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Investigating Built Environment Indicators to Develop a Local Walkability Index

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ABSTRACT

Many studies have been conducted over the last 20 years to determine and measure factors that affect the walkability of city streets. Walkability is an essential factor in deciding whether a city is green or sustainable. This paper creates a comprehensive walkability index by analysing built environmental indicators that affect walkability. This research was conducted on mixed land use streets in Cairo, Egypt, combining the results from an online survey and a walkability assessment model developed by multi-criteria decision analysis techniques. The results were based on a three-pillar approach starting with the theoretical background to frame the walkability indicator, numerical assessment over the Egyptian cases using a multi-criteria decision-making (MCDM) technique and a qualitative user perception survey. Our results confirm that determining to what extent Cairo's streets are walkable is crucial to enhancing pedestrians' perceptions of the walking environment. Furthermore, the results illustrated the essential factors within the built environment indicators that influence pedestrian walking behaviour.

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1. Introduction

Research describes the essential need for the start and endpoint of any walking experience (Capitanio, 2019; Caymaz, 2019). Walking is also the only way several people can approach everyday activities (Chapman & Olson, 2017; Hussein, 2018; Ferrer, Ruiz, & Mars, 2015). However, the streets and public spaces once meant for pedestrians are being degraded and invaded by private cars, pulling an active social life from residents that formerly walked on the streets (Balsas, 2021; Krambeck

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& Shah, 2006). Forsyth and Southworth (2008) argue that walkability is the foundation of a sustainable city, and it comes with substantial social, environmental and economic benefits.

Recently, walkable environments have been carefully considered in urban design and public health (Ewing & Handy, 2009; El Helou, 2019). One of the most critical aspects of city planning is walking. Research has linked walking to reduced obesity and the gain of other health benefits (Abedo, Salheen, & Elshater, 2020). For example, walking reduces cardiovascular disease, diabetes and hypertension; it also decreases traffic congestion, reduces carbon emissions, noise and pollution (Alfonzo, 2005; Banister, 2007; Capitanio, 2019; López & Wong, 2019; Pucher & Buehler, 2010). In addition to creating 'liveable communities,' walkability is an essential parameter to enhance the quality of life, safety and comfort (Elshater, Abusaada, & Afifi, 2019).

Over the past 20 years, definitions of terms such as 'walkability' and 'walk-friendly communities' have become prominent in the literature (Alawadi, Striedinger, Maghelal, & Khanal, 2021). The connection between these terms with the built environment has been investigated using different tools (Shaaban, 2019; Southworth, 2005). In the current research, walkability is the extent to which the built environment promotes safety and direct access to destinations while reducing travel time and effort and providing a comfortable and appealing visual environment (Dill, 2004).

Several pieces of research classify the indicators that support walkable, friendly environments (Lo, 2009; Forsyth & Southworth, 2008; Balsas, 2021; Reisi, Nadoushan, & Aye, 2019). Since 2009, most of the walkability studies focus on macroscale indices constructed from objective, measurable variables. However, these studies neglect the microscale indicators that could be subjective (Arellana, Alvarez, Oviedo, & Guzman, 2021). Furthermore, few studies combine several indicators to generate a single walkability index (WI). The available data is limited, and no previous research has focused on the methods used to determine the built environment's walking potential in Egyptian cases. More research is needed to address this issue (Abedo, Salheen, & Elshater, 2020; Abussada & Elshater, 2021b).

Regarding walkability in the Egyptian context, definitions and contributing elements require further investigation (Abedo, Salheen, & Elshater, 2020). The rapid deterioration of Egypt's street life is apparent in overcrowded cities like Cairo, with mixed-use/commercial streets becoming more common (Abussada & Elshater, 2021b). Building on the gap in the literature, studies must assess how to integrate the macro- and micro-scale indicators into walkability indices.

A definitive link between walkability and built environment has been challenging to prove. Here, we see a challenge identical to the traditional problem of the standard governmental solution: to increase street capacity to minimise road congestion by widening streets and narrowing sidewalks (Wahba, Kamel, Kandil, & Fadda, 2021). However, according to the best countries statistics in 2021 released by US News, Egypt is ranked 51 in overall quality of life, which is considered a poor ranking (US News, 2021). Therefore, the absence of public spaces, especially the sidewalks, expanding car lanes at the costs of sidewalks, the lack of walkways, or being congested (UN Habitat, 2013) are central issues that negatively affect local walkability and, therefore, reduce the day-to-day quality of life.

There are unanswered questions about the reliability of the built environment in Egypt and its effect on walkability. Therefore, this study addresses the specific research question, "What are the methods that can be applied to formulate a revised version that fit the Egyptian cases?"

This research focuses on the urban streets of Cairo City from the pedestrian-use perspective. The purpose of the present study is to generate a local walkability index (LWI) for urban highways in Cairo, Egypt, considering the restrictions on constructing LWI from actual measurements of built environment indicators. In addition, the study aims to explore the built environment factors that would make the streets of Cairo better places for walking and more adaptable to being used by pedestrians. With this aim in mind, it would be easy to determine the challenges that would stand in the way of achieving 'walkable streets' in Cairo and how to overcome those challenges.

The measurement of the walkability in the Egyptian built environment is the focus of this research. The method used three mixed-use

streets in Cairo. First, a literature review was the basis for developing a comprehensive walkability index using built environment indicators that influence walkability. Second, the authors conducted intense site observation and online questionnaires to analyse the built environment indicators and the users' satisfaction and walking perception in Cairo's three cases. Third, the selected built environment factors were weighted, normalised, and then aggregated to a single WI for each case with the aid of a multi-criteria decision-making (MCDM) technique using the analytical hierarchy process (AHP).
This paper adds to the present literature by developing a new composite indicator for a comprehensive framework that could enhance walkability, using macro and micro-scale built environment parameters to assess walkability and create LWI in Cairo.
The paper is structured into five parts after this introduction (Figure 1). The second part illustrates the selected methods conducted in the current work to answer the research questions. The third part shows the results of scanning relevant literature on Scopus, the Web of Science, and reports, ending with the index investigated in case studies. The fourth part presents the results of the mathematical development of the index and data analyses. Finally, the fifth and sixth sections provide deductive arguments about the LWI ranking results in the Egyptian cases and provide thoughts on directions for future work.

2. Material and Methods

This section introduces a conceptual framework for comparing walking conditions in different city zones using a pedestrian accessibility evaluation. Second, it explains the research field and context used for testing the proposed conceptual framework.

2.1 Theoretical Background: Framing the Indicators of Walkability

In this section, we define the term walkability and the influencing factors. To elucidate a walkable environment, the authors outline the assessment tools and determine the relationship between the built environment and walking behaviour. The literature review depends on two sources. First, articles in Web of Sciences and Scopus; second, published reports on the relevant topic of walkability, liveability and quality of life.

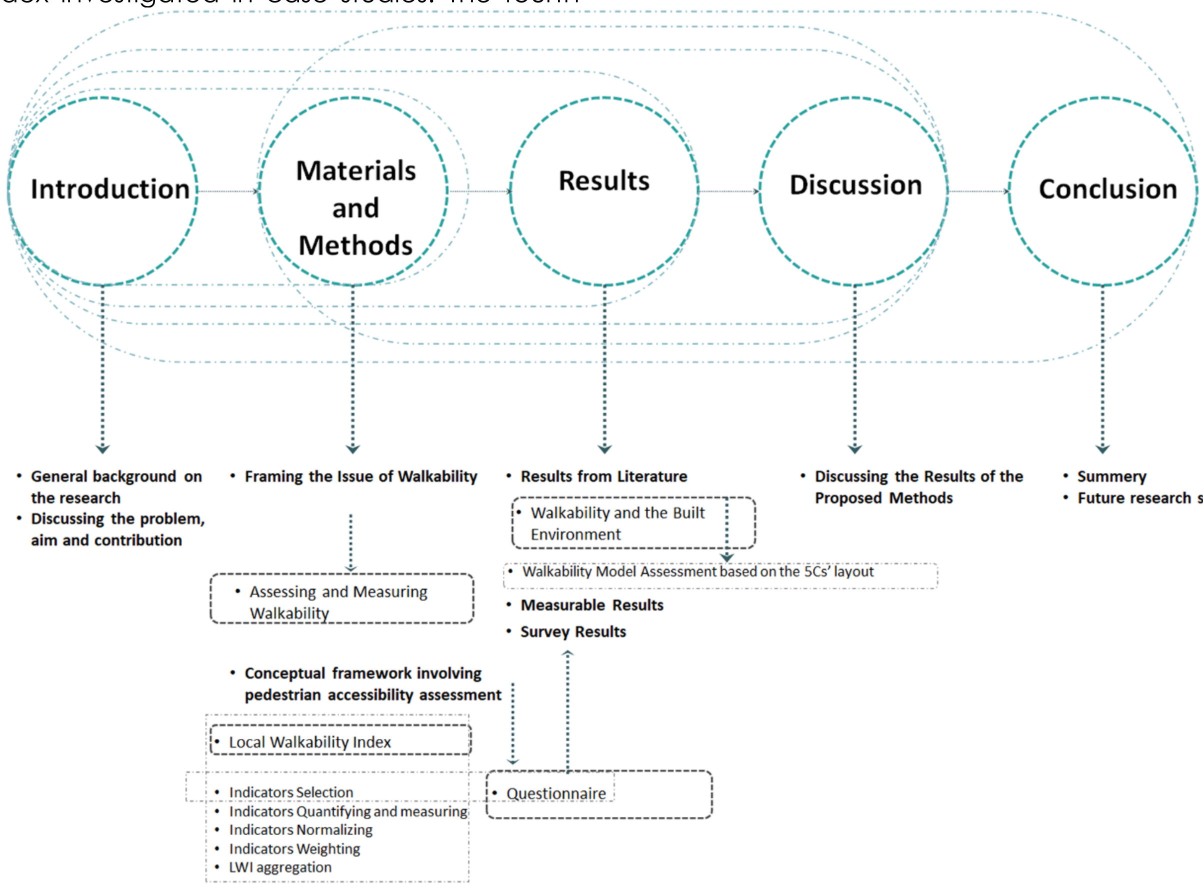

Figure 1. Research structure.

The results show that many tools have emerged to assess the quality of the built environment or the walking environment (Abusaada, Vellguth, & Elshater, 2019; Ewing & Handy, 2009; Leslie, Frank, Owen, Bauman, & Hugo, 2007). These tools gauge whether the built environment attributes are related to different physical activity levels, especially walking (Albers, Wright, & Olwoch, 2010; Alawadi, Striedinger, Maghelal, & Khanal, 2021; Department of Public Health, 2008). Like previous studies, literature was a secondary data source, and it illustrated the importance of various techniques and factors and existing measurement tools (Aghaabbasi, Moeinaddini, Shah, & Asadi-Shekari, 2017).

2.2 Study Area

Cairo is a large city with over 20 million people (CAPMAS, 2019). As documented in the literature, walkability is greatly affected by socioeconomic level and the built environment, including land use, urban form, street network, and landscape design (Alawadi, Striedinger, Maghelal, & Khanal, 2021). Therefore, three case studies were selected based on diversity in their socioeconomic status, built form, street systems and demographic composition. Figure 2 shows the three neighbourhoods on a google earth map.

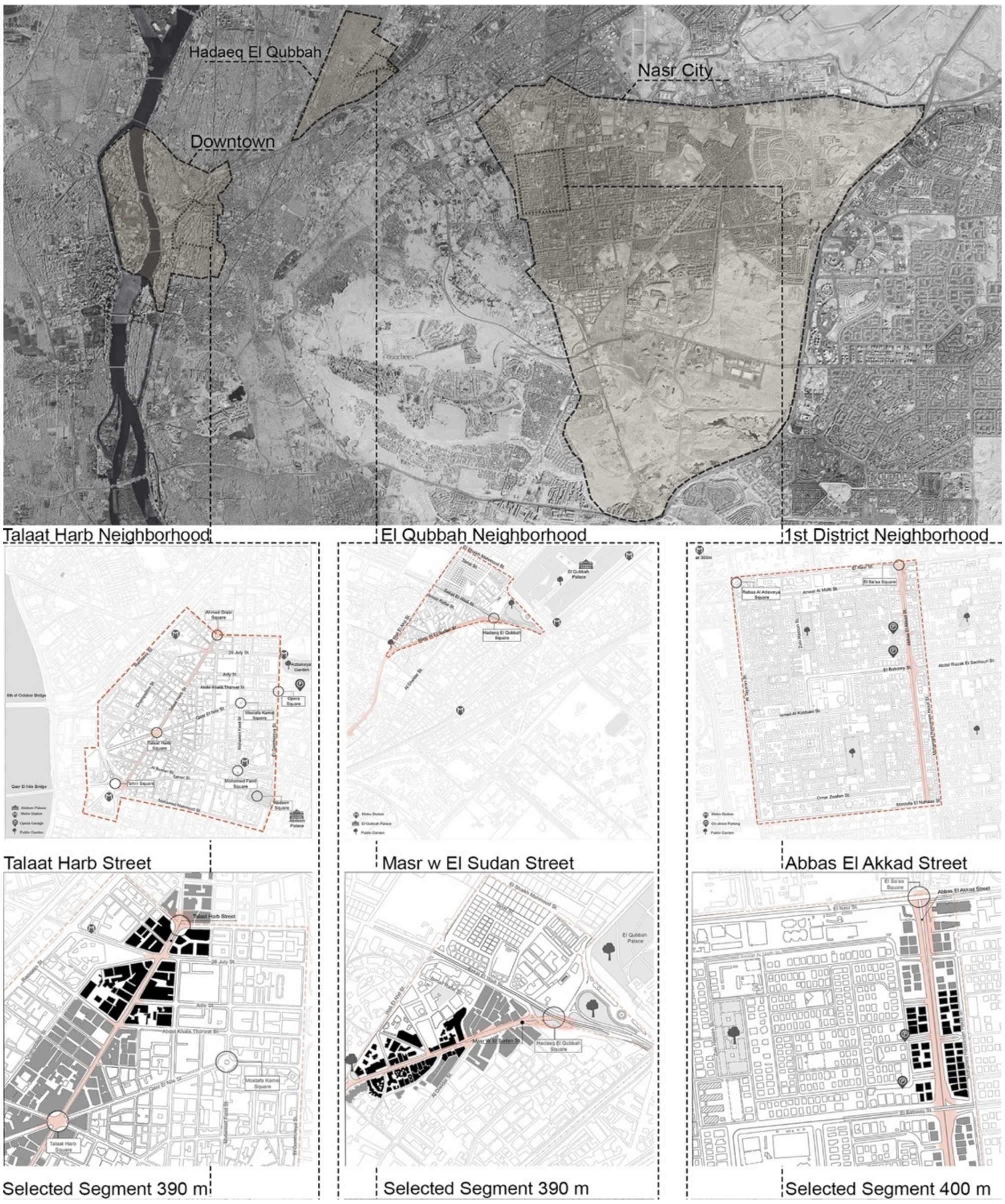

Figure 2. Case studies location.

The first case is Downtown (1798–1952), the second is Hadaeq El Qubbah (882-1908), and the third is Nasr City (1952–1987). Downtown is considered a medium socioeconomic area and the Cairo CBD. Hadaeq El Qubbah is an old urban community with historical background from 882 till 1908 when it became known as Hadaeq El Qubbah. It is now considered as a below medium-class area. While Nasr City is an intermediate urban community, it is considered an above medium-class area based on the apartment prices.

2.3 Mathematical Development of the Walkability Index

After selecting the different neighbourhoods to perform the measurement, it was necessary to choose the streets for data collection (Soba, Ersoy, Altınay, Erkan, & Şik, 2020), using criteria such as highly mixed land use (López, Toan, & Wong, 2020; Ewing, et al., 2011) and car parking along the streets. The criteria also include distances between 200m and 400m long (Pallas, 2010).

Converting the indicators first before summing the dimensionless values is critical when working with a variety of indicators. Previous research describes this process as normalisation (Nardo, Saisana, & Saltelli, 2005). Our selected indicators cover both positive and negative effects on the ability to walk in the case studies. Similar to previous research addressing positive and negative indicators, the normalisation equation differed (Reisi, Nadoushan, & Aye, 2019). Equations (1) and Equation (2) show the normalisation equations for positive and negative indicators (Krajnc & Glavič, 2005).

$$I^{+}_{N} = \frac{I^{+} - I^{+}_{min}}{I^{+}_{max} - I^{+}_{min}} \quad (1)$$

$$I^{-}_{N} = \frac{I^{-}_{max} - I^{-}}{I^{-}_{max} - I^{-}_{min}} \quad (2)$$

Where I^{+}_{N} is for the normalised positive indicator, and I^{-}_{N} represents the normalised negative indicator. I_{min} was the minimum value of indicator considering the three streets, I_{max} was the maximum value of indicator over the three streets.

Previous research has attempted to establish weighted walkability indices using various techniques to prevent equal weighting in their development (Albers, Wright, & Olwoch, 2010). Specific mathematical relations are used to assign weights (Organisation for Economic Cooperation and Development, 2008). In this study, we used the analytical hierarchy process (AHP) (Saaty, 1980). The AHP approach decomposes complicated situations into a hierarchical structure of the research aims and related criteria and sub-criteria.

AHP conducts paired comparisons for the indicators in each level of the hierarchy for obtaining weights for indicators. Pairwise comparisons are performed between pairs of indicators, demonstrating the relative relevance of one indication to the other, and quantified based on experts' judgments. Indicator weights and priorities were gained from experts and researchers from the reviewed secondary data and estimated from previous studies or other indicators measurements.

This research suggested an indicator aggregation and index composition after assigning a weight to each of the indicators. The aggregation occurred through the weighted linear combination (WLC) method shown in Equation (3). This method is an overlaying technique that considers the normalised values and relative weights of indicators in an aggregation (Al-shabeeb, 2015):

$$LWI = \sum W_{ij} \, . X_{ij} \quad (3)$$

Where LWI is the Local Walkability index. W_i stands for the weight of indicator i in parameter j. X_{ij} is the normalised value of indicator i in parameter j.

The normalised value of each indicator for each parameter was multiplied by the relative weights of the indicators extracted in the previous stage using AHP. Next, the relative weights of the indicators collected using AHP in the previous stage multiplied each parameter's normalised value. Finally, a sub-index was created by combining the weighted values of indicators in each parameter. The weight of each type was then multiplied by the sub-index value and combined into a single LWI (Aghaabbasi, Moeinaddini, Shah, & Asadi-Shekari, 2017; Gallin, 2001). Table 1 shows the interpretation of the LWI scores, ranges and the level of required improvements (LRI) at each grade (Aghaabbasi, Moeinaddini, Shah, & Asadi-Shekari, 2017).

Table 1. LWI interpretation Source: (Aghaabbasi, Moeinaddini, Shah, & Asadi-Shekari, 2017)

LRI	LWI	Grade	Condition	Description
1	80 ≤ LWI ≤100	A	Very Good	Streets deliver great services for its users
2	60 ≤ LWI < 80	B	Good	Streets adequately serve the users
3	40 ≤ LWI < 60	C	Regular	Streets serve the users adequately
4	20 ≤ LWI < 40	D	Poor	Streets do not support the users
5	0 ≤ LWI < 20	E	Awful	Streets are not provided by appropriate service to satisfy the users

This research used internal consistency to examine the applicability of the proposed tool's measurements. Cronbach's alpha was used to evaluate the consistency of this tool as it calculates how accurately a group of items measures a single unidimensional factor (Arellana, Saltarín, Larrañaga, Alvarez, & Henao, 2020). An alpha value of 0.7 or higher shows reliability (Cortina, 1993).

2.4 Qualitative Data Collection

After selecting the indicators, the authors visited the streets multiple times to gauge the 26 selected indicators in the three streets. Table 2 shows the proposed model of walkability assessment based on the 5Cs' layout and each indicator's measurement and quantification.
The survey was a pragmatic approach based on qualitative data to assess user's perception of their neighbourhood streets (Silva, Saraiva, Loupa-Ramos, & Bernardo, 2013). The aim was to evaluate the pedestrians' overall view of their walking environment. The purpose was to provide a holistic perspective of how they perceive the built environment of their neighbourhood streets and the level of satisfaction of the current situation. Due to the COVID-19 pandemic and lockdown, we distributed an online questionnaire to users of the three streets. A range of indicators was presented to determine if each met their needs and whether they were successfully designed. The survey results were then compared to the spatial observation of the built environment, and the walkability indices were developed for each street.

Table 2. The proposed model of walkability assessment is based on the 5Cs' layout and their way of measurement.

Key Attribute	Parameter	Indicator	Ways of measurement
Conspicuous	Safety	Surveillance	Number of surveillance cameras and first-floor windows
		Bollards	Number
		Signals and Signage	Number
	Security	Lighting	Number of lighting posts
	Security from Traffic	Traffic Volume	Number of vehicles per hour
		Traffic Speed	Average speed of vehicles
		Speed Reducers	Number
Connectivity Continuity Accessibility Permeability	Sidewalks	Obstructions	Number of obstacles along sidewalks
		Crossing and Intersections	Number of services available to aid in crossing and Number of Intersections
Convenient Efficiency Function	Sidewalks	Sidewalk width	Distance from building elevation to the edge of the curb in m.
		Street Width	Distance from the edge of curb on one side to the other edge in m.
		Buffer Width	Average width of on-street parking in m.
	Land Use Mix	Active Environment	Number of Public Transport

		Relational Environment	Area of Food destinations, Facilities and Commercial and social destinations in m2.
Comfortable Facilities Aesthetics Attractiveness	Thermal Comfort	Shade and rain cover	Number of shading elements as sheds and trees canopy span in meters
		Average skyline height	Height of buildings in meter, to measure average shade of them in meters
	Streetscape and Landscape	Paving Material	Area in m2
		Seating Areas	Number
		Trash Receptacles	Number
		Trees	Number
		Landscape strip	Area in m2
	Facilities	Vehicle Parking Facilities	Area in m2
		Facilities For Disabled People	Number of ramps along the street and sidewalks
Convivial User-friendly Livable	Sociability	Pedestrian Flow	Flow of user number of users per Hour.
		Enclosure	Average building width in meter.
		Spaces for interaction	Average area of open or green spaces

3. Results and Discussion

3.1 Findings from the Literature

The authors attempt to present a new measurement method that combines the built environment's macro and micro-scale design factors and the common vital concerns on the neighbourhood and street levels. This model for walkability assessment addresses the 5Cs. These fundamental concerns are categorised according to the definition of the 5Cs and then combined with other attributes; each had a set of parameters with different indicators. These parameters include: Be

1. The **connection** between pedestrian networks facilitating pedestrian movement and support their trips. Like other research, we assessed this factor using criteria including street permeability and connectivity (Elshater, 2019).
2. **Convivial** is the quality that can create lively, pleasant, and friendly activity and interaction places. In considering this quality, we include the parameters of liveability and sociability (Elshater, 2020; Shaftoe, 2008).
3. In line with a study conducted on the case of London, the **conspicuous** quality was recommended to create walkable streets (Transport for London - TFL, 2004). This quality of safety and the welcoming nature of the space is affected by the sidewalks, pedestrian paths and public spaces. This design quality relates to spatial legibility, complexity and coherence. Where walking routes are safe, visible, well-lit, and well furnished, in our work, this factor is assessed by criteria regarding route safety and security (Abedo, Salheen, & Elshater, 2020).
4. In creating **comfortable** places, this is related to the quality of the walking environment and how the design of these places support the local facilities. Furthermore, having these facilities in place alongside the walkable paths is affected by aesthetics and attractiveness (Abusaada & Elshater, 2021a).
5. Finally, **convivence in the walking experiences** is the quality that is affected by the land use through efficiency and functionality (El Helou, 2019; Elshater, 2020).

Based on the above factors and how this research adapted them to the new model, the combined indicator can be defined as a compilation of factors from the literature and adapted to the 5Cs layout to formulate a new set of parameters and indicators for the assessment of built environment attributes to evaluate the walkability of urban streets. We used 26 indicators based on the review of the literature. Table 2 presents a new model of the selected built environment indicators and parameters and their role in the various critical walkability factors. Our results confirmed that the walkability measurement tools are scattered between various forms, such as audits, indices and inventories (Boarnet, Day, Alfonzo, Forsyth, & Oakes, 2006; Clifton, Smith, & Rodriguez, 2007; Evenson, et al., 2009; Krambeck & Shah, 2006).

Walkability has usually been based on the features of the built environment (Forsyth, 2015). Generally, walkability is affected by factors like density (Newman & Kenworthy, 2006), while mixed land use and connectivity encourage people to walk (Iroz-Elardo, Adkins, & Ingram, 2021). In addition, the purpose of a walk might be for leisure or to access destinations without using their cars (Lu, Xiao, & Ye, 2017; Sivam, 2012). Hussein (2018) explained that the built environment and physical features on sidewalks are the primary factors influencing people's walk decisions. His study followed the concept used by Cervero and Kockelman (1997), where they defined the built environment as the physical features of the landscape architecture that mutually set a definition for the public realm of participation in everyday life experience.

According to The Transport for London -TFL (2004) report, a 5C's layout is necessary for a walkable environment. The classification and prioritisation of pedestrians' quality needs are often based on the approach (Refaat & Kafafy, 2014). Research has suggested design qualities that can support the walkability of the street environment, where the area should be convenient, conspicuous, convivial, comfortable and consistent (5Cs) (Abedo, Salheen, & Elshater, 2020; Iroz-Elardo, Adkins, & Ingram, 2021; Transport for London -TFL, 2004). The Public Transport Authority of Australia endorsed the 5C's layout (Australian Public Transport Authority, 2012).

In summary, Table 3 shows the mentioned Key Attributes and walkability concerns in the literature combined with the 5C's approach to develop the model to assess walkability. Consequently, Zayed (2016) deduced that 'walkability' is the extent that an urban context promotes walking. Furthermore, in reviewing relevant literature, there is consensus that the built environment's main physical attributes enhance walkability.

Table 3. Adoption of the walkability requirements and crucial keys driven from literature.

Concerns and Characteristics / Key Attributes	Connectivity Continuity Accessibility Permeability	Convivial User-friendly Liveable/ Sociability	Comfortable Aesthetics Attractiveness Facilities	Convenient Efficiency Functionality	Conspicuous Safety Security	Consistent Sustainable	Legibility Ease of use	Diversity/Coexistenc e Design /Density	Economic Feasibility Socio-Economic	Coherence	Human Scale
Mid-America Regional Council (MARC) (1998)	•	•	•	•	•			•			
Transport For London, UK (2004)	•	•	•	•	•	•					
Portland City, US	•	•	•	•	•	•		•	•		
Public Transport Authority of Australia	•	•	•	•	•	•					
New Zealand Transport Agency (2009)	•	•	•	•	•		•				
European Unio Financed Report	•	•	•	•	•	•	•				•

Sheila Ferrer, Tomás Ruiz, Lidón Mars, (2015)			•	•	•				
Handy, Cao& Mokhtarian (2006)	•	•	•	•	•				•
Pikora et al (2003)			•	•	•				
Stevens (2005)	•	•	•	•	•				
Boarnet et al. (2007)	•	•	•	•	•	•		•	•
Krambeck and Shah (2006) Darmoyono and Tanan (2015)			•	•	•				
Forsyth and Southworth (2008) Giles-Corti et al. (2009)	•		•	•	•		•		•
Ewing et al. (2011) Rebecchi et al. (2019)			•		•		•		
Cevrero and Kockelman (1997)							•		

3.2 Measurable Results

The LWI was derived for each of the three streets. Therefore, it is critical to determine the street level and the sidewalk amenities to calculate the LWI for each BI indicator and the total LWI for the selected segments. Table 4 shows the LWI for the streets and the level of required improvements (LRI) for the sidewalk BI factors and the entire street environment. For example, the LWI for Talaat Harb Street is 30.99, with a 'C' grade indicating that BI adequately serves the residents (Table 4). In this neighbourhood, the sidewalk condition is acceptable, but it could be better. In contrast, the LWI ratings of Masr w El Sudan and Abbas El Akkad streets are 20.94 and 28.45, respectively.

As a result, the grade for these streets is a 'D,' as the built environment indicators suggest that these streets are in poor condition and require significant improvement. Across the three selected streets, most BI indicators received 'poor' or 'awful' LWI ratings, indicating the need for substantial improvements in traffic speed, shade and rain cover, trees, landscape strips, crossing availability, and vehicle facilities. Over the selected streets, few sidewalk factors achieved 'good' or 'very good' LWI ratings, such as the availability of bollards, seating, and enclosures requiring minor improvements.

Table 4. LWI for the selected streets and the LRI.

Built Environment Indicator	Talaat Harb St.	Masr W El Sudan St.	Abbas El-Akkad St.	Indicator Weighting	Local Walkability Index (LWI) & LRI				
					Talaat Harb St.		Masr W El Sudan St.		Abbas El-Akkad St.
	Normalised Value	Normalised Value	Normalised Value		LWI	LRI	LWI	LRI	LWI
Surveillance	6.06	7.71	6.24	5.2	31.49	4	40.07	3	32.44
Bollards	16.84	1.05	2.11	5.5	92.63	1	5.79	5	11.58
Signals and Signage	10.00	2.86	7.14	5.6	56.00	3	16.00	5	40.00
Lighting	8.68	6.32	5.00	4.8	41.68	3	30.32	4	24.00
Traffic Volume	5.70	6.23	8.08	4.3	24.50	4	26.77	4	34.73
Traffic Speed	6.15	4.62	9.23	3.5	21.54	4	16.15	5	32.31

Speed Reducers	3.33	3.33	13.33	2.2	7.33	5	7.33	5	29.33
Obstructions	6.49	8.65	4.86	3.3	21.41	4	28.54	4	16.05
Crossing Availability	7.50	6.25	6.25	4.1	30.75	4	25.63	4	25.63
Sidewalk width	8.21	1.54	10.26	5.7	46.77	3	8.77	5	58.46
Street Width	6.10	2.93	10.98	2.5	15.24	5	7.32	5	27.44
Buffer Width	5.00	5.00	10.00	5	25.00	4	25.00	4	50.00
Active Environment	10.00	6.67	3.33	2	20.00	4	13.33	5	6.67
Relational Environment	5.98	4.11	9.91	4	23.92	4	16.44	5	39.64
Shade and rain cover	9.21	7.30	3.49	2.1	19.33	5	15.33	5	7.33
Average skyline height	6.85	4.93	8.22	5.5	37.67	4	27.12	4	45.21
Paving Material	7.22	4.98	7.79	5.6	40.44	3	27.91	4	43.65
Seating Areas	6.67	0.00	13.33	5.7	38.00	4	0.00	5	76.00
Trash Receptacles	9.23	7.08	3.69	5.5	50.77	3	38.92	4	20.31
Trees	8.67	7.67	3.67	2.01	17.42	5	15.41	5	7.37
Landscape strip	0.00	14.22	5.78	1.6	0.00	5	22.75	4	9.25
Vehicle Parking Facilities	1.11	6.82	12.07	1.1	1.22	5	7.50	5	13.28
Facilities for Disabled People	6.09	8.70	5.22	5.6	34.09	4	48.70	3	29.22
Pedestrian Flow	8.74	4.60	6.67	2.5	21.84	4	11.49	5	16.67
Enclosure	9.23	6.15	4.62	8.1	74.77	2	49.85	3	37.38
Spaces for interaction	8	8	4	1.5	12.00	5	12.00	5	6.00
Overall LWI					30.99		20.94		28.45
Overall level of required improvements					3		4		4
		Grade			Regular		Poor Condition		Poor Condition

3.3 Internal Consistency

Table 5 displays the Cronbach's alpha for each indicator's LWI in each street. As previously stated, to demonstrate a reliable scale, the Cronbach's alpha value should be at least 0.7. During this investigation, the Cronbach's alpha of the three studied streets have coefficients of 0.77 or more. The high, moderate, and increased alpha values in all three neighbourhoods indicate that the questionnaire produces consistent results over time and throughout the neighbourhoods with varying characteristics.

Table 5. Cronbach alpha results

	Talaat Harb St.	Masr W El Sudan St	Abbas El-Akkad St.
Surveillance	0.77	0.98	0.99
Bollards	0.81	0.96	0.95
Signals and Signage	0.83	0.94	0.97
Lighting	0.84	0.94	0.96
Traffic Volume	0.85	0.96	0.96
Traffic Speed	0.86	0.98	0.97
Speed Reducers	0.85	0.94	0.98
Obstructions	0.84	0.94	0.97
Crossing Availability	0.82	0.97	0.93
Sidewalk width	0.85	0.98	0.97
Street Width	0.84	0.94	0.94
Buffer Width	0.85	0.96	0.99
Active Environment	0.85	0.96	0.95
Relational Environment	0.85	0.96	0.98
Shade and rain cover	0.83	0.94	0.95
Average skyline height	0.83	0.94	0.95
Paving Material	0.83	0.99	0.91
Seating Areas	0.82	0.92	0.98
Trash Receptacles	0.85	0.96	0.96
Trees	0.87	0.95	0.99
Landscape strip	0.87	0.98	0.99
Vehicle Parking Facilities	0.83	0.90	0.97
Facilities for Disabled People	0.85	0.97	0.98
Pedestrian Flow	0.79	0.90	0.96
Enclosure	0.86	0.97	0.97
Spaces for interaction	0.97	0.95	0.97

3.4 Survey Results

The online questionnaire results were obtained after three days, the total number of respondents was 387. Table 6 shows the respondents' socio-demographic characteristics.

Table 6. Socio-demographic characteristics of the respondents.

Characteristic	Talaat Harb St. (n= 112)		Masr W El Sudan St (n=107)		Abbas El-Akkad St. (n=168)	
	N	Percentage %	N	Percentage %	N	Percentage %
Gender						
Male	46	41.1	39	36.4	65	38.7
Female	66	58.9	68	63.6	103	61.3
Age						
18 - 26	34	30	33	30.8	41	24.4
27 - 31	27	24.1	29	27.1	82	48.8
32 - 46	25	22.3	19	17.8	23	13.7
47 - 60	19	16.9	21	19.6	19	11.3
60+	7	6.7	5	4.7	3	1.8
Duration of the walk	.					
Less than 10 minutes	26	23.21	26	24.3	25	14.9

10-19 minutes	25	22.32	28	26.2	73	43.5
20-29 minutes	34	30.36	19	17.8	43	25.6
30 minutes or more	27	24.11	34	31.8	27	16.1
Type of Users						
Resident	22	19.30	24	21.30	21	18.40
Going to school/ Work	20	18.20	23	20.80	20	17.60
Exercise /sports	4	3.50	9	7.60	4	3.30
Going to bus stop/public transportation.	8	6.70	6	5.60	7	6.60
Going to a daily service	13	11.70	14	12.50	12	11.00
Shopping	51	45.70	45	40.30	52	46.30
Visit neighbours or relatives	23	20.10	25	22.30	22	19.50
Enjoy the outdoors	14	12.30	13	11.60	12	10.40

4. Discussion

Our findings identified relationships between the survey results and LWI values of three streets for the 5Cs' attributes, parameters, and indicators. User satisfaction for the three streets regarding the attribute of 'conspicuous' was less than the calculated indices for the attributes. There was a difference between the results for 'comfortable' compared to convivial and convenience attributes. The level of user satisfaction was higher than the calculated indices (Figure 3a).

The results confirm the importance of including users' perceptions and their satisfaction in perceiving the built environments to achieve the highest walkability indices. The result of the survey and the LWI for the 5Cs' attributes proved that people's perception of the three streets regarding conspicuousness is less than the measured index. Regarding convenience and conviviality, there was a slight difference between the two measures. However, for comfort, users showed high levels of more than the measured indices. The relationship between survey results and the measured indices differs from the parameters. The results here show that people's satisfaction level with safety from traffic is less than their index indicates for the three streets. While the quantitative assessment of the safety parameter was measured to be high, users did not feel safe from traffic, so the measure does not appear to meet the objective. Vice-versa, for the mixture of land uses, the satisfaction level is higher than the measured index that indicates applying all types of uses does not fulfil people's needs. Both indices and satisfaction are nearly equal in the three streets (Figure 3). Our results about walkability parameters in Egyptian cases align with other research that confirmed effective land use could promote walkability (Abedo, Salheen, & Elshater, 2020; Abussada & Elshater, 2021b; Balsas, 2021; Lu, Xiao, & Ye, 2017). Furthermore, these results demonstrated in this paper match state-of-the-art methods. Finally, the results from Egyptian cases confirm previous studies, where a convenient environment facilitates residents to go on food in their daily lives and walk for their commute (Elshater, 2020; Hussein, 2018).

Because of the inability to face-to-face interview residents, we decided not to investigate users' satisfaction using an online survey. One concern about the survey findings was that we used a limited sample size. Another limitation in the walkability investigation involves using various methods like space syntax or Walk Score to verify the numerical results of normalisation for positive and negative indicators.

The present findings confirm that 12 out of the 26 indicators were the most effective based on their opinions. However, their level of satisfaction was nearly equal to the calculated indices on the three streets (Figure 3c). In sum, these results show a gap between the level of satisfaction and how they perceive the walking environment and the theoretical framework for achieving a walkable street.

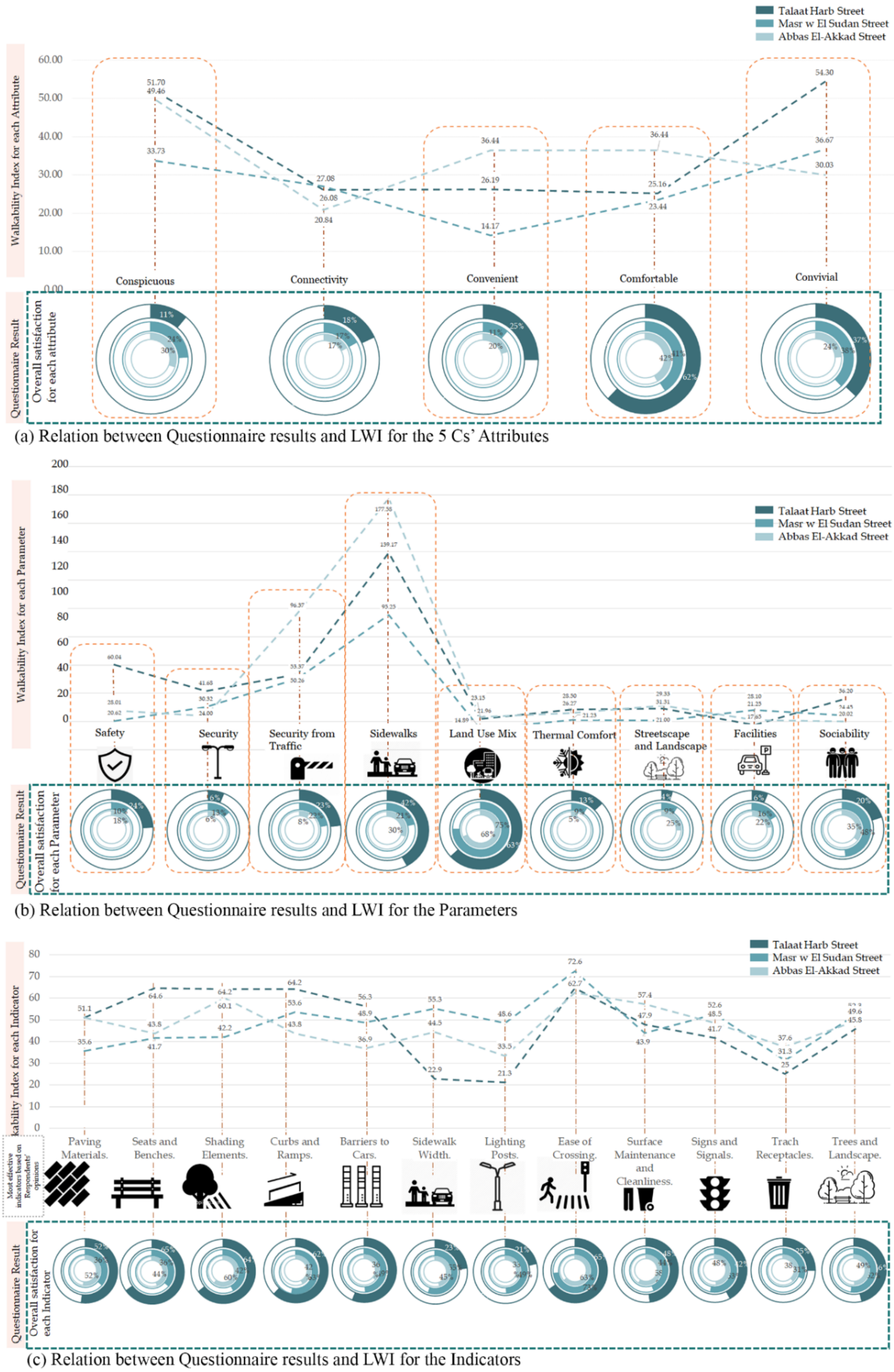

Figure 3. Relation between survey results and LWI for the indicators.

The further novel finding on the parameters is that the relationship between questionnaire results and LWIs had a colossal difference. For 'safety from traffic', the index obtained was higher than the level of satisfaction, and visa-versa with 'land use mix', and for 'sidewalks.' It had the most significant difference as the walkability indices were higher than the level of satisfaction (Figure 3b).

The added value of this research is in comparing the measured walkability indices for the built environment, which the authors have developed with users' level of satisfaction using a survey. This research breaks new ground in highlighting the importance of perceptions of the built environment on their walking behaviour. In this respect, investigating people's perceptions and the most effective indicators should be considered in developing local walkability.

5. Conclusion

This study looked at 26 environmental indicators that affect walkability on Cairo's streets, divided into nine parameters and five categories. A new compliance measuring method that combines the built environment's macro-and micro-scale design indicators and the common vital concerns mentioned in literature at the neighbourhood and street-level addressed to the 5Cs, was presented. Using this method to calculate the walkability indices for the selected streets in Cairo and comparing the resulting index to the respondents' answers and their level of satisfaction from the developed questionnaire could help decision-makers determine the features of the built environment that needs development to achieve more walkability levels. This spectrum of indicators can make this tool universally applicable. A single walkability index was developed by providing indicator weights based on their relevance and importance, then combining them. Finally, the reliability of the built environment indicators used in the LWI was tested using an internal consistency test. All indicators showed moderate to high reliability across the studied neighbourhoods.

Due to the limitations resulting from the COVID-19 pandemic and lockdown, future research should consider measuring perceptions and satisfaction with a range of on-site questionnaires, field studies, semi-structured interviews and analysis of the indicators. Multi-disciplinary approaches are also helpful, and the research should include input from urban planners, designers, sociologists and health care professionals. Based on the research limitations, future work includes an extensive study of streets in neighbourhoods of varying character, considering the design of new cities and how urban planners and governmental authorities plan them. Other quantitative measuring tools could be adopted alongside the established WI and the questionnaire.

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Conflict of interests

The authors declare no conflict of interest.

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