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Parameterize walkable urban forms considering perceptual qualities

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Abstract

Establishing new cities and communities to absorb the growth of the population is an urban regime for urban development; especially in developing countries like Egypt. Despite the massive construction done in new cities, people, as well as activities, are still attracted to traditional ones, where livability and walkability are well distinguished. That is all connected to what people perceive from the designed built environment. Much literature addresses this subjective relationship by specifying, measuring, and evaluating. Recent ones have correlated certain physical features and perceptual qualities related to walkability. This research aims to specify more this relationship by deducting design parameters that quantify perceptual walkable urban form. It measures 5 streets in 6 areas, which are already attracting walking and diverse activities in Greater Cairo. The research uses SPSS software to generate averages and ranges which represent values to describe certain urban form elements, the research concluded that different types of urban typologies endorse certain perceptual qualities more than others as well as present guiding design parameters for urban form elements that would help generate a well-perceived walkable urban form.

Keywords: Perceptual urban qualities, Urban form, Design parameters, Walkability

Introduction

Since the seventies of the last century, Egypt started establishing new settlements and communities to absorb the population increase. In the past 20 years, these efforts had doubled to advocate the development process in a certain time frame. The main catalyst for these new communities was to construct suitable and interesting places and to attract people and activities from the existing ones. However, those new cities did not earn the planned target of activities and the population; people find the traditional/existing cities are more livable in a humanized way. Literature had intensively addressed this problem, especially in the Egyptian context [1–10]. Scholars attributed various reasons such as the clear gap between academic research and field practice planning and applications on this topic. As well as, the Egyptian codes for urban and rural street works have no standards or norms for people's rights in street design, as well as the subjectivity between the built environments and how people perceive the designed features. Nevertheless, urban development is still growing and widely spreading, so there will be a need to learn lessons from the existing/traditional to add a superior experience in the new.

The increase of walkability as performance is considered an essential aspect in reaching livability, sustainability, health, and economic benefits. Much recent research [11–13] has focused on shaping walkable areas and healthy communities. The built environment, particularly urban design aspects, has appeared as a top significance for improving walkability [11, 14]. Identifying the link between urban design and walkability, on the other hand, necessitates a thorough understanding of the principles and main components that determine urban form elements. Furthermore, two main frameworks can be divided into two groups based on the sort of data collection used in each. The first, and most common, is perceptual frameworks, which focus on capturing human perceptions of the built environment through qualitative data collection methods and then analyzing and using this data to assess the street design to identify issues and propose solutions [15–18]. On the other hand, objective frameworks are emerging in which researchers are attempting to quantify walkability and to deconstruct the walkability of a street into the built environment parameters that impact it so that objective measurements for these parameters can be used as metrics to determine how walkable an urban form is for its users [13, 19–25]. Focusing on the quantities approach, and according to [26, 27], there is not enough specification to design parameters that could help generate walkable urban forms considering perceptual qualities.

By reviewing the pioneering literature in urban design, it could be noticed that after the rejection presented by users and inhabitants to the planned cities after the industrial revolution, designers and planners had concluded that the design they produce is not as perceived by the users' experience. Hence, theories began to raise to explicate the way people perceive the surrounding environment. Lynch, Cullen, and Spreiregen presented the primate foundation in people's perception and cognition in an urban environment [28, 29]. Mainly, they tried to present the relationship between the city's physical structure and people's perceptions. After that, it got more solid through the work of Cristopher Alexander and Jane Jacobs where it was possible to find more precise patterns that articulate the physical city elements and the people's perceptual qualities, as it began to identify missing concepts and aspects that are related more to the design process [30, 31]. Furthermore, the work of Gane Gel and lastly Ried Ewing [13, 32, 33] was more specified in the mean correlation between urban design qualities and physical elements in terms of measurements. Around all that, designers and planners are trying to learn more about their users and the best design practice needed for successful urban design quality. However, as people's perceptions and cognition are more subjective and harder to identify and measure, it is hard for designers and planners to achieve a milestone in the design process. A more specified relationship is much more recommended, where more solid tools could be easily presented to and used by urban designers and planners to identify and specify the perceptual qualities in urban design. With an overlooking view of the progress of visual perception and cognition as a concept in urban design, it looks at it the right way for specificity (see Fig. 1).

As so, the research argues that more specified parameters that describe urban form will guide designers and architects in generating well-perceived walkable urban areas. Hence, the research has a main question to answer: what are the design parameters that could generate a walkable urban form that considers perceptual qualities? And its goal is to reach several design guidelines that describe certain urban form elements.

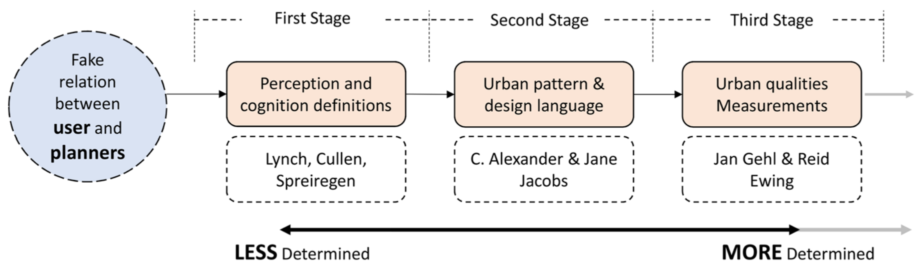

Fig. 1 Theoretical development of urban design and perceptual qualities

These guidelines represent the statistical average — ranges — ratios to several areas that are already distinguished in walkability from the Egyptian context. Furthermore, it could be more practical to generate new urban areas in the development process that consider perpetual qualities for more walkable, hence livable and attractive places. The research also considers a limitation for measuring and deducting these design guidelines. First, it took the traditional/existing urban areas in the Egyptian context not the new as case studies. Second, the selection of urban form elements/indicators was selected with the consideration of their ability to be used in further stages in parametric software. Finally, the selected perceptual qualities were the ones related to walkability based on the pioneer study of Ewing [13].

Literature review

Perception and walkability

The built environment, particularly the attractiveness of walkability or other physical activity, is influenced by urban design. The built environment has a significant impact on physical exercise and can either enhance or limit opportunities [34]. Building orientation and setback, block length, building height and street enclosure (aspect ratio), and building scale and variation are some of the urban design aspects that influence perception and walkability. Furthermore, walking influences elements such as wealth, personal preferences, cultural beliefs, and weather. The same location may be more or less walkable or have more or less real walking depending on this attribute [34, 35].

Pedestrian imitations are extremely important in the evaluation of the street environment. Pedestrians are the most appropriate group to examine their perception, knowledge [36], and attitude toward the streets to identify and develop a safe and acceptable walking environment [37]. By activating exploratory activity, perceptual qualities boost the pleasure of walking [38]. One of the pedestrian concerns while using a pedestrian walkway against oncoming traffic is personal safety [39–41].

A mental image is made up of beliefs, thoughts, feelings, and impressions about a location [28]. Street activities influence people's views of the street environment and add to an individual's perception of a street. This may explain why people like certain aspects of the city environment and enjoy walking or doing activities on specific streets. Therefore, a street image can be understood as a combination of a particular identity and how a place is seen (feelings and sensations) (feelings and impressions). This indicates that representations of place are formed by combining cognition (comprehension or understanding) and perceptions, as well as individual, group, and cultural "personality" structures or meanings [40, 41].

Perception studies of city streets are especially significant because they tell stockholders about how people perceive the streets: is a street pleasant and attractive, safe and vibrant, and clean, and does it inspire people to engage in activities? The merging of street characteristics and street activities, i.e., morphology and performative components, results in a different type of street environment [42]. The safety of pedestrians, beauty, and facilities are all important variables that influence perception [43]. These characteristics are significantly independent of the pedestrian transport purpose and have an impact on leisure and other activities associated with street use [34, 44]. All these studies prove a profound relationship between perception and its contribution in endorsing different urban activities such as walkability.

Urban form and perceptual qualities for walkability

Physical activity provides numerous physiological, environmental, and social benefits, including a decreased size rate, fewer traffic and greenhouse gas emissions, and increased livability. Walking or bicycling for transportation, recreation, shopping, or other purposes helps increase physical activity in everyday activities. Many research methods have been developed to assist communities in auditing and studying the built environment, as well as measuring walkability using the D factors [45, 46].

Density is frequently indicated by population density or housing density. The mix of land uses is referred to as diversity. The accessibility of activities or destinations in a neighborhood is investigated [11, 46]. The arrangement of the street grid is commonly referred to as design, and it is mostly measured by street intersection density or block size. However, as mentioned by [21], design should include micro aspects of the street environment that affect the pedestrian experience.

These micro and street-level traits, referred to as perceptual qualities of the urban environment [23], focus on the environmental psychology side of the built environment and describe how individuals perceive and interact with the elements of the street environment. They are often evaluated using both objective and subjective indicators obtained through surveys [47]. Tidiness, street amenities, cleanliness, street upkeep, and architectural design are examples of visual measures [19, 48]. Previous research has found that objective measurements perform better in association with physical activity or walking than their subjective counterparts based on regression model results [49].

Imageability, visual enclosure, human size, transparency, and complexity are five street-level urban design traits that have recently been recognized and characterized to aid in the research of their influences on walking [19]. Imageability describes how a location is recognized and remembered. A number of people, courtyards, buildings with nonrectangular silhouettes or identities, the presence of outdoor dining, the proportion of historical buildings, and noise level are all variables. The enclosure defines how vertical components such as buildings, walls, and trees visibly define streets. The proportion of the street wall, the fraction of the sky, and the quantity of lengthy sight lines are all variables. The term "human scale" refers to how the size and texture of physical features correspond to human size and walking pace. Variables include the number of long sight lines, the height of the building, the number of small planters and street furniture, and the proportion of the first floor with windows. What people can see beyond the boundary of a street block is described as transparency. Variables include the proportion of windows on the first level, active use, and the street wall. Complexity denotes a street's visual richness or the range of physical components and human activities. The number of buildings, outdoor dining, dominant and accent building colors, and the number of people are all variables [24]. Employed GIS to objectively quantify some of these factors to aid in the research of the street-level experience for developing healthy built environments. Modifications are frequently required when attempting to duplicate Ewing and Handy [13] and Purciel [50] due to the availability of secondary data and resources for gathering data by field observation. GIS also has limits in evaluating microscale urban design qualities, which were expressed in the inconsistency and subjectivity of the observation rating system, as well as the limitation of 2D GIS in measuring specific urban design aspects. Although Purciel and Marrone [50] provided appropriate methodological detail on data collection via observational survey, there may be various complications during the gathering process since different persons have varied judgments when utilizing the measuring scale established in the field manual. Variables and metrics that require three-dimensional information cannot be handled by 2D GIS. The Li Yin [46] technique, which is mostly based on observational surveys or 2D GIS, precludes a more extensive analysis and comparison of studies on these urban design features. Effective measurement is likewise limited in vast geographic contexts. As a result, several studies have asked for more strong and more objective measures of street design elements that contribute to the study of the built environment that promotes physical activity, healthy living, and sustainability [46, 51, 52].

Urban design qualities

The core of the urban design field is to address the appearance of cities to users. As so, the relationship between the creation of urban form and what the users perceive is preoccupying researchers as well as professionals. Urban design qualities are ones describing it [53–55]. A substantial corpus of literature on urban design identifies various perceptual features that are regarded as exceptional qualities of urban design for users of urban space [56]. Ewing [13, 21] underlined more than 50 qualities that are related to walkability; however, they stated that eight qualities are the more endorsing to walkability performance.

Imageability

It is the characteristic of a place that distinguishes it as distinct, recognized, and unforgettable. When specific physical elements and their arrangement attract attention, inspire feelings, and leave a lasting impression, a location has high imageability [13, 21]. According to Lynch [28], a city is imageable when it is firmly established, composed of distinct components, and can be identified directly by both visitors and locals. An imageable city, according to him, is one having elements that can be easily identified and arranged in a clear overall pattern [57].

Enclosure

It is the degree to which streets and other public places are visibly bounded by buildings, walls, trees, and other components. Spaces with a room-like quality feature vertical pieces whose height is proportionate to the width of the space between them [13, 21]. In urban environments, an enclosure is constructed by confining a street lined with buildings of similar height or a row of trees at a given level. According to Alexander [30], to produce a pleasant sensation of the enclosure, the overall width of the roadway from building to building should not surpass the height of the buildings. Meanwhile, Jacobs [31] claims that the ratio of building height to street width should be at least 1:2. Other urban planners advocate a maximum proportion of 3:2, or at least 1:6, to form the enclosure on the street in metropolitan areas [26].

Human scale

It refers to the size, texture, and articulation of physical parts that correlate to the size and proportions of humans, as well as the speed at which humans walk. Physical features that contribute to human scale include building details, pavement texture, street trees, and street furniture. To obtain a truly human scale, the breadth of the building must be appropriate to its height [20, 23]. According to some researchers, any building with more than four floors is considered out of human scale, while others specify limits of up to six levels and three floors alone [58]. Others suggest that if the building is tall enough, the lower levels should be seen to accommodate human size [59].

Transparency

The degree to which people can see or perceive what is beyond the edge of a street or other public place, and, more specifically, the degree to which people can see or sense human activity beyond the margin, is referred to as transparency. Walls, windows, doors, fences, landscaping, and openings into midblock spaces are all physical factors that influence transparency height [20, 23]. Walls, windows, doors, fences, landscaping, and openings in the area between building blocks are all physical characteristics that affect transparency. Transparency is essential for allowing interaction between indoor and outdoor activities. If an internal activity may be carried out externally or on the sidewalk, such as in outdoor restaurants and shops, the transparency quality is at great height [20, 23].

Complexity

The visual richness of a location is referred to as its complexity. The variety of a place's physical environment, specifically the number and types of buildings, architectural diversity and ornamentation, landscape components, street furniture, signage, and human activity, determines its complexity. The complexity is linked with the degree of variety that the observer can notice [39, 46, 60]. Humans are very comfortable receiving information that is at an appropriate level, not too little or too much. Pedestrians require a high level of environmental complexity to be enticed to wander around the neighborhood. In essence, complexity relates to the area's diversity [59].

Coherence

A sense of visual order is referred to as coherence. Consistency and complementarity in the scale, character, and placement of buildings, landscaping, street furniture, paving materials, and other physical components determine the degree of coherence. Individual assessment of coherence sceneries is commonly used in visual environment investigations [59]. The street is more coherent if the building has a building style that is suitable with the style of buildings in the surrounding neighborhood. A street is also considered coherent if existing buildings are not more than twice the size of the surrounding structures. The observer favors views of a street with signage that is relatively complicated and has a high degree of coherence. If the signage shares similar qualities, passersby will see the roadway as ordered, logical, and predictable, whereas otherwise the street will appear disorderly or incoherent [61].

Legibility

Legibility relates to how easily a place's spatial organization can be comprehended and navigated as a whole. A street or pedestrian network that gives travelers a sense of orientation and relative placement, as well as physical elements that act as reference points, increase a place's readability. A network system determines a location's legibility by making it simple for users to supply environmental direction. In other words, legibility is the look of a background clarity and out in such a way that each part can be easily distinguished and placed in a fused pattern [28]. The pattern uniformity of a street that makes the route easy to grasp and "read" is referred to as legibility [59, 61].

Urban form indicators

Urban form and morphology can be defined as the physical properties of settlements such as their shape, size, density, and layout [62]. There are different approaches to classifying and indicating urban morphology [19, 63–65]. The research's technique is based on the approach of M. Conzen, who provides a clear and basic description of the urban form [66]. He claimed that the urban form is made up of three essential components: streets, parcels/blocks, and buildings. The spatial combination of streets, parcels, and buildings defines the city in two dimensions, whereas the building fabric is significant in three dimensions and the function it serves. Jason takes a similar approach, identifying three basic morphological units: the street plan, the building shape, and the function of both [67]. In 1997, Moudon proposed that the main physical elements of urban morphology were streets, plots, and buildings with open spaces [68]. The same physical factors were introduced in Levy's 1999 study [69]. Then, as a component of urban morphology, land use was incorporated. The natural environment was provided as a component, as well as greenery [70]. Figure 2 represents an illustration of the coming indicators used in this research.

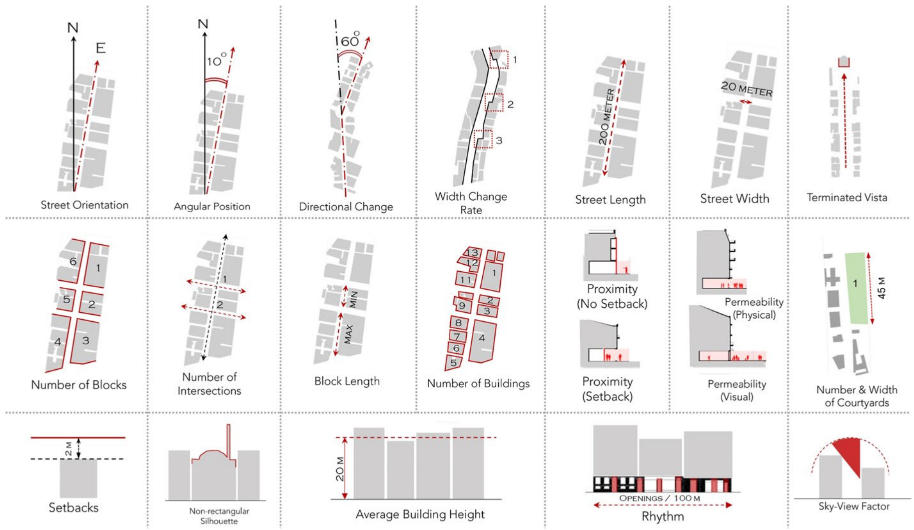

Fig. 2 Parameters used in urban form indicators, illustrated by the author based on various sources [67, 70–72]

Street indicators

The classification of street indicators is based on the arrangement and simplification of spaces (urban morphology) to make analysis easier. Marshall defined the structure of a street network as a distinct collection of indicators known as the route structure analysis. This approach classified roadways according to their configuration and makeup [73]. Furthermore, Hillier argued that axial lines and segments may be used to measure street designs [64, 74]. In several ways, space syntactic units can be utilized in different scales, depending on the application scale. One of the most prevalent objections leveled about axial space syntactic analysis is its overall disregard for physical distances and its assumption that people favor straight movement over the shortest route. Critiques should be directed toward an existing urban morphology [70]. The research focuses on the process of creating urban morphology. Such a generating procedure is initially based on measurements of spatial configurations employing various variables that influence the composition of streets to generate a street network [75]. Egin Zeka proposed additional indicators that measure other parameters in streets, such as the orientation of streets, angular position, directional changes angle, and others [67]. As well as street shift and width change rate, he tried to propose a measurement that could measure organic urban areas, so a change in the street width with different rates was yet very crucial in his measurement. On the other hand, Ewing correlated the terminated vista as an indicator of street composition [13]. Table 1 indicates the street indicators in two categories orientation and composition. There are other indicators regarding the configuration of the street network; however, it was not used in this methodology as it was assumed that it has no direct effect on the visual perception of a pedestrian on a streetscape.

Table 1 Street indicators: classifications, measurements, and sources

Street indicators	Measurements	Source
Orientation		
Street orientation	Orientation	[67]
Angular position	Angle	[67]
Directional change angle	Angle	[67]
Composition		
Street length	Distance	[76]
Street width	Distance	[67]
St. width/building height	Proportion	[13]
Street shift	Dimension	[67]
Width change rate	Y/N	[67]
Terminated vista	Y/N	[13]

Table 2 Blocks indicators: classifications, measurements, and sources

Block indicators	Measurements	Source
Number of blocks	Number value	[67]
Block length max	Distance	Authors
Block length min	Distance	Authors
Number of intersections	Number value	[67]

Block indicators

Block is a morphological unit located between public and private zones (parcels and buildings) [61]. The street line forms the outer section of the block, while parcels and buildings make the inside part [67]. Table 2 indicates the block indicators that were used in this research. The research separates the block length into a minimum value and another one for a maximum value.

Building indicators

The building is the smallest morphological unit to be examined, but it is the most essential in shaping the city's form and function. The buildings are elaborated in several aspects connected to their form, orientation, location on the lot, and the spatial interaction they make with one another using this process [67]. We adapt the indicators used by Ewing [13] that are related to building indicators, such as building numbers, average building height, non-rectangular silhouette, and whether the building in a street contains arcades or not. Physical permeability refers to the quality of the street interface that allows pedestrians to physically enter the ground floor of a building from the street. It specifically refers to public entrances connecting two realms. The connection between the two places encourages social interaction and guarantees that pedestrians circulate in and around the interface. This variable has only been defined as the interfaces that allow pedestrians to freely cross from public to private areas. The analysis of this variable was based on mapping the collective spaces of each interface in the selected samples [71]. The distance between the interface and the

Table 3 Building indicators: classifications, measurements, and sources

Building indicators	Measurements	Source
Building numbers	Number value	[13]
Average building height	Number value	[23]
Setbacks	Number value	[67]
Nonrectangular silhouette	Number value	[13]
Arcades	Y/N	[23]
Permeability	Visual/physical	[71]
Proximity	With setback/without	[71]
Rhythm	Rate/100 m	[71]

Table 4 Open space indicator: classifications, measurements, and sources

Open spaces indicators	Measurements	Source
Number of courtyards	Number value	[13]
Courtyard width	Number value	[76]
Sky view factor	Proportion	[72]

street is referred to as the interface's proximity (setback). This variable was studied by measuring how close the building is to the street, that is, if the interaction is direct (no setback) or involves a space (setback) [71]. The rhythm variable counts the number of doors and windows perceived by walkers at various street interfaces. The rhythm variable evaluates any entry or corridor that connects public and private spaces and is primarily meant for pedestrians. This variable sought to measure the "rhythm" of doors and windows (number of accesses per 100 m) in the various interface configurations that pedestrians may encounter when crossing the street [71]. Table 3 shows the different measurement types that are used in every indicator.

Open space indicators

There are three classifications for open space indicators: horizontal, vertical, and volumetric, all of which are affected by building height. Horizontal indicators quantify the horizontal morphological linkages between urban morphology elements that are influenced by built environments. Vertical indicators quantify the vertical morphological relationship between urban morphology components. Volumetric indicators quantify the volumetric morphological relationship between urban morphology vocabularies [70]. However, the researcher uses the concept of courtyards as an element to indicate the open spaces in a street design. Furthermore, it only uses horizontal and vertical indicators (courtyard width, sky view factor) as shown in Table 4. Ewing correlated the number of courtyards with imageability in streets [13]. Alradi indicates that the width of open space is an indicator of the urban form [76]. A sky view factor is an indicator defined as the mean value of the ratio of the solid angle of the visible sky from each point of the façades to the sky vault is used to compute the sky view factor. $SVF = IV/IH$ (16) IV: the ratio of the solid angle of the visible sky and IH: the sky vault [72].

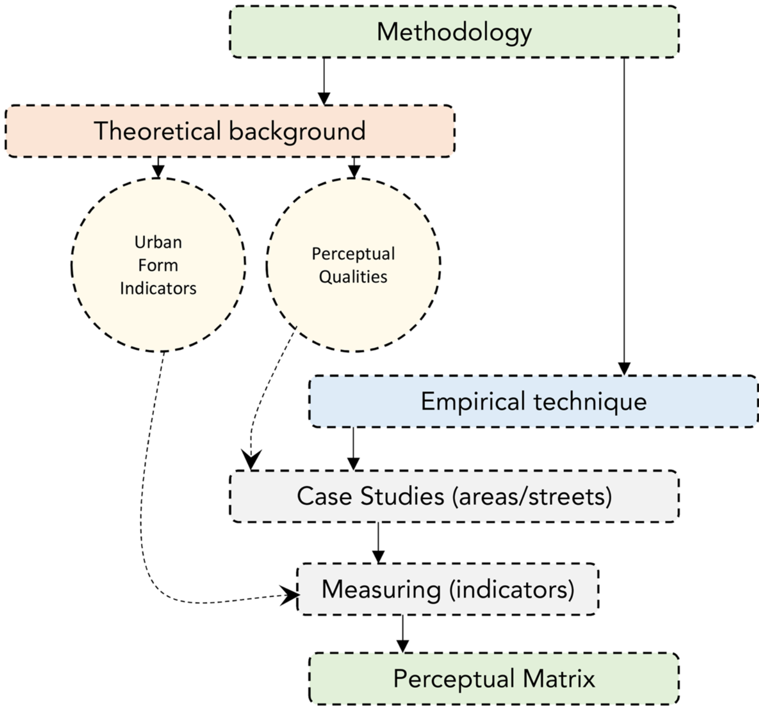

Fig. 3 The research methodology and flowchart

Methods

The research claims to learn from urban areas that had already successes in attracting pedestrians and activities, by deconstructing it to their urban form design parameters. The following methods were adopted:

- Identify and select perceptual qualities that are related to walkability and what are the physical elements that have a direct association with it depending on the literature.
- Identify and select urban form indicators that will represent the measurable variables in the selected case studies.
- Choosing Greater Cairo Region to be the context for specifying the walkable areas, as it contains rich urban typologies.
- Select the most walkable urban areas that attract pedestrians and activities in Greater Cairo.
- To ensure that the selected areas endorse the perceptual qualities needed for walkability, a questionnaire was done to a group of professionals and academics in urban design and planning as well as a residence of Greater Cairo.
- Based on the questionnaire, areas were selected for further analysis, where 5/6 streets were selected to be representing the design parameters for urban form elements in the area.
- Mathematical averages, ranges, and standard deviations were taken to the streets to present the whole areas; furthermore, the same process was done among the areas to produce a number that is representable to the urban form indicator. Figures 3 and 4 illustrate the research methodology and framework.

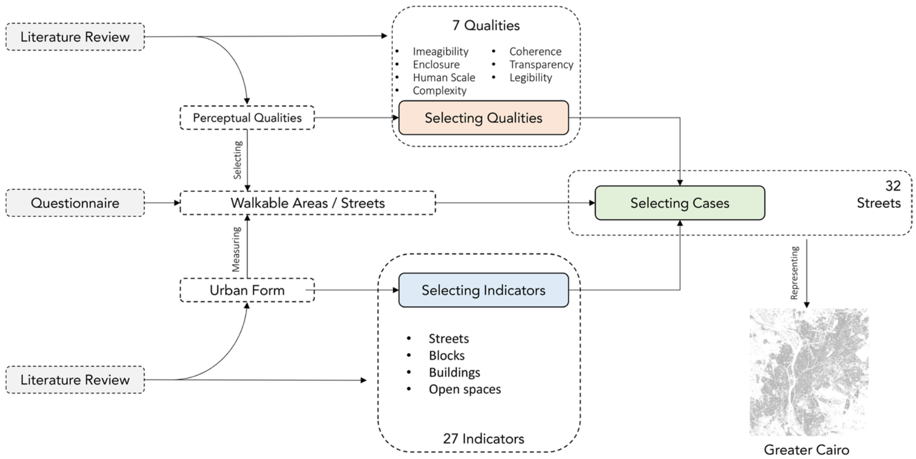

Fig. 4 The research methodology and framework

Case study

The Greater Cairo Region is the largest populated area in Egypt. It consisted of three compact major cities: Cairo, Giza, and Shubra. Greater Cairo is well known for its historical layers which hold various characteristics to learn from. As an accident city, every era has its marks and addition to this city. Consequently, Greater Cairo represents a valuable case study where we can find various typologies of urban morphologies in the same urban region. This study focuses on pedestrian movement and walkability as a performance. It uses areas that are considered already walkable to the residence as well as holds different types of urban typologies. As shown in Fig. 5, ten walkable urban areas were selected: Heliopolis, Khedivial Cairo, Zamalek, Garden City, Islamic Cairo, Maadi, Nasr City, El Mohandeseen, Shubra, Zahraa, and El Maadi. Furthermore, five to six streets were selected from every area to measure its urban form indicators. The streets were chosen to be the most walkable in the area.

Questionnaire

After choosing the 10 walkable areas in Greater Cairo, the research uses a photo questionnaire to clarify the well-perceived areas as walkable. Taking the opinion of the users is consider the best way to measure perception. The questionnaire contained an introduction about the aim and goals of the research, as well as questions regarding the.profession, specialization, and scientific degree and whether or not a resident of Greater Cairo. Furthermore, a simple definition of the perceptual qualities is in English and Arabic as well as a representable photo for each area under one another. These photos were meant to be representable to the area as a whole not to describe the qualities' definition in the questionnaire. As so, the photos were the same in every quality; only definitions of qualities that differ. The participants were asked to rank the photos (as a reference to the area) from GOOD to POOR per the quality presented in the question. The research uses

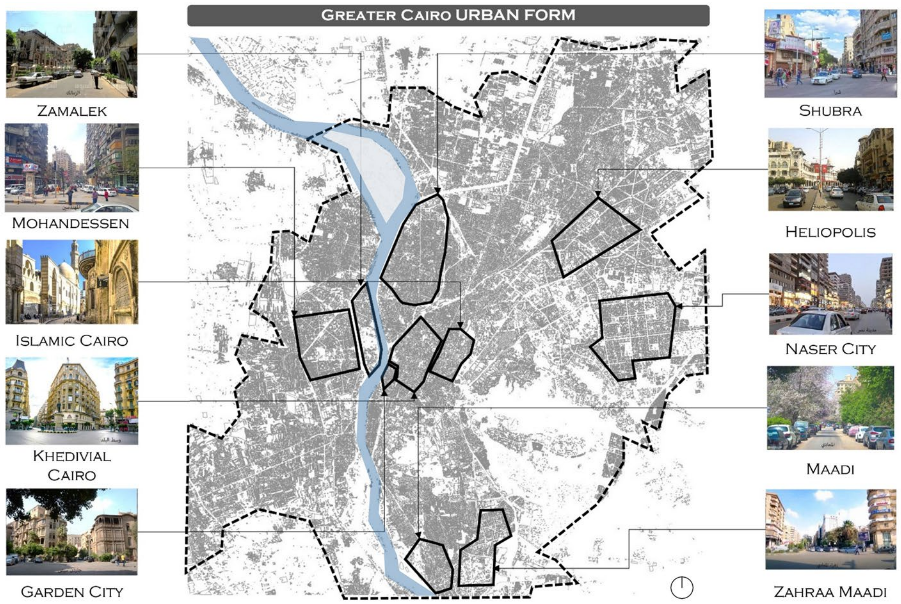

Fig. 5 Selected walkable areas in the Greater Cairo Region

an online platform (Surveymonkey.com)[1] to generate the questionnaire as it supports the dragging and dropping feature of the photos in the form. Afterward, the survey's shared links were shared on academic and professional online platforms (ResearchGate and LinkedIn), as well as, sent to experts and professors in an urban design known by the authors to participate.

Statistical method

Statistical method was conducted to guarantee a representative number to describe urban form elements Therfore, 5/6 streets were selected to be measured in each area, to ensure the collection of most of the used design parameters in each area. The collected data were categorized into two types. The first type is numerical which describes indicators such as (street width — block length, setback — number of intersections, etc.). And the second type is nominal which describes indicators such as (permeability — proximity — terminated vista, etc.). Ranges, mathematical averages, and standard deviations were taken among the streets of every area to represent the measurements for this area. Furthermore, to generate numbers/values that represent urban form indicators, the same process had been repeated, by taking a descriptive statistical method, ranges, mathematical averages, and standard deviations for all areas together.

Results and discussion

The most perceived walkable urban typologies

One of the bases of selecting the study areas is to be a walkable built environment. The researchers found ten areas in Greater Cairo that are walkable to the residents of Cairo. We found a variety of urban typologies among thought's ten areas. Using the

[1] https://www.surveymonkey.com/r/FJR7FBF

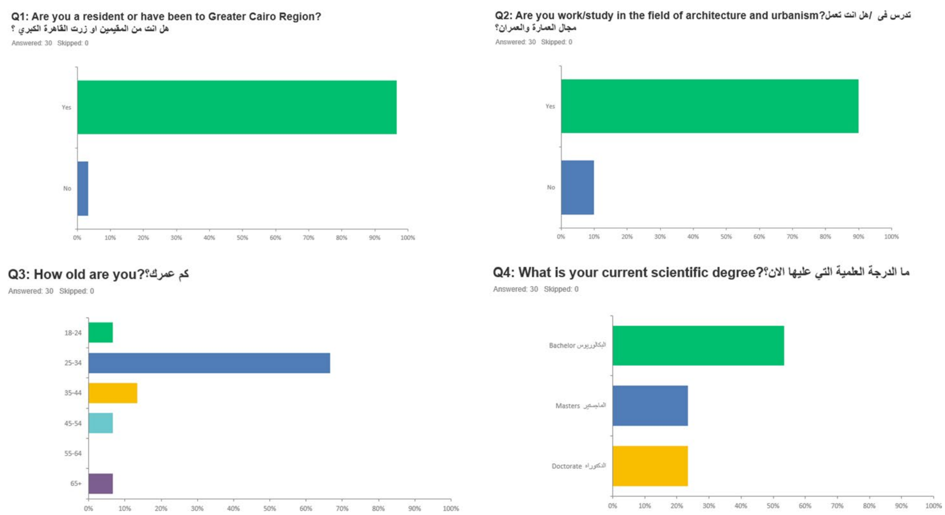

Fig. 6 Questionnaire results present the majority of the sample ranked the selected areas

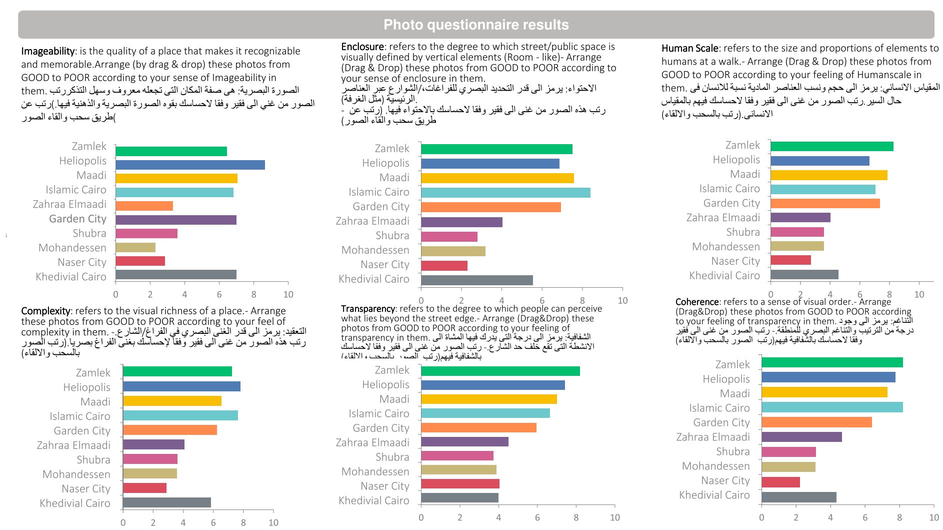

Fig. 7 Questionnaire results present the six areas that hold the highest ranks in all qualities

questionnaire, the research aimed to identify the most perceived walkable areas. A link for the questionnaire was left on online platforms for more than a month. And there was a continuous observation by the researchers of the analytical data generated from the participant response. Furthermore, it was noticed from the beginning that ranked areas could be categorized into two groups. The first group stayed in the top-ranked places in all qualities. However, the second one stayed in the bottom-ranked places in all qualities. And despite the variance in order within each group according to the measured qualities, the order of ranking the groups did not once change. As so, it was appearing to the researchers that there will not be a change in these ranks after all (see Fig. 6). So, the link was stopped at 32 participants. As shown in Fig. 7, the results indicate that six areas varied in order in each quality; however, those remain among the top 6.

Regarding imageability, the ranking was Islamic Cairo, Heliopolis, Garden City, Khedivial Cairo, Maadi, and Zamalek. Enclosure was ranked as Islamic Cairo, Maadi, Zamalek, Garden City, Heliopolis, and Khedivial Cairo. However, the human scale quality holds Zamalek to be the first and then Maadi, Garden City, Islamic Cairo, Heliopolis, and Khedivial Cairo. Complexity had Heliopolis and then Islamic Cairo, Zamalek, Maadi, Garden City, and Khedivial Cairo. Transparency had orders like Zamalek, Heliopolis, Maadi, Islamic Cairo, Garden City, and Khedivial Cairo. Coherence was ranked as Islamic Cairo, Zamalek, Heliopolis, Maadi, Garden City, and Khedivial Cairo. And finally, legibility was ranked as Heliopolis, Zamalek, Islamic Cairo, Maadi, Garden City, and Khedivial Cairo. As for the other 4 areas (Mohendessen, Shubra, Zahraa Maadi, Nasr City), they were among the last 4 places in all qualities so they were ignored in further stages of analysis.

The top six areas were found to be contained various urban morphologies regarding the type of urban tissue as well as the street network. Through using the types of urban tissue classified by Habraken [77] which were categorized as compact, linear, and pointer tissue, the compact tissue would be presented in Islamic Cairo; however, the linear tissue would be presented by Heliopolis and Khedivial Cairo, and the pointer type would be presented by Zamalek, Maadi, and Garden City. The street network typologies were a combination between axiality and orthogonal grids in Maadi and Khedivial Cairo. However, it was axiality and spider web like in Heliopolis. And it was curved in Garden City, yet it was organic in Islamic Cairo. As shown in Fig. 8, the variation of typologies in both urban tissues and street networks provides rich data to deduct design parameters that would reflect all of them.

Consequently, it was found a variance among urban morphologies in their ability to produce a specific perceptual quality. The compact urban tissue (Islamic Cairo) did not support all perceptual qualities, especially in an enclosure, transparency, and legibility. And the pointer urban tissue (Zamalek, Maadi) did not support all perceptual qualities, especially in legibility and imageability. However, the linear tissue (Heliopolis, Khedivial Cairo) was the most in meeting the average level that embraces the needed qualities. Regarding the street network type, it was found that the combination of the orthogonal grid type and the axial was the high ranked among others in delivering legibility and imageability. The ranks of every type of typology are presented in Fig. 6.

Design parameters for a visually perceived walkable urban form

After generating averages for each urban form indicator presented by the case studies, Tables 5 and 6 represents the ranges for the average in each area from the least measured values to the large ones. The table represents the percentage of whether each indicator exists or not among the case studies. And by taking the average of all case studies, Table 7 and Table 8 are combining values for each indicator that would represent a design parameter for an urban form that is visually walkable.

For the street indicators, the street orientation was more to the northeast direction, with a degree that varied in its range between 3 and 138 and a mean of 42 to the east. As for the street change in direction, most of the cases had a change in direction (not a straight line) with an average of the 13.5-degree change in direction. Regarding the street shift, there was not a significant percentage among the selected cases, as well as the width rate change; it had 81% of the cases with no direct shift in the street width. However, the composition indicators of a street, the street length, had an average of 810 m as a suitable mean for a pedestrian street. The width of a street holds a mean of around 20 m with direct assistance to the height of buildings that holds an average proportion of almost 1:1. Regardless of other physical features in the streetscape, an urban form could propose a sense of enclosure by a proportion that is 1:1.

For the block indicators, the average number of blocks in a street was 8 blocks, with a dimension that varied between a minimum and a maximum, 71 m for a minimum, and 160 m as a maximum. As for the number of intersections in a street or between blocks, it had a mean of 6 intersections.

For the building indicators, the total number of buildings varied from 7 to 115 with an average of 10 buildings; these counts considered the two sides of a street. The height of the buildings should not stick to one height value; however, it should have an average of 21 m among all the proposed heights. The non-rectangular silhouette is an important indicator of imageability as an urban quality; 60% of the cases had a non-rectangular silhouette with one or two buildings in a street as an average. The presence of arcades in the buildings was not a dominant element in the case as 91% of them did not have arcades. However, the rhythm of a door opening every 120 m had an average of 12 openings/120 m, which indicates mixed activities in land use. Regarding permeability, 63% of the cases had visual accessibility on the ground and first floor, and the least had physical access with only 9% of the cases. In addition, proximity reached 65% of the cases without setbacks, and 28% had no interacting environment.

For the open space indicators, the existence of courtyards in the cases varied between zero and 3 courtyards with an average of around 0.45 count in the street. With this value, we could consider the existence of courtyards as an option not a must in the Egyptian context. However, in the case of its existence, the width of it would have an average of 9.5 m from the street regardless of its depth. As for the sky view factor, it had a mean of 0.4 which means that around 40% of the view of the street should be a view of an overhead sky.

Consequently, the research was able to highlight concepts in street design, starting from its orientation in an area, as it was found that it should have an angular position in the northeast or west as well as the directional change in a street. The proportion between the height and the street width was found to be 1:1 as a suitable proportion that is supporting the proposed angular position of a street to have a sunny unforgettable urban space. The other proposed design parameters are aiming to learn from an experienced walkable urban form to generate more creative ones using the essential design parameters.

The relation between urban form indicators and perceptual qualities

The research was able to conduct a relationship between the measured urban form indicators and the 7 perceptual qualities. Based on the pioneer study of Ewing and Handy [13], where they had proven a correlation between perceptual qualities and certain physical features, the research connected the physical features proposed by Ewing and urban form indicators that were already implicated in the physical feature. Figure 9 presents a perceptual matrix that holds all of the results done in this research. It mainly

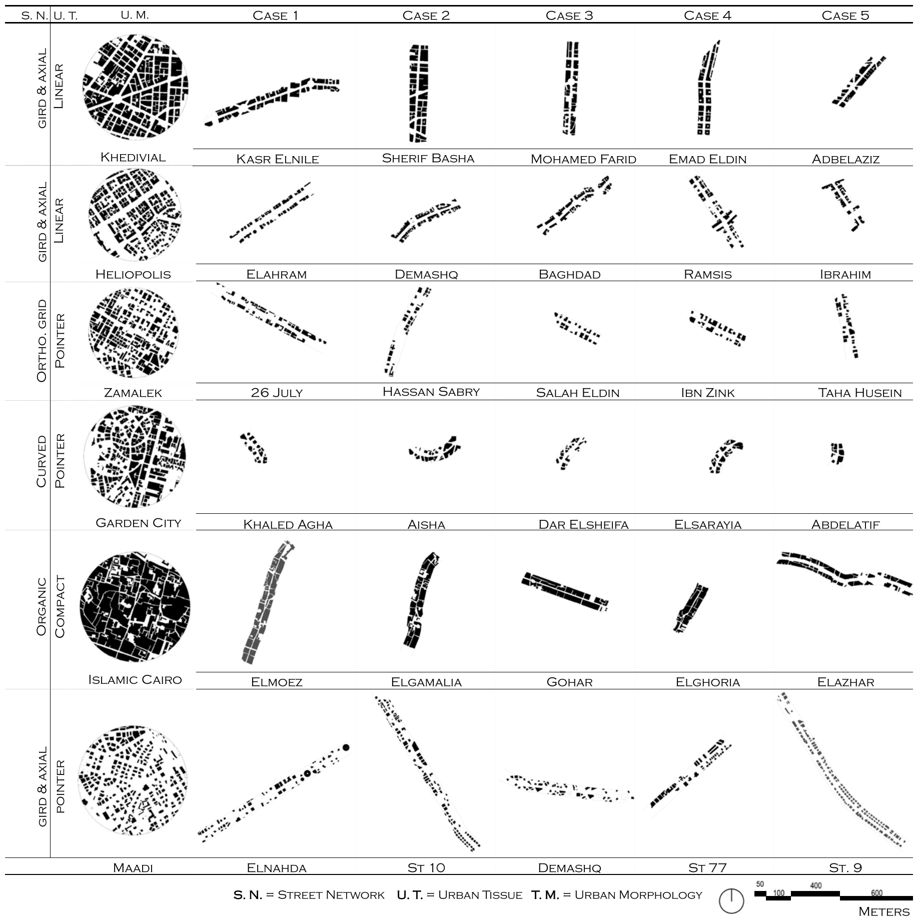

Fig. 8 Urban typologies analysis and the selected streets in the selected areas

holds a relation between the perceptual qualities that are related to walkability and urban form indicators. And it presents a measurement scale for each measured quality and states the minimum, average, and max values measured in each indicator. On the other side, it presents the morphological context concerning the perceptual qualities based on the questionnaire, to indicate that each type of urban typologies could perform high in specific qualities, unlike others.

Conclusions

The study investigated the relationship between urban form and perceptual qualities. Despite the various attempts to design new cities and communities, they have not yet attracted the target population and activities from the existing ones, traditional areas are always considered more walkable, which is an essential aspect of attracting people as well as activities. Literature has reverted to the subjectivity between what designers see and what people perceive; therefore, they act and perform. The research has gone through urban design theories, and it was concluded that it all try to identify and specify more the relationship between urban form/physical features and what people perceive as urban qualities. The research aimed to add to this topic by identifying and quantifying

Table 5 The measurements of urban form indicators (interval) in the selected cases

Indicator	Case study	Range	Mean ± SD
Angular position	Khedivial Cairo	3–70	20.50 ± 28.36
	Heliopolis	30–56	43.67 ± 10.54
	Garden City	14–138	45.00 ± 52.35
	Islamic Cairo	18–72	42.40 ± 26.47
	El Maadi	45–85	58.40 ± 16.06
	Zamalek	7–60	41.40 ± 25.88
Directional change	Khedivial Cairo	0–156	32.67 ± 61.29
	Heliopolis	0–29	10.17 ± 12.12
	Garden City	11–14	12.60 ± 1.14
	Islamic Cairo	0–23	6.80 ± 10.23
	El Maadi	0–30	14.60 ± 11.35
	Zamalek	0–10	3.00 ± 4.47
Street length	Khedivial Cairo	614–1580	938.50 ± 367.51
	Heliopolis	445–880	666.50 ± 156.19
	Garden City	15–419	256.20 ± 158.28
	Islamic Cairo	450–1222	867.80 ± 297.56
	El Maadi	905–2113	1473.20 ± 514.29
	Zamalek	414–1045	665.40 ± 254.28
Street width	Khedivial Cairo	18.5–21	19.83 ± 0.82
	Heliopolis	18–48	25.33 ± 11.34
	Garden City	15–15	15.00 ± 0.00
	Islamic Cairo	8–28	13.00 ± 8.49
	El Maadi	20–20	20.00 ± 0.00
	Zamalek	18–30	20.80 ± 5.22
Setbacks	Khedivial Cairo	0–0	0.00 ± 0.00
	Heliopolis	0–8	1.67 ± 3.20
	Garden City	4–4	4.00 ± 0.00
	Islamic Cairo	0–0	0.00 ± 0.00
	El Maadi	3–3	3.00 ± 0.00
	Zamalek	0–4	0.80 ± 1.79
Height/width	Khedivial Cairo	0.5–1	0.58 ± 0.20
	Heliopolis	0.5–2	1.08 ± 0.49
	Garden City	0.5–1	0.90 ± 0.22
	Islamic Cairo	0.5–1	0.60 ± 0.22
	El Maadi	1–1	1.00 ± 0.00
	Zamalek	0.5–1	0.80 ± 0.27
Number of blocks	Khedivial Cairo	5–12	7.50 ± 2.51
	Heliopolis	5–10	6.33 ± 1.97
	Garden City	2–4	2.60 ± 0.89
	Islamic Cairo	8–15	11.60 ± 2.88
	El Maadi	3–19	9.80 ± 5.81
	Zamalek	2–12	6.20 ± 3.63
Block length min	Khedivial Cairo	40–110	73.67 ± 24.25
	Heliopolis	27–70	48.50 ± 13.68
	Garden City	50–140	90.00 ± 43.73
	Islamic Cairo	27–60	43.80 ± 15.82
	El Maadi	45–120	77.00 ± 31.54
	Zamalek	20–280	101.00 ± 102.25

Table 5 (continued)

Indicator	Case study	Range	Mean ± SD
Block length max	Khedivial Cairo	130–304	192.50 ± 58.48
	Heliopolis	70–175	123.33 ± 42.86
	Garden City	135–170	152.80 ± 14.82
	Islamic Cairo	100–250	155.00 ± 57.08
	El Maadi	108–420	204.60 ± 126.97
	Zamalek	70–280	139.20 ± 86.16
Number of intersections	Khedivial Cairo	4–11	6.50 ± 2.51
	Heliopolis	4–9	5.33 ± 1.97
	Garden City	1–3	1.60 ± 0.89
	Islamic Cairo	7–16	11.00 ± 3.54
	El Maadi	2–18	8.80 ± 5.81
	Zamalek	1–11	5.20 ± 3.63
Building numbers	Khedivial Cairo	22–45	34.00 ± 7.92
	Heliopolis	19–35	27.83 ± 5.56
	Garden City	7–19	14.00 ± 4.36
	Islamic Cairo	16–27	20.60 ± 5.41
	El Maadi	15–115	56.40 ± 37.31
	Zamalek	20–42	26.40 ± 8.99
Average building height	Khedivial Cairo	16–35	30.17 ± 7.36
	Heliopolis	16–25	17.83 ± 3.60
	Garden City	16–26	18.00 ± 4.47
	Islamic Cairo	15–26	17.80 ± 4.60
	El Maadi	16–18	17.20 ± 1.10
	Zamalek	16–35	26.80 ± 9.93
Rhythm	Khedivial Cairo	8–27	16.00 ± 6.32
	Heliopolis	6–15	10.83 ± 3.92
	Garden City	6–8	6.40 ± 0.89
	Islamic Cairo	13–23	19.60 ± 4.16
	El Maadi	8–14	10.40 ± 2.51
	Zamalek	4–18	7.40 ± 5.94
Number of courtyards	Khedivial Cairo	0–3	1.17 ± 1.17
	Heliopolis	0–0	0.00 ± 0.00
	Garden City	0–0	0.00 ± 0.00
	Islamic Cairo	0–3	0.60 ± 1.34
	El Maadi	0–1	0.40 ± 0.55
	Zamalek	0–1	0.40 ± 0.55
Courtyards width	Khedivial Cairo	0–50	24.67 ± 20.45
	Heliopolis	0–0	0.00 ± 0.00
	Garden City	0–0	0.00 ± 0.00
	Islamic Cairo	0–20	4.00 ± 8.94
	El Maadi	0–48	16.60 ± 23.19
	Zamalek	0–26	9.60 ± 13.22
Sky view factor	Khedivial Cairo	0.23–0.5	0.28 ± 0.11
	Heliopolis	0.25–0.75	0.50 ± 0.16
	Garden City	0.25–0.5	0.45 ± 0.11
	Islamic Cairo	0.25–0.5	0.30 ± 0.11
	El Maadi	0.5–0.5	0.50 ± 0.00
	Zamalek	0.25–0.5	0.40 ± 0.14

Table 6 The measurements of urban form indicators (nominal) in the selected cases

Indicator			Khedivial Cairo	Garden City	Islamic Cairo	Heliopolis	El Maadi	Zamalek
Street orientation	NE	N	6	3	3	4	2	1
		%	100.0%	60.0%	60.0%	66.7%	40.0%	20.0%
	NW	N	0	2	2	2	3	4
		%	.0%	40.0%	40.0%	33.3%	60.0%	80.0%
Street shift	No	N	6	5	2	3	5	5
		%	100.0%	100.0%	40.0%	50.0%	100.0%	100.0%
	Yes	N	0	0	3	3	0	0
		%	.0%	.0%	60.0%	50.0%	.0%	.0%
Width change rate	No	N	6	5	2	3	5	5
		%	100.0%	100.0%	40.0%	50.0%	100.0%	100.0%
	Yes	N	0	0	3	3	0	0
		%	.0%	.0%	60.0%	50.0%	.0%	.0%
Terminated vistas	No	N	4	4	1	4	5	5
		%	66.7%	80.0%	20.0%	66.7%	100.0%	100.0%
	Yes	N	2	1	4	2	0	0
		%	33.3%	20.0%	80.0%	33.3%	.0%	.0%
Nonrectangular silhouette	No	N	2	3	0	4	5	5
		%	33.3%	60.0%	.0%	66.7%	100.0%	100.0%
	Yes	N	4	2	5	2	0	0
		%	66.7%	40.0%	100.0%	33.3%	.0%	.0%
Arcades	No	N	5	5	5	4	5	5
		%	83.3%	100.0%	100.0%	66.7%	100.0%	100.0%
	Yes	N	1	0	0	2	0	0
		%	16.7%	.0%	.0%	33.3%	.0%	.0%
Permeability	Non	N	0	5	0	0	0	4
		%	.0%	100.0%	.0%	.0%	.0%	80.0%
	Visual	N	6	0	4	4	5	1
		%	100.0%	.0%	80.0%	66.7%	100.0%	20.0%
	Physical	N	0	0	1	2	0	0
		%	.0%	.0%	20.0%	33.3%	.0%	.0%
Proximity	Non	N	0	5	0	0	0	4
		%	.0%	100.0%	.0%	.0%	.0%	80.0%
	With	N	0	0	0	2	0	0
		%	.0%	.0%	.0%	33.3%	.0%	.0%
	Without	N	6	0	5	4	5	1
		%	100.0%	.0%	100.0%	66.7%	100.0%	20.0%

design parameters that are willing to inherit perceptual qualities. Six urban areas were selected among ten areas to deduct the design parameters. Those areas represent the most well-perceived walkable areas in Greater Cairo. Five to six streets were selected in each area to address its design parameters, which were related to certain urban form indicators based on the literature. Furthermore, two mathematical averages were taken to the deducted values; the first was among the streets in a single area — to represent the areas — however, the second was the average of all areas to represent a value for an urban indicator.

Table 7 The averages and ranges of urban form indicators (numerical)

Indicator	Range	Mean ± SD
Angular position	3–138	41.28 ± 29.08
Directional change	0–156	13.81 ± 27.59
Street length	15–2113	810.72 ± 462.98
Street width	8–48	19.22 ± 7.11
Setbacks	0–8	1.53 ± 2.08
Height/width	0.5–2	0.83 ± 0.33
Number of blocks	2–19	7.31 ± 4.10
Block length min	20–280	71.63 ± 48.05
Block length max	70–420	161.03 ± 72.12
Number of intersections	1–18	6.38 ± 4.23
Building numbers	7–115	29.94 ± 19.63
Average building height	15–35	21.47 ± 7.61
Rhythm	4–27	11.88 ± 6.18
Number of courtyards	0–3	0.44 ± 0.84
Courtyards width	0–50	9.34 ± 16.10
Sky view factor	0.23–0.75	0.40 ± 0.14

Table 8 The averages and ranges of urban form indicators (nominal)

Indicator		Number	Percentage %
Street orientation	NE	19	59.4
	NW	13	40.6
Street shift	No	26	81.3
	Yes	6	18.7
Width change rate	No	26	81.3
	Yes	6	18.7
Terminated vistas	No	23	71.9
	Yes	9	28.1
Nonrectangular silhouette	No	19	59.4
	Yes	13	40.6
Arcades	No	29	90.6
	Yes	3	9.4
Permeability	Non	9	28.1
	Visual	20	62.5
	Physical	3	9.4
Proximity	Non	9	28.1
	With	2	6.3
	Without	21	65.6

By analyzing more than 30 walkable streets from 6 different areas in Greater Cairo, it was possible to reach averages, ranges, and ratios for certain urban form elements. Through the analysis of these areas, we found a differentiation among their typologies regarding urban tissue as well as the street network; some of these typologies/street networks help in inherent certain perceptual qualities and weaken others. Regarding the design parameters, it was able to reach solid values such as the ratio between the street widths and building height; the 1:1 was proven to have the highest rank with a street

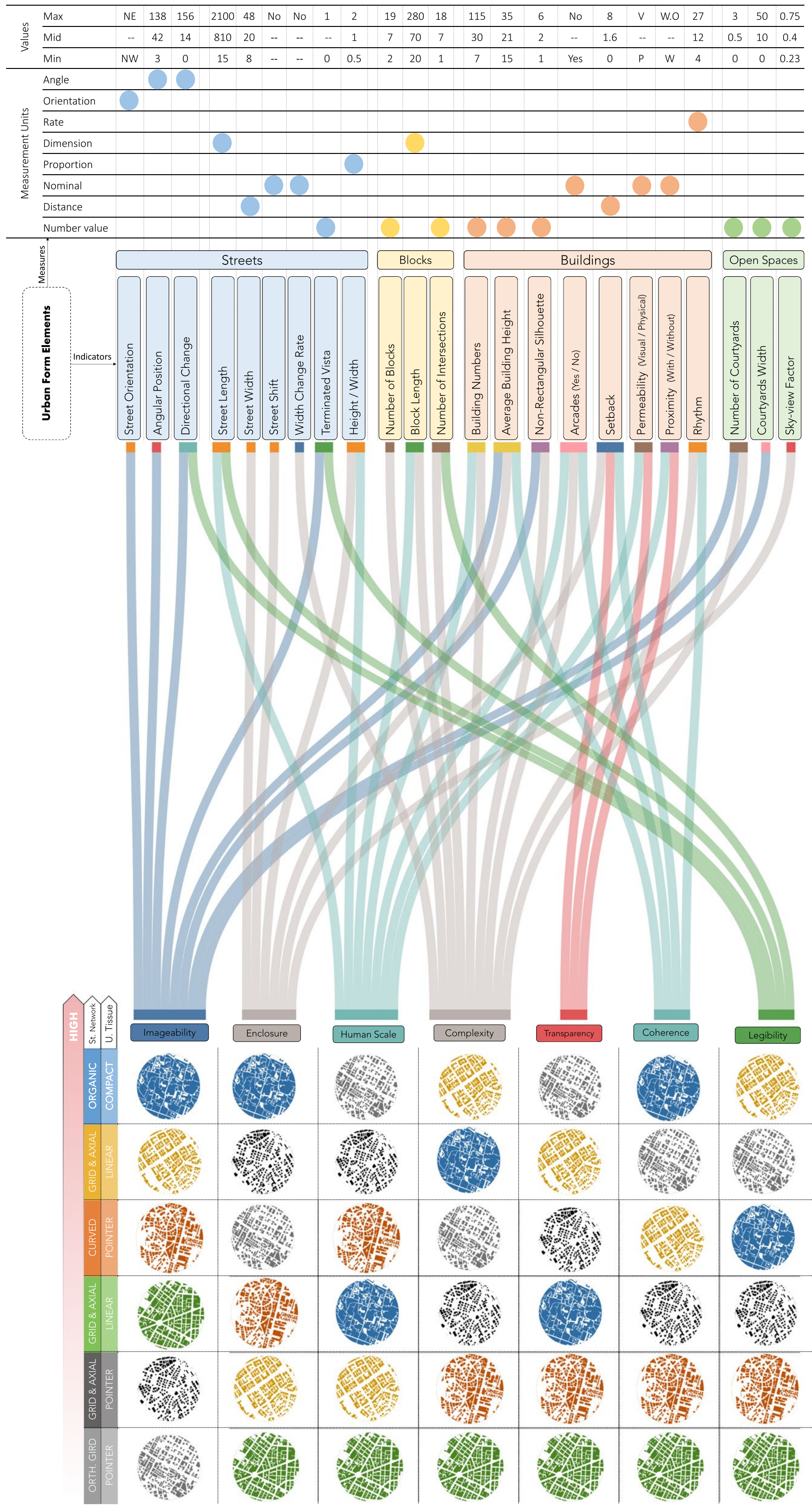

Fig. 9 Perceptual matrix for a walkable urban form

width of 20 m for best practice, as it gives a high sense of imageability, enclosure, and human scale. The street network was to be orthogonal gird and axial, as it has given a high sense of legibility and coherence. However, the linear urban tissue was ranked at the top, with the use of non-rectangular silhouette buildings and approximate building heights. Furthermore, it was to define values for urban form indicators that were not yet had a quantity to describe such as angular position, change in angle, orientation, and number of intersections.

The generated values for design parameters could be considered an added value to urban design codes and guidelines in the field of practice (especially in Egypt) to create a walkable urban form considering perceptual qualities. In addition, these proposed values contribute to a more specific relationship between urban design elements and perceptual qualities. Despite the limitation that all the selected areas were in the Egyptian context, and the selection of urban form indicators was based on its ability to be used and draw in a parametric software, this methodology could be used to deduct more design parameters for more urban form indicators as well as more contexts worldwide. In further stages, the research aims to use the generated values to be coded/used in parametric software to support urban designers with a tool that would help in generating various walkable urban forms with a reference to these values that is considering perceptual qualities in its core to ensure the livability of newly established cities and urban areas.

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Authors' contributions
WS, generating the idea, collecting data, methodology, and original draft preparation. SM, validation and editing. SB, reviewing and supervision. AA, reviewing and supervision. All authors read and approved the final manuscript.

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Declarations

Competing interests
The authors declare that they have no competing interests.

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