   | (0.25, 0.83, 6)   | (0.25, 0.12, 7)            | (1, 1)                     |

### Table 5. Pairwise comparison matrix for environmental factors based on group decision-making.

|                                      | Cleanliness and density of green areas | Sidewalk surface quality | Obstacles on sidewalks | Lighting | Walking utilities |
|--------------------------------------|---------------------------------------|--------------------------|------------------------|----------|-------------------|
| cleanliness and density of green areas | (1, 1, 1)                             | (0.16, 0.61, 5)          | (0.14, 0.37, 6)        | (0.13, 0.32, 4) | (0.15, 3.65, 6)  |
| Sidewalk surface quality             | (0.2, 1.64, 6)                        | (1, 1, 1)                | (0.16, 0.68, 4)        | (0.16, 0.43, 5) | (0.2, 4.75, 6)   |
| Obstacles on sidewalks               | (0.17, 2.7, 7)                        | (0.25, 1.49, 6)          | (1, 1, 1)              | (0.25, 1.27, 6) | (0.17, 5.15, 4)  |
| Lighting                             | (0.25, 3.13, 8)                       | (0.2, 2.33, 6)           | (0.17, 0.71, 4)        | (1, 1)     | (0.13, 6.34, 5)  |
| Walking utilities                    | (0.13, 0.21, 6)                       | (0.13, 0.79, 5)          | (0.16, 0.19, 7)        | (0.25, 0.16, 4) | (1, 1, 1)        |

As seen in Figure 6, among the BE variables, the level of stress, lighting, and the physical characteristics of sidewalk such as obstacles on sidewalks, width of sidewalk, and sidewalk surface quality, as well as pedestrian bridges, and cleanness and density of green areas have found the highest priority.

### 4. Discussion

Using the FAHP approach, we tried to assess the effects of BE variables on pedestrian travels in terms of three general criteria: network design, safety, and environment. The priority of each alternative is determined by combining the weights of the variables and the criteria (Figure 6). Based on the results of Table 11, the priority of variables for each set of criteria is demonstrated in Figure 7. As can be shown, the environment criterion group’s variables not only have large weights, but the variance between the weights is also minimal, causing this criterion group to take precedence over other criteria. However, in the network design group, despite the large weights for variables of the level of stress and width of sidewalk, the discrepancy in the values of the variables’ weight is significant, so variables with small weights like network connectivity and topographic condition are also in this category. The variables in the safety criteria, on the other hand, were considered less significant by experts as compared to other categories’ variables; however, the variation in the weights of the variables in this group is slight, meaning that they are similar in importance.
Table 6. Synthetic values for criteria and variables.

| Synthetic index | Describes | Triangle fuzzy numbers |
|-----------------|-----------|------------------------|
| $S_1$           | Network Design | (0.04, 0.35, 2.84) |
| $S_2$           | Safety      | (0.04, 0.26, 2.13)    |
| $S_3$           | Environment | (0.04, 0.4, 2.9)     |
| $S_4$           | Level of stress | (0.01, 0.36, 2.38) |
| $S_5$           | width of Sidewalk | (0.02, 0.31, 2.98) |
| $S_6$           | Access to public transportation | (0.01, 0.15, 2.86) |
| $S_7$           | Topographic condition | (0.01, 0.07, 2.36) |
| $S_8$           | Network connectivity | (0.01, 0.1, 2.61) |

| Criteria        | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | $S_8$ |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Network design  |       |       |       |       |       |       |       |       |
| Safety          |       |       |       |       |       |       |       |       |
| Environment     |       |       |       |       |       |       |       |       |
| Level of stress |       |       |       |       |       |       |       |       |
| width of Sidewalk |     |       |       |       |       |       |       |       |
| Access to public transportation |     |       |       |       |       |       |       |       |
| Topographic condition |     |       |       |       |       |       |       |       |
| Network connectivity |     |       |       |       |       |       |       |       |

Table 7. Normalised weights for decision criteria.

| $S_1$ | $S_2$ | $S_3$ | Raw weight | Normalised weight |
|-------|-------|-------|------------|------------------|
| $V(S_1 \geq S_2, S_3)$ | –     | 1     | 0.98       | 0.98             |
| $V(S_2 \geq S_1, S_3)$ | 0.96  | –     | 0.94       | 0.94             |
| $V(S_3 \geq S_1, S_2)$ | 1     | 1     | –          | 1                |

Table 8. Normalised weights for network design variables.

| $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | Raw weight | Normalised weight |
|-------|-------|-------|-------|-------|------------|------------------|
| $V(S_4 \geq S_5, S_6, S_7, S_8)$ | –     | 1     | 1     | 1     | 1          | 0.212            |
| $V(S_5 \geq S_4, S_6, S_7, S_8)$ | 0.98  | –     | 1     | 1     | 0.98       | 0.208            |
| $V(S_6 \geq S_4, S_5, S_7, S_8)$ | 0.93  | 0.95  | –     | 1     | 0.93       | 0.198            |
| $V(S_7 \geq S_4, S_5, S_6, S_8)$ | 0.89  | 0.91  | 0.97  | –     | 0.98       | 0.189            |
| $V(S_8 \geq S_4, S_5, S_6, S_7)$ | 0.91  | 0.93  | 0.93  | 1     | –          | 0.193            |

Table 9. Normalised weights for safety variables.

| $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | Raw weight | Normalised weight |
|-------|-------|-------|-------|-------|------------|------------------|
| $V(S_9 \geq S_{10}, S_{11}, S_{12}, S_{13})$ | –     | 1     | 0.97  | 1     | 1          | 0.205            |
| $V(S_{10} \geq S_9, S_{11}, S_{12}, S_{13})$ | 0.97  | –     | 0.93  | 1     | 0.99       | 0.196            |
| $V(S_{11} \geq S_9, S_{10}, S_{12}, S_{13})$ | 1     | 1     | –     | 1     | 1          | 0.211            |
| $V(S_{12} \geq S_9, S_{10}, S_{11}, S_{13})$ | 0.94  | 0.97  | 0.90  | –     | 1          | 0.190            |
| $V(S_{13} \geq S_9, S_{10}, S_{11}, S_{12})$ | 1.02  | 1     | 0.94  | 1     | –          | 0.198            |

There are a variety of approaches in selecting high-priority variables. The average value of the cumulative combined weights of the variables, which we use in our analysis, is one of them. Figure 8 indicates the importance of the studied variables depending on their combined weight, and the horizontal line represents the average value of the weights, which is approximately tangent to the variable of access to public transportation.

According to the average value, variables that have larger and equal weights to the average value, such as level of stress, lighting, obstacles on sidewalks, width of sidewalk, sidewalk surface quality, pedestrian bridges, cleanliness and density of green areas, and...
Table 10. Normalised weights for environment variables.

|       | \( S_1 \) | \( S_2 \) | \( S_3 \) | \( S_4 \) | \( S_5 \) | Raw weight | Normalised weight |
|-------|------------|------------|------------|------------|------------|-------------|------------------|
| \( V(S_14 \geq S_{15}, S_{14}, S_{15}, S_{16}, S_{18}) \) | – | 0.98 | 0.95 | 0.95 | 1 | 0.95 | 0.196 |
| \( V(S_{15} \geq S_{14}, S_{15}, S_{17}, S_{18}) \) | 1 | – | 0.97 | 0.97 | 1 | 0.97 | 0.200 |
| \( V(S_{16} \geq S_{14}, S_{15}, S_{17}, S_{18}) \) | 1 | 1 | – | 0.99 | 1 | 0.99 | 0.205 |
| \( V(S_{17} \geq S_{14}, S_{15}, S_{16}, S_{18}) \) | 1 | 1 | 1 | – | 1 | 1 | 0.207 |
| \( V(S_{18} \geq S_{14}, S_{15}, S_{16}, S_{17}) \) | 0.98 | 0.96 | 0.93 | 0.93 | – | 0.93 | 0.192 |

Figure 5. Prioritising decision criteria based on BE factors.

Figure 6. Prioritisation of the BE variables.

access to public transportation can be considered as high-priority variables. These variables have a cumulative combined weight of approximately 0.55. The cumulative weight of all variables is equal to one, indicating that the selected variables using the weighted average value approach will achieve the objective function’s 55 percent expectation level.

Another method for selecting high-priority variables is to analyse the differences in weight values of two consecutive variables. We may define the sequence of variations in the weights of the variables and decide precisely where the linear slope between the weights breaks down by looking at these values. Figure 9 illustrates the weights of variables and
Table 11. The cumulative weight estimation for the BE variables.

| Variables                                | Weight of related criteria | Normalised weight | Combination weight |
|------------------------------------------|----------------------------|-------------------|--------------------|
| Level of stress                          | Network design             | 0.212             | 0.0712             |
| Width of sidewalk                        |                            | 0.208             | 0.0698             |
| Access to public transportation          |                            | 0.198             | 0.0663             |
| Topographic condition                    |                            | 0.189             | 0.0634             |
| Network connectivity                     |                            | 0.193             | 0.0648             |
| Intersection traffic controls            | Safety                     | 0.205             | 0.0659             |
| Marked crosswalks                        |                            | 0.196             | 0.0632             |
| Pedestrian bridges                       |                            | 0.211             | 0.0679             |
| Presence of police officers              |                            | 0.190             | 0.0611             |
| Presence of security cameras             |                            | 0.198             | 0.0638             |
| Cleanliness and density of green areas   | Environment                | 0.196             | 0.0672             |
| Sidewalk surface quality                 |                            | 0.200             | 0.0686             |
| Obstacles on sidewalks                   |                            | 0.205             | 0.0700             |
| Lighting                                 |                            | 0.207             | 0.0708             |
| Walking utilities                        |                            | 0.192             | 0.0658             |

Figure 7. The priority of variables for each set of criteria.

variations in the weights of the successive variables in sections (a) and (b), respectively. The analysed variables can be classified into three sections based on the interpretation of these values: high priority, medium priority, and low priority variables.

As seen in Section (b), there are two minimal variances between the weight values for variables of width of sidewalk and walking utilities sequentially equal to 0.0002 and 0.0001. In section (a), it can also be shown that these variables have the lowest linear slope. The neighbouring variables with smaller weights, on the other hand, all have significant weight differences compared to one another, and the linear slope of the weights of the variables
Figure 8. Selected variables using the weighted average value approach.

Figure 9. The weights of variables and variations in the weights of the successive variables.
is almost uniform. Therefore, variables width of sidewalk and walking utilities were identified as breaking points of the weights of the variables. As a consequence, the variables’ priority can be divided into three categories: level of stress, lighting, obstacles on sidewalks, width of sidewalk as high-priority variables, sidewalk surface quality, pedestrian bridges, cleanliness and density of green areas, access to public transportation, intersection traffic controls, walking utilities as medium priority variables, and network connectivity, presence of security cameras, topographic condition, marked crosswalks, and presence of police officers as low priority variables.

Furthermore, by obtaining the cumulative combined weight of the variables of high and medium priority, according to Figure 10, we can attain a location of 68 percent of the objective function. As a result, investment in these BE variables will significantly improve pedestrian urban commuting.

5. Conclusions and Future Works

Our research reveals the built environment effects on pedestrian urban travels using the FAHP approach. Based on the three criteria groups including the network design, environment, and safety, Fifteen different walking variables were identified. We developed a TFN-based pairwise comparative survey and collected data from 43 academic and industry experts. The findings suggest that environmental factors have the greatest impact on walking, followed by network construction and safety considerations. Two methods were used to evaluate and compare the significance of variables: the average value of cumulative weights and the analysis of variation weights values. In the average method, the variables’ priorities were determined using the average value of the combined weights of the variables. As a result, variables with a larger weight than the average value were prioritised. However, in the weights variation method, BE variables were classified into three categories
as high, medium, and low priority depending on the breaking points of the weight pattern slope. The results indicate that the weights variation approach is more effective, with a 13 percent higher likelihood of success in the objective function when selecting variables influencing walking using this method.

The results from the study could achieve the research goals, however, there is a need for more exploration in research scopes. Furthermore, more studies of the socio-demographic factors’ impacts on the walking choices can clarify the reasons for the failure of some active travel investments. Examining the impact of urban form, travel purposes, people’s behaviour, and social-demographic characteristics will expose non-transparent aspects of pedestrian active travels. Consequently, in order to explore better policies, further studies would be crucial to evolve in this area.

Acknowledgements
We appreciate the editorial team and the reviewers of Fuzzy Information and Engineering Journal for their time and efforts in improving our article.

Disclosure statement
No potential conflict of interest was reported by the author(s).

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