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Walkability and thermal comfort: an integrated evaluation system.

Case study: the Mediterranean outdoor environments (Annaba).

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**Walkability and thermal comfort: an integrated
evaluation system.**
Case study: the Mediterranean outdoor environments (Annaba)

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*To my family,
my country, my people,
and my profession.*

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Research papers

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Abstract

In recent years, walkability is increasingly involved in many sustainable strategies, considering its many health and environmental benefits. Thermal comfort has also been progressively promoted as a critical measure for pedestrian comfort and well-being. This thesis explores how to combine walkability and thermal comfort with a quantitative approach, by considering walkability and thermal comfort measurement tools. Two urban components are of interest in this research; the neighbourhood level and the street scale. We propose the comfort walkability index (CWI) at the neighbourhood micro-scale, based on two questionnaires; 330 respondents answered the first questionnaire to evaluate each indicator's coefficient (Cis). The second questionnaire was based on 282 respondents using a simple random sampling technique to assess the selected factors' scores (Sis). While the physiological Equivalent temperature (PET) is calculated using RayMan software. The Street Walkability and Thermal Comfort index (SWTCI) focuses on comfort facilities and PET at the street scale. The method requires combining a questionnaire survey (Cis), observation (Sis), and in situ measurements (air temperature, wind velocity, and relative humidity). SWTCI associated two software; Envi-met was used to calibrate microclimatic data (air temperature, wind velocity, relative humidity and mean radiant temperature); in comparison, RayMan was used to calculate PET. We tested the CWI and SWTCI tools in Annaba, Algeria, characterized by the Mediterranean climate (Csa), during summer 2017. The results showed a noticeable difference in both indices depending on PET values. The two indices achieved their highest score when the thermal perception is neutral ($20 < PET < 26$). Despite the divergence in PET values, the highest CWI and SWTCI scores were 40.95% and 32.90%, respectively, reflecting two categories: a rarely acceptable comfort quality and uncomfortable streets with minimal pedestrian comfort facilities. This thesis highlights the importance of assessing pedestrian comfort facilities at the neighbourhood and street scales, heeding the importance of thermal comfort in promoting a satisfying walking experience.

Keywords

Mediterranean climate (Csa), comfort walkability index (CWI), Street Walkability and Thermal Comfort index (SWTCI), Walkability, Physiological Equivalent Temperature (PET), RayMan.

Résumé

Ces dernières années, la marchabilité a connu un essor important, en effet elle est de plus en plus impliquée dans d'innombrables stratégies durables, compte tenu de ses nombreux avantages liés à la santé et l'environnement. Le confort thermique a été progressivement promu comme une mesure essentielle pour le confort et le bien-être des piétons. Cette thèse propose une méthode innovante par la combinaison de la marchabilité et le confort thermique à deux échelles ; le quartier et la rue. Ceci dit la méthode présentée se réfère aux outils d'évaluation des deux concepts. Nous proposons l'indice de confort de marche (CWI) à l'échelle du quartier, sur la base de deux questionnaires; 330 personnes ont répondu au premier questionnaire pour évaluer le coefficient de chaque indicateur (Cis). Le second questionnaire se base sur 282 réponses, suivant la technique d'échantillonnage aléatoire simple afin de mesurer les scores des indicateurs sélectionnés (Sis). Alors que la température physiologique équivalente (PET) est calculée par RayMan. L'indice de marchabilité et de confort thermique de la rue (SWTCI) se concentre sur les installations de confort et PET à l'échelle de la rue. La méthode combine un questionnaire (Cis), observation (Sis), et des mesures in situ (température de l'air, vitesse du vent, et humidité relative). Le SWTCI a associé deux logiciels; Envi-met a été utilisé pour calibrer les données microclimatiques (température de l'air, vitesse du vent, humidité relative et température radiante moyenne); en comparaison, RayMan a été utilisé pour calculer la PET. Nous avons testé le CWI et le SWTCI à Annaba, Algérie, caractérisée par le climat méditerranéen (Csa), durant l'été 2017. Les résultats ont montré une différence remarquable des deux indices en fonction des valeurs du PET. CWI et SWTCI ont atteint leurs scores maximales lorsque la perception thermique était neutre ($20 < PET < 26$). Malgré la divergence des valeurs du PET, les scores les plus élevés de CWI et SWTCI ont été respectivement de 40,95 % et 32,90 %, ce qui reflète une qualité de confort rarement acceptable, et des rues inconfortables avec des aménagements de confort piétonnier réduits. Cette thèse souligne l'importance d'évaluer les équipements de confort pour les piétons à l'échelle du quartier et de la rue, en tenant compte de l'importance du confort thermique afin de promouvoir une activité de marche satisfaisante.

Mots clés : Climat méditerranéen (Csa), indice de confort de marche (CWI), indice de confort thermique et de marche dans la rue (SWTCI), Marchabilité, latempérature physiologique équivalente

Template thesis

Acknowledgements	ii
List of publications	iii
Abstract	iv
Chapter 1. Introduction	1
1.1 Background.....	1
1.2 The research question, aims and objectives of the study.....	3
1.4 Structure of the dissertation.....	4
Chapter 2. Walkability and thermal comfort	6
2.1 Chapter outline.....	6
2.2 Walkability a sustainable transportation mode.....	10
2.2.1 Walkability, definition and origin of the concept.....	10
2.3 Walkability and comfort.....	11
2.4 Keys factors of walkability.....	12
2.4.1 The neighbourhood scale.....	12
2.4.1.1 Neighbourhood macroscale.....	12
2.4.1.2 Neighbourhood microscale	16
2.4.2 The street scale.....	17
2.5 Measurement tools of walkability.....	21
2.5.1 Neighbourhood scale.....	21
2.5.1.1 Neighbourhood macroscale.....	21
2.5.2 Street level.....	23
2.5.2.1 Audit tool.....	23

2.5.2.2 PLOS method.....	27
2.6 Thermal comfort in the outdoor environment.....	29
2.6.1 Thermal comfort indices and assessment tools.....	29
2.6.2 PET comfort range in different climate zones.....	30
2.6.3 Main methods to calculate PET.....	31
2.7 Thermal comfort as a walkability indicator.....	31
2.7.1 PET as a walkability comfort indicator.....	33
2.8 Conceptual framework of the thesis.....	35
2.9 Chapter summary.....	38
Chapter 3 Methods and material.....	39
3.1 Chapter outline.....	39
3.2 The Comfort walkability index (CWI) at neighbourhood microscale.....	41
3.2.1 Review of effective indicators.....	43
3.2.2 Data collection.....	44
3.2.3 Assessing indicators.....	44
3.2.4. Data collection.....	46
3.2.5. Process indicator evaluation.....	46
3.2.5.1 Pedestrian comfort facilities and scores.....	46
3.2.5.2 Calculating and scoring PET.	47
3.3 The Street Walkability and thermal Comfort Index (SWTCI).....	48
3.3.1 Microclimatic measurements.....	51
3.3.2 Sidewalk measurement in the pedestrian level of service (PLOS) methods.....	53
3.3.3 Thermal comfort indices	55

3.4 Assessing indicators.....	58
3.4.1 Pedestrian comfort facilities coefficients and scores.....	58
3.4.2 Calculating and scoring PET.....	59
3.5 Case study Annaba city within Csa climate.....	59
3.5.1 Case study 1 Neighbourhood microscale.....	62
3.5.2 Case study 2 Street scale.....	66
3.6 Chapter summary	68
Chapter 4 Results	66
4.1 Chapter outline	69
4.2 Results of applying the CWI in the Mediterranean climate.....	70
4.2.1 Pedestrian comfort facilities coefficients and scores in the selected neighbourhood.....	70
4.2.2 PET values and scores in the three neighbourhoods.....	74
4.2.3 The CWI results.....	77
4.2.4 CWI and Walkscore rates.....	79
4.3 Results of applying the SWTCI in the Mediterranean climate.....	81
4.3.1 Pedestrian comfort facilities coefficients and observation scores.....	81
4.3.1.1 Sample characteristics.....	81
4.3.1.1 Coefficient results.....	81
4.3.1.2 Observation scores results.....	81
4.3.2 Thermal comfort scores.....	84
4.3.2.1 Microclimatic data	84
4.3.2.2 PET coefficient and scores.....	86

4.3.3 Street Walkability and Thermal Comfort Index (SWTCI).....	88
4.4 Chapter summary.....	92
Chapter 5 Discussion.....	93
5.1 Chapter outline.....	93
5.2 The CWI	94
5.2.1. Coefficients and scores of pedestrian comfort facilities.....	94
5.2.2 CWI and PET	95
5.2.3 CWI and Walk score.....	96
5.3 The SWTCI	98
5.3.1 Impact of the pedestrian comfort facilities.....	98
5.3.2 The PET effect walking comfort.....	99
5.3.3 Interactivity of PET and pedestrian comfort facilities on SWTCI....	100
5.4 Overview interactivity of CWI and SWTCI.....	105
5.5 Chapter summary.....	108
Chapter 6 Conclusion and Future research.....	109
6.1 General conclusion.....	109
6.1.1 Response to the research questions and beyond.....	110
6.2 Research contributions.....	113
6.2 Limitations.....	116
6.4 Perspectives for future researches.....	118
References.....	120
Appendices	136
List of abbreviations.....	147

List of tables..... 149

List of figures..... 150

Chapter 1. Introduction

1.1. Background

Cities include complex and concurrently occurring systems, such as transport, land use, social, physical and digital infrastructure, as well as energy and utilities (Boulangé et al., 2018). In recent years, walkability has experienced significant development and has been included in multiple sustainable urban strategies. According to Hall and Ram (2018), increased walking highlighted benefits for transport and the environment, reducing traffic congestion, air pollution and emissions (Forsyth, 2015; Talen and Koschinsky, 2013). Besides improving public and private health (Durand et al., 2011) as well as economic performance (Leinberger and Alfonzo, 2012; Trowbridge et al., 2014).

The urban built environment has been explored to encourage physical activities (e.g. walking, cycling) and promote citizens' active lives. Many studies demonstrated the effect of city design characteristics (e.g., street connectivity, land–use mix, and residential density) on people walking behaviours (Ferdinand et al., 2012; Saelens et al., 2012; Saelens and Handy, 2008), including people with physical and non-physical disabilities (Helbich, 2018; Jeong et al., 2018; Stafford and Baldwin, 2018).

Neighbourhoods are defined as more "walkable" when walking is the first people's transport mode choice (Badland et al., 2013). Several studies have investigated macro-level indicators at the neighbourhood scale, such as design, diversity, density and destination (Habibian and Hosseinzadeh, 2018) besides greenness, nightline, and shading area (Taleai and Taheri Amiri, 2017) to improve walking rates in urban areas. Other studies have attempted to address key elements that help create a pedestrian-friendly neighbourhood (Wang and Yang,

2019) by considering comfort and convenience indicators (Aghaabbasi et al., 2017; Landis et al., 2001; Ussery et al., 2019). In addition, various studies focused on evaluating walkability at the street level (Aghaabbasi et al., 2019, 2017) since it is the main pedestrian activity scale. The street design facilities, such as shaded trees and benches, offer a pleasant walking experience (Battista and Manaugh, 2018), encourage people's walking activity and improve their comfort.

From another perspective, thermal comfort can affect the use of the outdoor environment. Many studies have shown the importance of climatic conditions for the well-being of inhabitants in urban spaces (Cohen et al., 2013; Nikolopoulou and Lykoudis, 2006). People in outdoor environments are vulnerable to thermal conditions throughout the different seasons of the year, ranging from heat stress and cold stress to neutral and comfortable conditions. Even during a single day, people can be subject to varying hot and cold thermal stress (Mahmoud, 2011). Many studies have elaborated universal indices to define thermal comfort in hot and cold conditions (Potchter et al., 2018). The two leading thermal comfort indices, the physiologically equivalent temperature (PET) and the Universal Thermal Climate Index (UTCI) have been widely used and applied to cold and hot conditions (Johansson et al., 2014; Potchter et al., 2018). However, PET has been successfully tested in different climate zones and urban spaces such as streets, squares, parks (Cohen et al., 2013; Gulyás et al., 2006; Mahmoud, 2011; Matzarakis et al., 2007; Thorsson et al., 2007). Moreover, PETcomfort range had been based on a questionnaire confirmed by people's vote (Nikolopoulou et al., 2001; Nikolopoulou and Lykoudis, 2007; Potchter et al., 2018).

The thermal conditions of walking environments acquired little attention despite composing the most immediate contiguous surrounding occurring pedestrians. Indeed street life and outdoor activities vary depending on the climatic conditions (Costamagna et al., 2019). Moreover, thermal stress could debase the walking experience and indirectly hinder walkability.

This association could make streets more comfortable for pedestrians by elucidating the correlation between human thermal comfort and walkability rates. Thus, a pedestrian-friendly environment could be developed by realizing standards and assessing walking facilities. Previous studies have linked comfort to urban design features, attractiveness and safety (Aghaabbasi et al., 2017; Asadi-Shekari et al., 2015; Kwon et al., 2017; Nilles and Kaparias, 2018). However, few

studies have considered the micro-level factors at the neighbourhood scale. Moreover, walkability in urban areas has rarely been assessed using thermal comfort indices, such as PET.

1.2 The research question, aims and objectives of the study

By creating a comfortable walkable environment, the walkability is significantly improved. This prospect is one of the major objectives of sustainable strategies. Such approaches are meant to resolve several problems, from environmental health and social isolation to traffic crowding, pollution, and climate. The correlation between walkability and thermal comfort seems to be an excellent alternative to sustainable ecological approaches.

This thesis aims to explore the following research questions: (i) How to combine thermal comfort and walkability? (ii) What are the indicators that define walkability comfort? (iii) What is the most appropriate thermal comfort index for walkability? (iv) Does thermal comfort affect the walking scores?

It is hypothesized that;

1. Thermal comfort affects walking rates and should thus be included in walkability indicators.

2. Using many walkability indicators involves people's perceptions. That can positively affect walkability accuracy rates. Compared to the Walkscore tool, which claims to be universal and includes few assessing parameters.

Understanding how to combine walkability and thermal comfort within a quantitative approach can be valuable in proposing new assessment tools. That supports the importance of pedestrian comfort facilities and thermal comfort efficiency, which helps to improve the walking experience.

This study includes specific objectives based on the following aims

(i) Understanding how to combine walkability and thermal comfort. (ii) Developing assessment tools to quantify this correlation. (iii) Inform urban planners, architects and municipalities, about the usefulness of these tools, by integrating them into environmental approaches and sustainable perspectives.

Objective 1

- Identify the essential pedestrian comfort features for all users, including people with disabilities.
- Identify the most applied and validated thermal comfort indices in the outdoor urban spaces.

Objective 2

- Develop new assessment tools at the primary urban scale, the neighbourhood microscale level, and the street scales.
- Evaluate the importance of pedestrian facilities and thermal comfort by users. That involved examining the relationship between the pedestrian environment and citizen perception.
- Assess the quality of the environmental furniture objectively according to the standard guideline.

The application covers the Mediterranean climate (Csa). Thus, we have chosen the city of Annaba, Algeria, a pilot city in the Mediterranean area, to verify the reliability and relevance of the proposed methods.

1.3 Structure of the dissertation

Chapter I of this dissertation includes the background, questions, research, aims and objectives, besides thesis structure.

Chapter II discusses the literature reviews concerning: 1/ Walkability and its measurement tools, 2/ Thermal comfort, the most used indices and assessment methods, 3/ Thermal comfort as a walkability indicator, and 4) a summary diagram of the thesis.

Chapter III presents the developed methods at the neighbourhood micro-scale and streets level. The first method involved a new assessment tool at the neighbourhood micro-scale. Which focuses on 1/ Identifying pedestrian comfort indicators at the neighbourhood micro-scale, and 2/ the selected thermal comfort index (The physiological Equivalent temperature (PET)), and finally 3/ suitable assessment techniques such as the questionnaire survey and software (Rayman).

This chapter also includes the proposed method on the street level that concentrates on 1/ analyzing pedestrian comfort indicators and 2/ thermal comfort index (PET). 3/ Appropriate techniques such as the questionnaire survey, observation in situ measurements, and association of the two software (Envi-met and Rayman).

It is worthy to note that we chose Annaba, Algeria, characterized by the Mediterranean climate, to apply and validate the two methods. The case study includes climate type, population walk score results, neighbourhood and street consideration and choice.

Chapter IV presents the results of the proposed tools in the Csa. 1) At the neighbourhood micro-scale. It also includes a comparison between the CWI and the walk score results. 2) At the street scale (SWTCI), and finally 4) data interactions (CWI and SWTCI).

Chapter V highlights the discussion section 1. The neighbourhood micro-scale level. 2. The street level, 3. The relevance of using observation and T_{mrt} within PET calculation, and finally Improve walkability scores by identifying pedestrian environment failure.

Chapter VI is the conclusion chapter. It summarizes the two assessment tools' findings besides discussing the implication and the feasibility of applying both tools in operational urbanism besides their contributions to sustainable strategies and public health.

Chapter 2. Walkability and thermal comfort

2.1 Chapter outline

Walkability refers to the suitability of an urban environment to provide pedestrian walkways (Asadi-Shekari et al., 2019; Burden, 2001; Moeinaddini et al., 2015; Ruiz-Padillo et al., 2018). Walkability also enhances the liveability and environmental quality (Badland et al., 2013; Boulange et al., 2018). It depends on simple infrastructure (Aghaabbasi et al., 2017, 2018; Asadi-Shekari et al., 2019; Moeinaddini et al., 2015). Walking is now considered a significant factor in promoting healthier, sustainable and active communities (Moura et al., 2017). It has pertinent effects on reducing pollution in cities and ensuring inhabitants' well-being and health (Habibian and Hosseinzadeh, 2018; Hall and Ram, 2018; Taleai and Taheri Amiri, 2017). Encouraging walking environments in cities is viewed as a relevant goal in attaining sustainable mobility patterns. Streets, sidewalks, parks, squares and other urban design elements play a crucial role in promoting walkability as they can affect pedestrian walking behaviour (Moura et al., 2017; Rahaman et al., 2012; Saelens and Handy, 2008).

Several authors explored the impact of the built environment furniture on likeliness and walking ability (Ewing and Cervero, 2010; Ewing and Handy, 2009; Mateo-Babiano, 2016; Saelens and Handy, 2008). Thus, walkability has generally been assessed by considering three main factors: land use mix, street connectivity, and residential density (Dannenberg and Wendel, 2011; Lee and Dean, 2018). Besides, jobs and buildings; street safety; security from crime; landscaping; thriving public life and sense of place (Lamour et al., 2019).

Cain et al.(2017) noted two methods for assessing walkability at the neighbourhood scale. The first concerns macro-level characteristics, including existing neighbourhoods (e.g.,

street connectivity, land-use mix, residential density). Those are not exposed to frequent changes in the urban environment (Saelens and Handy, 2008). The second approach is related to the micro-level at the neighbourhood scale, consisting of the quality and attractiveness of sidewalks, affecting the comfort and safety of walkability in urban spaces (Aghaabbasi et al., 2017, 2019; Asadi-Shekari et al., 2013a).

A number of studies have investigated macro-level indicators at the neighbourhood scale to improve walking rates in urban areas (Habibian and Hosseinzadeh, 2018; Hall and Ram, 2018). Other studies have attempted to address key elements that help create a pedestrian-friendly neighbourhood (Wang and Yang, 2019) by considering important safety, comfort and convenience indicators (Aghaabbasi et al., 2017; Landis et al., 2001; Ussery et al., 2019).

On the other hand, many studies explored outdoor thermal comfort since it significantly correlates with health and well-being. Moreover, a comfortable urban environment could enhance human activities. The climatic conditions and human factors affect outdoor thermal comfort (Andreou, 2013). Liu et al. (2016) proved the importance of microclimatic variables for human outdoor thermal comfort. Many indices had been developed, such as Physiologically Equivalent Temperature (PET) (Höppe, 1999), Perceived Temperature (PT) (Jendritzky et al., n.d.) and Universal Thermal Climate Index (UTCI) (Fiala et al., 2012). These indices are established according to the mechanism of the heat conductivity between the human body and outdoor climate (Liu et al., 2016).

The thermal conditions of the walking environment have been under-investigated, despite the importance of the outdoor thermal environment for pedestrians. Only a few recent studies associated walkability and thermal comfort. Lee et al. (2020) explored the influence of biometeorological related factors on pedestrian behaviour by calculating PET and UTCI to express thermal stress at semi-open space in Hong Kong, China. The findings highlighted the correlation between thermal sensation and pedestrian choice of the shaded zone. However, the walkability indicators have not been considered in the assessment method.

The literature review presented in this chapter is divided into two main sections. Fig 1 shows the principal sections and their related contents. The first section intended to identify the origin and meaning of the walkability concept. Indeed, many research fields explored it

depending on their objectives, such as health, transportation, urban design. This section also reviewed the primary keys of the built environment. Besides the compelling pedestrian- features related to the comfort concept at the neighbourhood and street scales. In an attempt to understand the importance of pedestrian comfort amenities and their influence on walking behaviour. Key papers were identified from walkability studies, transport research, built environment and physical activity. Measurement tools and methods had also been described and analyzed to understand clearly the representative assessment of walkability.

The second section consists of the thermal comfort concept. This section focused on the meaning of thermal comfort, the most accurate and appropriate thermal indices for walkability, how to calculate the physiological Equivalent Temperature (PET) and finally, the PET comfort range within different climates. The key papers were explored from thermal comfort studies, and the impact of thermal comfort on physical activity, thermal comfort range, simulation, Rayman and Envi-met.

The third section explains the feasibility of associating walkability and thermal comfort. Indeed, the term comfort is considered a common explored area for the two concepts. Moreover, the climate is another fundamental factor because climatic conditions affect pedestrian comfort and outdoor activities. In addition, some other factors, such as urban components and measurement tools, are related to both field research.

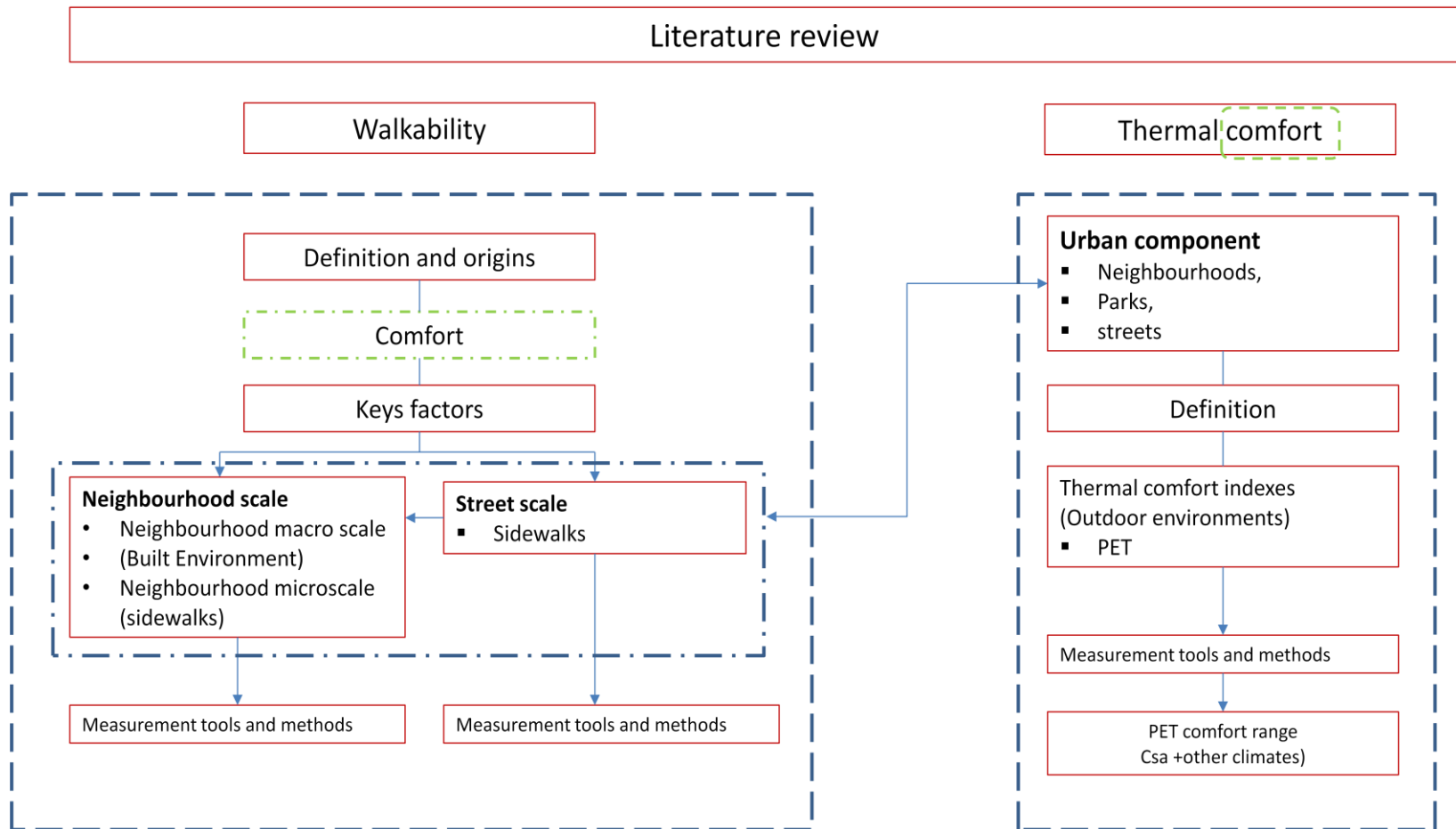


Fig. 1. Conceptual framework of the literature review.

2.2. Walkability a sustainable transportation mode

2.2.1 Walkability; definition and origin of the concept

The word "walkable" had been used since the 18th century (Oxford English Dictionary, 2013). In contrast, walkability is a recent term rarely defined in dictionaries but everyday use (Forsyth, 2015). The walkability concept is widely used by multiple streetscape designers, health and leisure promoters, and urban designers.

Lee and Dean (2018) defined walkability as the underpinning attributes of sustainable, friendly and healthy cities. Walkable urban spaces can enhance physical activities across purposeful or entertaining walking, promoting social value to the community besides improving health benefits (Black, 2008; Lee and Dean, 2018).

Walkability may characterize the neighbourhood's capacity to provide physical activity behaviour (Carr et al., 2011). It referred to the set of factors representing design, diversity, and density. Including street connectivity, land use mix and residential density (Hajna et al., 2015). In other terms, walkability indicates all attributes that encourage various forms of physical activity, including accessibility to walking destinations (e.g., stores and parks) and urban environment design features such as street connectivity and sidewalk access (Duncan et al., 2011; Hall and Ram, 2018).

During the last years, the urban built environment has been investigated to enhance the general population's active life participation. That highlighted walking over the home neighbourhood and its spatial aspects (Huang et al., 2019; Schreuer et al., 2019). The built environment can be characterized as the physical environment created by human activity (Saelens and Handy, 2008). Indeed, a neighbourhood's built environment promotes or discourages walking (Lamour et al., 2019). Wang and Yang (2019) related the concept of walkability to measure how favourable the built environment is to walking. That can be exploited to anticipate human physical activity (Frank et al., 2006; Sallis et al., 2004).

Hall and Ram (2018) defined walkability as the degree to which an urban environment empowered walking (Kelly et al., 2011), besides being suitable (Moura et al., 2017) and friendly

(Burden, 2001; Ruiz-Padillo et al., 2018). Park (2008) identified walkability as the walking environment conditions that pedestrians perceived. Indeed, a pedestrian-friendly area that compromises a high degree of vegetation, low density, high street connectivity and good land use mix may promote the walking activity (Taleai and Taheri Amiri, 2017). Walkability also refers to the suitability of an urban environment to provide pedestrian walkways (Burden, 2001; Moeinaddini et al., 2015; Ruiz-Padillo et al., 2018). Various studies have been explored to report the quality of walking conditions, including safety, comfort, and convenience (Aghaabbasi et al., 2018; Ruiz-Padillo et al., 2018).

Based on the current literature, we estimate that walkability is a multidimensional concept. That involved measurable dimensions and allowed designing walkability indicators. Besides, defining conditions that enhance the walking experience, improve urban areas and promote sustainable strategies.

2.3 Walkability and comfort

Comfort assign the level of convenience and complacency of the person (Alfonzo, 2005). It could be affected by different factors such as climate, physical conditions, perceived safety, familiarity, accessibility and convenience (Mehta, 2008). Some factors such as crowding, noise, pollution, traffic congestion, footpath quality, crime and violence, can influence pedestrian activities (walkability) and decrease social support (Hart and Parkhurst, 2011; Mehta, 2008; Pikora et al., 2002; Ramirez et al., 2006; Southworth,2005).

According to Gehl et al. (2006) and van der Ploeg et al. (2010), walking is one of the main opportunities to comfort people. Moreover, the climatic conditions (e.g. hot temperature, cold weather) influence pedestrian comfort. However, enjoying the positive aspects of climate encourage outdoor activities and contribute to comfort.(Lorraine Fitzsimons, 2013; Mehta, 2008; van der Ploeg et al., 2010).The built environment component, urban design furniture, footpath quality, street furniture, street trees are an inherent part of a comfortable walking experience. Despite the importance of comfort for walkability, few studies explored it and defined the related factors.

2.4. Keys factors of walkability

Several urban design theories explored walkability at the neighbourhood scale and street level. That essentially considered physical features to improve the walking experience. According to Forsyth (2015), many studies analyzed the physical facilities and conditions that allowed walking, such as accessible areas, compact cities, and physically-enticing or safe. Others characterize the walkable environments' outcomes or performance by improving sustainable transportation modes, making outdoors friendly and animated or enhancing exercises. Finally, some studies focused on identifying walkability as a proxy to improve urban environments using measurement tools. That can strengthen walkability and solve many urban problems.

This section presents the most used indicators at the neighbourhood scale and the street level.

2.4.1 At the neighbourhood scale

Many studies have investigated macro-level indicators at the neighbourhood scale to improve walking rates in urban areas (Habibian and Hosseinzadeh, 2018; Hall and Ram, 2018; Taleai and Taheri Amiri, 2017). Other studies have attempted to address key elements that help create a pedestrian-friendly neighbourhood (Wang and Yang, 2019) by considering important safety, comfort and convenience indicators (Aghaabbasi et al., 2017; Landis et al., 2001; Ussery et al., 2019). The neighbourhood microscale level is essential to identify pedestrian amenities within the walking environment's quality (Aghaabbasi et al., 2017).

The listed factors were coordinated in two classes, separating the relevant macro scale and micro scale indicators. Thus, the built environment factors are described in the first part of this section, followed by a characterization of pedestrian features that encourage walking.

2.4.1.1 Neighbourhood macro scale

The literature review presented in this section describes the physical attributes of the environment that impact walkability. The urban features such as 5Ds: Density, Diversity, Design, Destination accessibility and Distance to transit (Ewing et al., 2009; Ewing and Cervero, 2010; Giles-Corti et al., 2016) are usually presented in the literature (Jeffrey et al., 2019). Combining

these attributes encourages walking, cycling and neighbourhood benefits besides improving health (Frank et al., 2005; Giles-Corti et al., 2015; Saelens et al., 2003).

Boulangé et al. (2018) identified six (6) design characteristics, including residential density, land use mix, street connectivity, the proximity of destinations, presence of sidewalks, and access to public transport infrastructure (Adams et al., 2013). These design attributes affect physical activity and are considered to be constantly correlated with walking transport participation (Ainsworth, Barbara E and Caroline A, 2012).

Schreuer et al. (2019) defined three main variables of the spatial layout of neighbourhoods that affect its walkability degree; (1) The land use compound, which is characterized by the disposition of shops, schools, workplaces, health and other public services. (2) Density; a high residential density generates a compact environment that enhances walkability. (3) The street pattern increases walkability by creating a high degree of connectivity and continuity when streets are in the grid network order. Besides, offering short and direct paths between the various destinations.

The land-use diversity is a critical indicator to stimulate walking activity (Ewing and Cervero, 2010). The land-use defines a combination, such as commercial ground-floor façades, which has an important impact in attracting people at different times, including at night (Lamour et al., 2019). It is also known to foster the occupation and livability of the streets. Moreover, the proximity to a destination encourages people for selecting walking as the first mode of transport (Agrawal et al., 2008). Furthermore, land-use diversity improves a neighbourhood's liveliness and generates a good quality of life (Burdett et al., 2005; Lamour et al., 2019) besides providing a secure community.

Gehl et al. (2006) and Marcus and Francis (1997) highlight the necessity of diversity in the urban landscape because the visual dynamicity and crowded rhythm improve the urban walking experience. In contrast, endless walls and whole closing blocks transform the streets into monotonous and unsure urban spaces (Lamour et al., 2019).

The high population density is usually associated with walkability in the literature (Lamour et al., 2019). It increases the efficiency of using infrastructure and enhances street life vivacity. However, it is considered an isolated attribute that is not up to improve walkability

(Jacobs, 2016). Therefore, it must be considered a critical feature in promoting walking indirectly (Lamour et al., 2019). The walkability is upgraded when multiple land uses are associated with residential areas (Schreuer et al., 2019). High street connectivity increased land use mix and increased residential density conduct to a high level of walkability (Frank et al., 2006).

Alternatively, another study carried out by the London Planning Advisory Committee designed the multidimensional 5Cs plan (Gardner et al., 1996). Accordingly, a pedestrian-friendly environment must be: Connected, Convenient, Comfortable, Convivial and Conspicuous (Moura et al., 2017). Indeed, these characteristics emphasize the interaction between the built environment and walkability (Saelens and Handy, 2008). Table 1 shows the description of the 5Cs layout. Moura et al.(2017) proposed two extra factors emphasising the built environment's major attractiveness-related amenities. These two factors are not mentioned in the existing 5Cs, such as (1) Coexistence related to pedestrian safety from traffic and the traffic effect on public space. (2) Commitment that includes the pedestrian politics development by local authorities (Table 1).

Table 1 The 5Cs and 7 Cs dimensions definition

Dimensions	Definition	References
7Cs	<p>Connected: The degree to which the pedestrian network links to major trip provenances and destinations, besides the extent of connections between different itineraries within the network. Connectivity is identified as an essential environmental feature for designing several options and a shorter and direct roadway to destinations.</p>	<p>Berrigan et al., 2010; Saelens et al., 2003; Tal, G and Handy, S, 2012</p>
	<p>Convenient: The degree to which walking is available and can be combined with other transport modes with concerns to efficiency (time, money and space). It is associated with the diversity of land uses and activities conveniently accessible by walking.</p>	<p>Cervero et al., 2009; Frank et al., 2005</p>
	<p>Comfortable: The level to which walking is appropriate for all pedestrian abilities and skills (including people with disabilities), considering facilities and design furniture, and facilitates the walking experience.</p>	<p>Rahaman et al., 2012; Saelens and Handy, 2008</p>
	<p>Convivial: The level to which walking is an enjoyable and pleasurable activity, considering interaction with people, built environment and natural landscape and recreation activities.</p>	<p>Cervero and Duncan, 2003.</p>
	<p>Conspicuous: The level to which walking streets and urban spaces are visible and attractive for pedestrians, with concerns noticeable, good signing and information, and good spatial coherence and complexity.</p>	<p>Ewing et al., 2006</p>
	<p>Coexistence: The degree to which walking and other transport modes can coexist simultaneously in order. The pedestrians are identified as the most vulnerable street users regarding the traffic accident risks on walking activity (Koh and Wong, 2013). Besides the perception of volume cars dominance in the roadway. (Kelly et al., 2011) highlighted the negative impact of the traffic on the walking environment by generating the feeling of inadequacy within the pedestrian survey (Moura et al., 2017).</p>	<p>Moura et al., 2017</p>
	+2 Cs	<p>Commitment: The level to which the local administrations have a duty of liability and responsibility for the pedestrian environment. This dimension seeks to apprehend an urban agreement to promote the pedestrian environment.</p>

These dimensions are intended to address the most significant built environment indicators that can affect pedestrian walking behaviour and promoting a walker-friendly environment. However, some of these indicators could be mentioned in two dimensions. For example, the pavement's cleanness is considered a critical factor in pedestrian reference (Kelly et al., 2011). It may be filed under the comfort category or classified as a convenience factor because a clean walkway is always considered more comfortable and/or more convenient than its opposite condition (Moura et al., 2017).

2.4.1.2 Neighbourhood microscale

The micro-scale, or another term, the minor attributes of the environment, includes sidewalk quality and aesthetics (Cain et al., 2017). That can influence people's comfort and safety during the walking experience in neighbourhoods (Cain et al., 2014; Sallis et al., 2015). The neighbourhood micro-scale characteristics have rarely been effectively studied (Cain et al., 2017). However, they should be measured to apprehend the all-inclusive dimensions of the sidewalk's physical condition (Aghaabbasi et al., 2017). Many works on health and urban planning highlighted the positive correlation between high physical activity scores (walking) and sidewalks availability at the neighbourhood scale (Aghaabbasi et al., 2018; de Vries et al., 2007; Rodríguez et al., 2008). The micro-level approach at the neighbourhood scale, which can more easily account for frequent changes than at the macro level, has rarely been explored (Cain et al., 2017).

Using the micro-scale approach can contribute to the provision of attractive sidewalks, pleasant and comfortable walking paths. Urban furniture such as drinking fountains (Cambra, 2012; Sarkar S., 2002), slope (Aghaabbasi et al., 2017; Akiyama and Kim, 2005a) and benches (Architectural and Board, 2004; Clifton et al., 2007) provide a comfortable environment for pedestrians in urban areas besides other social benefits (Jacobs, 1993; Lamour et al., 2019; Marcus and Francis, 1997). Walkability is also influenced by artificial shade's visual quality and aesthetics (Kim et al., 2012; Laurentin et al., 2000) as well as natural shade. Indeed, vegetation has the aesthetic potential to create attractive spaces (Jacobs, 1993; Lamour et al., 2019). Trees that provide shade (Taleai and Taheri Amiri, 2017) encourage citizens to walk around the streets during the hot hours of the day (Lamour et al., 2019). The efficiency of vegetation associated

assessments such as green roofs and green walls (Lee and Jim, 2017). Which have been examined in improving biometeorological conditions (Lee et al., 2020).

Moreover, this approach adds a safe dimension to the neighbourhood, for example, by implementing a speed limit for motorized vehicles (30 km/h) (Hamilton-Baillie, 2008) and appropriate signage for pedestrian crossing (Lamour et al., 2019). The quality of pavement is another parameter considering pedestrian safety, which must be spacious, without steps or obstacles, and good quality to assure security and comfort to all users (Gehl et al., 2006a). Accessible open spaces such as parks and squares have a crucial role regarding pedestrian activity, safety and comfort (Gehl et al., 2006a; Lamour et al., 2019; Marcus and Francis, 1997; Mateo-Babiano, 2016). Walkability micro-scale assessment models allow perceiving the walking environment better (Asadi-Shekari et al., 2019). That must be considered in designing walkable neighbourhoods (Schreuer et al., 2019).

2.4.3 Street scale

According to Aghaabbasi et al. (2019), sidewalks are the principal links to ensure walking (Hooker, 2007). They are crucial factors for promoting sustainable transportation (e.g., walking, cycling) (Aghaabbasi et al., 2017; Saito et al., 2013; Taboada, 2015). The street users include all categories (e.g., age, gender, physical condition). Accordingly, it is requisite to design sidewalks that are adequate with an extensive range of users (Aghaabbasi et al., 2017; Asadi-Shekari et al., 2013b). These primary channels should provide safe, healthy and all-inclusive walking conditions (Aghaabbasi et al., 2018).

Sidewalk amenities conducive to comfortable walking involve main facilities (e.g., kerbs, ramps, sidewalk width), encouragement facilities (e.g., lighting, sitting areas, landscaping and trees) and convenience facilities (e.g., toilets, drinking fountains) (Asadi-Shekari et al., 2019). Such indicators can transform spaces into accessible, walkable and comfortable areas (Grahn and Stigsdotter, 2003; Ruiz-Padillo et al., 2018).

Aghaabbasi et al. (2018) divided walkability indicators into different components, such as accessible design factors (e.g., accessible drinking fountains, accessible toilets, tactile pavements, kerb ramps, accessible signage and signals, skybridge lifts); safety design factors (e.g., landscaping and trees, signage, bollards, surfaces and materials, lighting, signals);

attractiveness design factors (e.g., landscaping and trees, benches and sitting areas, rubbish bins, effective sidewalk width, lighting, cleanliness); and sidewalk path conditions (e.g., maintenance, slope, natural barriers). Other studies have used similar walkability indicators, such as seating areas, bollards, landscaping and trees, toilets, rubbish bins, skybridge lifts, driveways, slope, materials/surfaces, effective sidewalk width, signals, signage, tactile pavements, ramps, kerb ramps, cleanliness, lighting (Aghaabbasi et al., 2017), drinking fountains (Asadi-Shekari et al., 2019), shady trees, accessibility to green spaces, benches and pedestrian-scale lighting (Asadi-Shekari et al., 2014; Battista and Manaugh, 2018; Dixon, 1996; Grahn and Stigsdotter, 2003; Jensen, 2007).

According to Asadi-Shekari et al. (2014), improvement in sidewalk conditions can be achieved by integrating certain walkability factors such as slower traffic, midblock crossing landscaping and trees, facilities (e.g., fire hydrants), lighting, signals, bollards, slope, kerb ramps, wheelchair-accessible drinking fountains, tactile pavements (warning and guiding), signals, benches and seating areas.

Street lighting is essential to ensure security and safety (Loukaitou-Sideris, 2006). These walkability indicators are suitable for all users, including people with disabilities. It is also necessary to constantly measure existing sidewalks to verify their accommodation with all people needs considering socio-demographic properties, physical, sensory and cognitive conditions (Aghaabbasi et al., 2019, 2017; Asadi-Shekari et al., 2013b; Kadali and Vedagiri, 2016). Table 2 shows the street facilities and their impact on pedestrian comfort.

Table 2 Pedestrian comfort facilities on street level

Pedestrian comfort facilities	Description of comfort impact	References
Slower traffic speed	Aid to ensure pedestrian safety and comfort in neighbourhoods. Higher automobile speeds are firmly combined with the pedestrian crash and pedestrian injury	Asadi-Shekari et al., 2015, 2014
Buffer and barriers (kerb and furnishing zone)	increase the comfort and safety of pedestrians optimally and reduce the risk of a crash (Shaaban, 2019)	Asadi-Shekari et al., 2015, 2014
Fewer traffic lanes	The comfortable street concept reflects the travel lane width's safety comfort zone; the reduced numbers of lines imply a significant pedestrian comfort and safety feeling(Karim et al., 2015)	Asadi-Shekari et al., 2015, 2014
Mid-block crossing	Indicated with pavement marking and warning signs, and provide comfort and safety to pedestrians.	Asadi-Shekari et al., 2015
Landscape and trees	Improve pedestrian comfort by providing a shaded area and a pleasant environment for pedestrians. Trees reduce the effect of the urban heat island and can offer an aesthetical value to the streets(Shaaban, 2019)	Aghaabbasi et al., 2019, 2018, 2017; Asadi-Shekari et al., 2019, 2014
Furniture (rubbish bins)	Improves the walking experience Trash receptacle is an essential component of the sidewalk's visual comfort and cleanness (Aghaabbasi et al., 2019).	Aghaabbasi et al., 2019, 2017; Asadi-Shekari et al., 2019, 2014
Footpath Pavement	The physical condition of the sidewalk influences pedestrian comfort. For example, a footpath with cement tiles contributes to increased comfort during the walking experience and makes accessible wheelchair and stroller mobility. Tiles with lighter pigmentation consume less heat, affording higher thermal comfort	Asadi-Shekari et al., 2015; Moura et al., 2017; Nilles and Kaparias, 2018
Marking (crosswalk)	It helps orient pedestrians and shows the shortest distance across a complicated intersection. It is fundamental for a pleasant and safe walking network.	Asadi-Shekari et al., 2015
Sidewalk on both sides	Required for safe and pleasant walking; for facilitating direct pedestrian access and bus stops	Asadi-Shekari et al., 2015
Width of footpath	Gives an acceptable width and clear sidewalk (Krambeck, H.V, 2006), providing comfort to the pedestrian (Aghaabbasi et al., 2017; Azemati et al., 2011; Kubota, 2012). That is required, especially the busy times of the day	Aghaabbasi et al., 2019, 2018, 2017; Asadi-Shekari et al., 2019, 2014

Continued Pedestrian comfort facilities	Description of comfort impact	References
Slope	The sidewalk's minimum slope provides utility for people with disability (Aghaabbasi et al., 2019; Akiyama and Kim, 2005b). However, an improper slope makes pedestrians in wheelchairs uncomfortable. It also ensures a suitable runoff of rainwater to avoid compromising the security of pedestrians.	Aghaabbasi et al., 2018, 2017; Asadi-Shekari et al., 2014
Lighting,	Provides sufficient lighting and the street, ensuring security and visibility at night and increasing the pedestrian's visual comfort light.	Aghaabbasi et al., 2019, 2018, 2017; Asadi-Shekari et al., 2019, 2015, 2014
Ramp	An accessible curb ramp contributes to comfortable and safe access for people with mobility impairments from inhibiting sidewalk to a roadway, or vice versa.	Aghaabbasi et al., 2019, 2017; Asadi-Shekari et al., 2019, 2015, 2014
Park and space for playing	Provide a pleasant environment where people can enjoy walking and a pleasurable play area for children. Trees and vegetation have environmental benefits and improve pedestrian comfort.	Koh and Wong, 2013; Tsukaguchi et al., 2010
Social space (café)	Provides life to pedestrians' streets and comfort; however, some furniture like tables, chairs, and advertising sandwich boards are used if their dimensions do not disturb pedestrian mobility.	Gunn et al., 2017; Moura et al., 2017
Shade	Buildings high and trees provide a shaded area along city streets. Trees along streets can improve pedestrian thermal comfort significantly	Clifton et al., 2007; Taleai and Taheri Amiri, 2017
Bench and seating areas	improve the walking experience along city streets; and provide comfort for pedestrians (Aghaabbasi et al., 2019; Galanis and Eliou, 2011)	Aghaabbasi et al., 2019, 2017; Asadi-Shekari et al., 2019, 2014
Toilet	Help to ensure a pleasant walking experience. Besides considered an attractive design for the landscape at sidewalk scale (Aghaabbasi et al., 2017).	Aghaabbasi et al., 2019, 2018, 2017
Pedestrian signal	Provide audibly and flashing crossing indications(Shaaban, 2019). It affects pedestrian security, accessibility (Aghaabbasi et al., 2017), and comfort.	Aghaabbasi et al., 2019, 2018, 2017; Asadi-Shekari et al., 2015, 2014
Shorter crossing distance (kerb extension)	Enhances pedestrian comfort and reduces pedestrian risk during the crossing by shortening crossing distance, allowing pedestrians to see and be seen before crossing.	Asadi-Shekari et al., 2015

2.5 Measurement tools of walkability

2.5.1. Neighbourhood scale

Neighbourhood and streets are the main scales explored by measurement tools. The impact of environmental indicators on walkability has defined a broad range of assessment tools. Hall and Ram (2018) identified two primary research approaches that are used in developing walkability. The first was related to creating walkability measurements (Ewing and Handy, 2009; Gebel et al., 2009; Lwin and Murayama, 2011; Vale et al., 2016). It includes a qualitative and quantitative assessment of the built and social environments (Lo, 2009; Riggs, 2017; Southworth, 2005), trip purpose (Forsyth and Southworth, 2008), and cultural, gender within the walkability context (Forsyth, 2015; Hall et al., 2017).

The second approach (minor stream) is related to the reviews summarizing the walkability concept. However, this assignment has many challenges since the idea of walkability has been explored by many disciplines. Every field of research has a specific framing of the concept (Hall and Ram, 2018). On another side, researchers have tried to resolve the complexity of the relationship between neighbourhood micro-scale indicators, walking behaviour, and the role of individual perception from an elaborate framework. However, few studies developed measurement tools at the neighbourhood micro scale.

This section reviews the most used measurement tools and methods based on quantitative and qualitative measurements at the neighbourhood macroscale and street level. It also includes some measurement tools at the neighbourhood micro- scale because of their lack.

2.5.1.1 Neighbourhood macroscale

Various methods assess walkability by considering three main factors: land use mix, street connectivity, and residential density (Dannenberg and Wendel, 2011; Lee and Dean, 2018). The walkability index, which correlates net residential density, intersection density, the retail floor area ratio, and the land-use mix, is the most usually adopted type of assessment (Wang and Yang, 2019). Some walkability index has been explored to analyse the link between walking and the built environment (Frank et al., 2006). They also illustrate the level to which a census segment is walkable (Leslie et al., 2007) and investigate the frequency of walking and walkability

as a transport mode (Owen et al., 2007). Other studies combined objective and subjective measurements such as the walkability audit, the Senior Walking Environmental Assessment Tool - Revised (SWEAT-R) (Lee and Dean, 2018). That measured walkability scores objectively using the GIS tool (Leslie et al., 2005) and people's perception (the seniors). However, this study was based on a tiny sample which minimizes the accuracy of the data.

Another study by Leslie et al. (2007) advanced a new walkability index that many studies have accepted. Moreover, some studies approved the index's applicability and proposed improvements for multiple contexts. Ellis et al. (2016) used an adapted version by replacing the road network with a footpath network in walkability assessment. Other models get improved by considering additional attributes such as green factors or spaces, aesthetic factors, imageability, enclosure, human scale, transparency and complexity). These have a significant improvement on the walkability evaluation. Lwin and Murayama (2011) investigated walkability within the urban green area to evaluate neighbourhood environments and help citizens choose their prospective houses.

According to Wang and Yang (2019), many studies validate exploring street segments, besides considering macro variables at the neighbourhood scale, such as sidewalks and safety indicators. Cubukcu et al. (2015) investigated network design besides the accessibility of various facilities and GIS platforms to develop an assessment model for measuring street walk scores. Aghaabbasi et al. (2018) used data collection by combining techniques such as the geographic information system (GIS) and questionnaires (people's perception of their neighbourhoods). In addition, audit tools concentrate on the operational and physical environment, land use, density, and other relevant attributes. Audit tools are also advantageous in analysing and assessing walkability.

Walk Score® measures the "walking potential "of an urban environment over the combination of three components: the shortest path of an association of preselected destinations, the block length, and the intersection density over the origin. Moreover, the index relies on a gravity-based assessment (distance accessibility) and topological accessibility (Street connectivity). That is evaluated as penalties within two interdependent factors in the last score (linearly extended the scope of 0-100) (Hall and Ram, 2018). However, this measurement tool lacks some walkability attributes in its assessment (Wang and Yang, 2019).

Many studies adopted Walk Score® within the built environment index (Hall and Ram, 2018), such as Hajna et al. (2015), Kim and Park (2016) and Lee et al. (2016a) besides transport/purposive walking measure (Thielman et al., 2015; Wasfi et al., 2016) as well as walking behaviour (Xu and Wang, 2015).

Carr et al. (2011) measured walkability using the walk score within four metropolitan areas in the US. Another study explored walkability scores of 31 regions in Khulna City (Bangladesh) using GIS for further decisions and sustainable research (Chow et al., 2014). However, very few studies addressed perceptions (Chiu et al., 2015). However, other studies developed assessment tools besides using Walk Score®. In other terms, Walk Score® was correlated to many methods. Indeed, these approaches included the built environment characteristics (Carr et al., 2010; Duncan, D. T et al., 2011; Pivo and Fisher, 2011; Tuckel and Milczarski, 2015; Xu and Wang, 2015), crime (Carr et al., 2010; Gell et al., 2015; Li et al., 2015), purposive walking type (Carr et al., 2010). All walking categories (Gell et al., 2015; Nykiforuk et al., 2016) convenience (Carr et al., 2011, 2010; Towne et al., 2016). Facilities (Carr et al., 2011; Duncan et al., 2011; Nykiforuk et al., 2016; Xu and Wang, 2015) and perceptions (Towne et al., 2016; Tuckel and Milczarski, 2015).

Despite the usefulness of Walk Score®, it lacks considering indicators related to pedestrian comfort and safety. Indeed, this measurement calculates neighbourhoods and street walking rates based on the simulation of only 3 characteristics, highlighting the gap of indicators, especially those related to the pedestrian scale.

2.5.2 .Street level

2.5.2.1 .Audit

In recent years, numerous studies have adopted an objective approach to evaluating walkability. Indeed, there is an increasing effort to measure pedestrian communities and sidewalks at different levels (Asadi-Shekari et al., 2014; Cerin et al., 2011; Clifton et al., 2007; Galanis and Eliou, 2012). Many assessment tools such as audits and Pedestrian Level Of Service (PLOS) methods explored the street level based on various techniques and factors. However, each one has its benefits and drawbacks within sidewalk measurement. A summary list of the most eminent walkability assessment tools is presented in Table 3.

The Path Environment Audit Tool (PEAT) (Troped et al., 2006) uses a variety of walkability indicators at the microscale level. However, many comfort indicators, such as sidewalk material and width, besides trees and shade, are not considered. The Walking Suitability Assessment Form (WSAF) (Emery et al., 2003) and the PIN3 Neighbourhood Audit Instrument (Evenson et al., 2009) examine a restricted number of walkability indicators and focus on the presence of trees and shading effects on the walking area and street lighting. However, many comfort factors are not included (e.g., toilet slope, fountains, benches, seated drinking fountains, toilet, slope).

The Neighbourhood Environment Walkability Survey (NEWS) (Saelens et al., 2003) is the most commonly used tool in survey question formats. It includes several walkability indicators such as lighting, cleanliness and separation of pedestrians and vehicles (buffering). However, NEWS also lacks specific comfort indicators (e.g., drinking fountains, tactile pavements, toilets). Clifton et al. (2007) proposed the Pedestrian Environment Data Scan (PEDS) tool, which includes a broad range of indicators (e.g., path material, path condition, slope and path obstructions). However, many comfort indicators are missing (e.g., drinking fountains, slope and kerbs). Aghaabbasi et al. (Aghaabbasi et al., 2017) focused on the Neighbourhood Sidewalk Assessment Tool (NSAT), which considers a wide variety of comfort indicators besides extended pedestrian categories increased satisfaction among people with different physical abilities. Overall, there is a generalized lack of comfort indicators in the assessment of walkability in measures such as PIN3, PEAT, NEWS and PEDS, besides the exclusion of consideration of people with disabilities.

Table 3 Summary of previous walkability assessment tools

Tool	Author	Sidewalk facilities
Path Environment Audit Tool (PEAT)	Troped et al., 2006	Benches and seating areas are in the street. Availability of wheelchair and benches and seating areas (3) bollards, (4) wheelchair accessible bollards, (5) Availability of drinking fountains, (6) Function of drinking fountains, (7) Cleanliness of drinking fountains, (8) accessibility of wheelchair to drinking fountains, (9) toilets, (10) Functional toilets along the street (11) cleanness of existing toilets, (12) Availability of wheelchair-accessible toilets, (13) Slope (14) Path quality(15) pedestrian signal, (16) signage, (17) lighting
Walking Suitability Assessment Form (WSAF)	Emery et al., 2003	(1) Material, (2) Surface Condition, (3) Sidewalk Width, (4) Neediness pedestrian signals at the intersection, (5) Availability of curb ramps, (6) Availability of adequate lighting
PIN3 Neighbourhood Audit Instrument	Evenson et al., 2009	(1) Availability of shading trees in the street, (2) Availability of public lighting
Irvine Minnesota Inventory (I-M)	Boarnet et al., 2006	(1) Unit seating areas, (2) Unit trees, (3) shade trees, (4) unit of visible driveways on the segment, (5) Slope of the segment, (6) Availability of pedestrian signal, (7) Availability of lighting on the segment
Analytics Audit Tool	Brownson et al., 2003	(1) Availability of comfort facilities (shade trees, benches, or other types of amenities), (2) Availability of path obstructions (trees, trash receptacles), (3) Availability /visibility of trash receptacles, (4) existence of street amenities (trash receptacles), (5) Availability /visibility of destinations of driveways, (6) Width of the sidewalk, (7) Unit benches
Neighbourhood Environment Walkability Survey (NEWS)	Saelens et al., 2003	(1) Availability of trees on the streets in the neighbourhood, (2) Shade trees to provide cover at the sidewalks and neighbourhood, (3) Availability of pedestrian signals at intersections in the neighbourhood, (4) Availability of trees along the streets in the neighbourhoods
Twin Cities Walking Survey	Forsyth et al., 2009	(1) Shade trees to provide sidewalks cover in the neighbourhood, (2) Availability of pedestrian signals at intersections in the neighbourhood

Continued Tool	Author	Sidewalk facilities
Pedestrian Environment Data Scan (PEDS)	Clifton et al., 2007	(1) Availability of street amenities (benches), (2) Unit of shade trees in walking area, (3) Availability of medium-/high-volume driveways, (4) Path material, (5) Sidewalk width, (6) Availability of crossing assistance (pedestrian signal, signage), (7) signs, (8) Cleanliness of sidewalk, (9) Roadway/path lighting
Systematic Pedestrian and Cycling Environmental Scan (SPACES)	Pikora et al., 2002	(1) Availability of path obstructions (trees, sign poles), (2) Unit of verge trees, (3) standard height of trees, (4) Driveway, (5) Path material, (6) Path surface condition, (7) Cleanliness, (8) Availability of lighting
Micro scale Audit of Pedestrian Streetscapes (MAPS)	Brownson et al., 2003	(1) Availability of street amenities (benches and seating area, drinking fountain), (2) existence of path obstruction (trees), (3) Unit of trees within 5 feet of either side of the sidewalk, (4) The plan of planting the trees, (5) Shade trees along the sidewalk (percentage), (6) Unit of driveways on the segments, (7) slope, (8) Sidewalk width, (9) Availability of signal (pedestrian signal)
neighbourhood sidewalk assessment score(NSAT)	Aghaabbasi et al., 2017	(1) Seating areas, (2) Bollards, (3) Drinking Fountains, (4) Landscape and Trees, (5)Toilets, (6) Trash Receptacles, (7)Elevators next to skybridges, (8) Driveways, (9) Slope,(10) Material/Surface,(11) Effective Sidewalk Width,(12) Signals,(13) Signage,(14)Tactile Pavement, (15) Ramps, (16) Curb Ramps,(17) Cleanliness,(18) Lighting.
Pedestrian safety index (PSI)	Asadi-Shekari et al., 2015	(1) slower traffic speed, (2) buffers and barriers (curb and furnishing zone), (3) fewer traffic lanes, (4) shorter crossing distance (curb extension), (5) mid-block crossing, (6) landscape and trees, (7) footpath pavement, (8) marking (crosswalk), (9) pedestrian refuge and median, (10) corner island, (11) sidewalk on both sides, (12) advance stop bar, (13) driveway, (14) lighting, (15) signing, (16) bollard, (17) slope, (18) lift, (19) curb ramp, (20) tactile pavement (guiding),(21) tactile pavement (warning), (22) ramp, (23) grade and (24) signal.

2.5.2.2. PLOS method

PLOS methods are advanced to measure the quality of service, street facilities, and pedestrian infrastructure (Asadi-Shekari et al., 2014). It is generally encouraged in urban and transportation structures. Aghaabbasi et al. (2019) reported the usefulness of the PLOS system; indeed, it is a valuable measurement tool. This measure helps designers and planners evaluate the street environment's quality for pedestrians and guide enhancements to solve existing problems. Although some studies have used PLOS to assess sidewalk capacity (Aghaabbasi et al., 2019), PLOS models have generally focused on the street characteristics involving micro-design factors and pedestrian amenities (Aghaabbasi et al., 2019; Asadi-Shekari et al., 2014, 2013a; Landis et al., 2001). Table 4 summarizes the most used PLOS method.

Table 4 Summary of operational indicators assessed by PLOS

Pedestrian facilities	Scale	References
(1) Width of outside lane, (2) width of shoulder or bike lane, (3) on-street parking effect coefficient, (4) percentage of the segment with on-street parking, (5) buffer area barrier coefficient, (6) buffer width, (7) sidewalk presence coefficient, (8) width of sidewalk	Street	Landis et al., 2001
(1) Sidewalk width, (2) shoulder width, (3) on street parking, (4) barriers, (5) buffer width.	Street	National Cooperative Highway Research Program et al., 2008
(1) Total sidewalk width, (2) free height (without obstacles), (3) guide for the blind, (4) pavement condition of sidewalk, (5) ramps, (6) trees and plants	Street	Christopoulou and Pitsiava-Latinopoulou, 2012
(1) Plants or trees, (2) visual damage of sidewalk surface, (3) barrier separation of sidewalk from motor vehicle traffic, (4) decorated sidewalk surface, (5) sidewalk width	Street	Kang et al., 2013
(1) Buffer and barriers (kerb and furnishing zone), (2) landscape and trees, (3) facilities (fire hydrants), (4) furniture (trash receptacles), (5) footpath pavement, (6) sidewalk on both sides, (7) width of footpath, (8) driveway, (9) lighting, (10) signage, (11) bollard, (12) kerb ramp, (13) wheelchair accessible drinking fountain, (14) tactile pavement (guiding), (15) tactile pavement (warning), (16) ramp, (17) grade, (18) Signal, (19) bench and seating area, (20) drinking fountain, (21) slope.	Street	Asadi-Shekari et al., 2013a
(1) Bollard, (2) cleanliness, kerb ramp, (3) drinking Fountain, (4) driveway, (5) effective width of the (6)sidewalk,(7) elevator, (8) landscape and tree,(9) lighting, (10) ramp,(11) signal,(12) signage,(13)seating area,(14) slope, (15) surface/material,(16) tactile pavement,(17) toilet,(18) rubbish bins	Street	Aghaabbasi et al., 2017

Table 4 Summary of operational indicators assessed by PLOS

Continued Pedestrian facilities	Scale	References
(1) Slower traffic speed, (2) buffer and barriers (kerb and furnishing zone), (3) fewer traffic lane, (4) shorter crossing distance (kerb extension), (5) mid-block crossing, (6)landscape and trees (7) footpath pavement, (8) marking (crosswalk), (9) pedestrian refuge and median,(10) corner island, (11) sidewalk on both sides, (12) advance stop bar, (13) driveway,(14) lighting, (15) signing, (16) bollard, (17) slope (18) lift, (19) kerb ramp,(20) tactile pavement (guiding), (21) tactile pavement (warning),(22) ramp, (23) grade, (24) signal.	Street	Asadi-Shekari et al., 2015
(1) slower traffic speed, (2) buffer and barriers (kerb and furnishing zone), (3) fewer traffic lanes,(4) mid-block crossing, (5) landscape and trees, (6) facilities (fire hydrants), (7) Furniture (rubbish bins)(8) footpath pavement (9) marking (crosswalk), (10) corner island, (11) sidewalk on both sides(12) advance stop bar, (13) width of footpath,(14) driveway, (15) lighting, (16) signing, (17) bollard, (18) slope, (19) kerb ramp, (20) wheelchair-accessible drinking fountain, (21) tactile pavement (guiding), (22) tactile pavement (warning), (23) ramp, (24) grade, (25) signal, (26) bench and seating area and (27) drinking fountain).	micro-level design factors	Asadi-Shekari et al., 2019

Based on this literature review, many studies have included several indicators at the neighbourhood scale level, besides the street level. The comfort concept was one of the aims attributes at the neighbourhood macro level, within 5C and 7C. Concerning the street scale, the comfort attributes are appropriate to the pedestrian scale. To this end, many indicators have been considered (e.g. slower traffic speed, buffers and barriers (curb and furnishing zone), fewer traffic lanes, shorter crossing distance (curb extension), mid-block crossing, landscape and trees, footpath pavement, marking (crosswalk)). Moreover, some assessment tools used these indicators related to usefulness, attractiveness, safety, and comfort to assess walkability rates at the street scale. However, there is a gap considering the neighbourhood microscale. Because most of these objectives focused on the street level, few methods are available for the neighbourhood micro-scale level.

The walkability researchers often missed out on thermal comfort as a physical environmental indicator. The physical walkability environment usually assigned street connectivity to spatial-environment such as sidewalks, land use diversity and street connectivity..

However, a complex urban landscape can impact radiation field and heat transfer to pedestrians (Chan et al., 2006; Henry et al., 2004; Jamei et al., 2016; Lee et al., 2020; Sharmin et al., 2015).

The literature review also showed the lack of considering thermal comfort in the assessment of walkability. Indeed, thermal conditions of the walking area get minimal attention despite composing the most immediate surrounding of pedestrians. Moreover, thermal stress could have a negative impact on walkability and reduce the walking average (Lee et al., 2020). Thus, these correlations call for interpreting the relationship between human thermal comfort and walkability. Moreover, considering the microclimate effect on pedestrian behaviour and definitely, walkability is worthy of investigation.

2.6. Thermal comfort in the outdoor environments

2.6.1 Thermal comfort indices and assessment tools

In recent years, researchers have paid particular attention to thermal comfort in urban environments and its effect on inhabitants (Givoni, B et al., 2003; Knez and Thorsson, 2006; Nikolopoulou et al., 2001; Nikolopoulou and Lykoudis, 2006; Potchter et al., 2018; Spagnolo and De Dear, 2003). Numerous studies have attempted to define thermal comfort conditions to determine the concept of thermal sensation in outdoor urban spaces (Cohen et al., 2013; Elnabawi et al., 2016; Hwang et al., 2011; Kántor et al., 2012a; Knez and Thorsson, 2006; Lai et al., 2014a; Tseliou et al., 2010).

Thermal comfort refers to user satisfaction regarding the thermal environment (ASHRAE Standard, 2004; Potchter et al., 2018). The microclimate environment characteristics are essential to understand because they influence people's comfort and outdoor activities (Cohen et al., 2013). Some studies have focused on developing universal indices that can measure thermal comfort in hot and cold climates (Cohen et al., 2013; Potchter et al., 2018). Indices such as Perceived temperature (Pt) (Potchter et al., 2018; Staiger et al., 2012), Standard Effective Temperature (SET*) (Gonzalez et al., 1974; Potchter et al., 2018) and its outdoor variant OUT-SET* (Pickup, J and De Dear, R, 2000), UTCI (Jendritzky, G et al., 2012), PET (Matzarakis et al., 1999; Mayer and Höpfe, 1987) and predicted mean vote (PMV) (Berkovic et al., 2012; de

Freitas and Grigorieva, 2015; Lai et al., 2014b; Potchter et al., 2018). Have been effectively applied to urban areas for thermal comfort assessment.

Most current indices for outdoor thermal perception include PET, PMV, UTCI and SET* (Potchter et al., 2018), and these are suitable for calculating heat and cold stress. PMV allows the classification of thermal sensation; PET, UTCI and SET* provide an evaluation in °C of thermal sensation. SET* is a more suitable index for hot climates, whereas PET and UTCI are typically employed in hot and cold environments (Johansson et al., 2014). However, several studies explored PET within different urban spaces and climate environments. In addition, PET was correlated to the user's thermal perception.

2.6.2 PET comfort range in different climate zones

PET was introduced in Western and Central Europe (Cohen et al., 2013; Elnabawi et al., 2016; Matzarakis and Mayer, 1996); The "neutral" scale for the PET index in hot climates of 24–26°C was confirmed in 95% of studies. In a cold climate, 89% of studies showed a "neutral" range of 15–20°C. Lin (2009) examined thermal sensation and its adaptation to the tropical climate in Taiwan and reported PET values of 21.3–28.5°C all year round, higher than the European scale PET values of 18–23°C. Another study in the Csa of Tel Aviv, Israel, demonstrated that the PET values were higher than the European PET scale by 3°C and lower by 5°C than the lower boundary of the PET values recorded in Taiwan (Cohen et al., 2013). Mahmoud (2011) studied thermal comfort in an urban park in Cairo, Egypt, where the PET values were 22–30°C in summer and 21–29°C in winter, which were also higher than the European scale (Potchter et al., 2018). These results demonstrated the influence of urban climatic characteristics on human balance, energy and people's thermal perception, all of which affect the use of outdoor environments (Elnabawi et al., 2016). These studies thus highlight the impact of the duality of microclimatic measurement and thermal perception in cities and the use of the outdoor environment in different climates.

2.6.3 Main methods to calculate PET

Thermal comfort assessment requires combining meteorological variables with thermo-physiological parameters (Mayer, 1993; V. VDI, 1998). Many studies applied a numerical simulation model of the climatic variable at the street level (Acero and Herranz-Pascual, 2015; Klemm et al., 2015; Lee et al., 2016; Morakinyo et al., 2017) using software to optimize thermal comfort index accuracy. ENVI-met and Rayman are well-known software used to calculate outdoor thermal comfort. Envi-met simulation allows predicting the mean radiant temperature (T_{mrt}), relative humidity, air temperature, wind speed and surface temperature (Acero and Herranz-Pascual, 2015). These four microclimatic variables are essential to calculate outdoor thermal comfort, besides metabolic rate and clothing insulation (Watanabe et al., 2014). Thus, different scholars (Cohen et al., 2013); Elnabawi et al. (2016); Kántor et al.(2012); Lai et al.(2014); Tseliou et al. (2010) combined simulation and field surveys in outdoor environments. To provide an extensive perspective concerning the impact of microclimate on outdoor thermal comfort and urban space use.

2.7 Thermal comfort as a walkability indicator

Walking and cycling have been demonstrated to promote physical activity (Bödeker et al., 2018; Chaix et al., 2014; Fishman et al., 2015). That has a positive effect on people's physical and mental health (Boulangé et al., 2018). Walking reduces the risks of obesity, depression, and other chronic diseases in the older adult population (Takano et al., 2002), besides children and all age categories. Because walking activity can boost metabolism, lower blood sugar and improve mental health. Thus, the walkability has inclined to a quantified approach to explore the health impact of the built environment (Yang et al., 2021). Moreover, walkability that could be verified through pedestrian behaviour and observation could be influenced by thermal adaptation, expectations and psychological state (Knez and Thorsson, 2006; Laurentin et al., 2000; Lee et al., 2020; Matzarakis and Mayer, 1996; Nikolopoulou and Lykoudis, 2007).

The review of theories and models of walkability and thermal comfort revealed the possibility of linking the two concepts. Indeed (1) Thermal comfort could be considered as a walkability indicator (Fig 2). The term comfort is the great common denominator between the

two concepts. Indeed, this concept was analysed with walkability at neighbourhood scale (5D) and street level (related to safety design factors, attractiveness design factors, and sidewalk path conditions). (2) The climate conditions could significantly affect outdoor activities, especially during the walking experience. (3) Moreover, considering individuals' perception in assessing walkability and thermal comfort is an additional correlated factor. The literature review showed an essential use of pedestrian perception in assessing walkability or measuring thermal comfort range in outdoor environments. Walkability and thermal comfort were applied, assessed and analysed on urban components such as streets, neighbourhoods and parks. The development of a comprehensive assessment tool that can combine the pedestrian facilities and thermal comfort index within reviewed theories must be considered. To improve the walking experience, enhance its frequency, and achieve a sustainable environment.

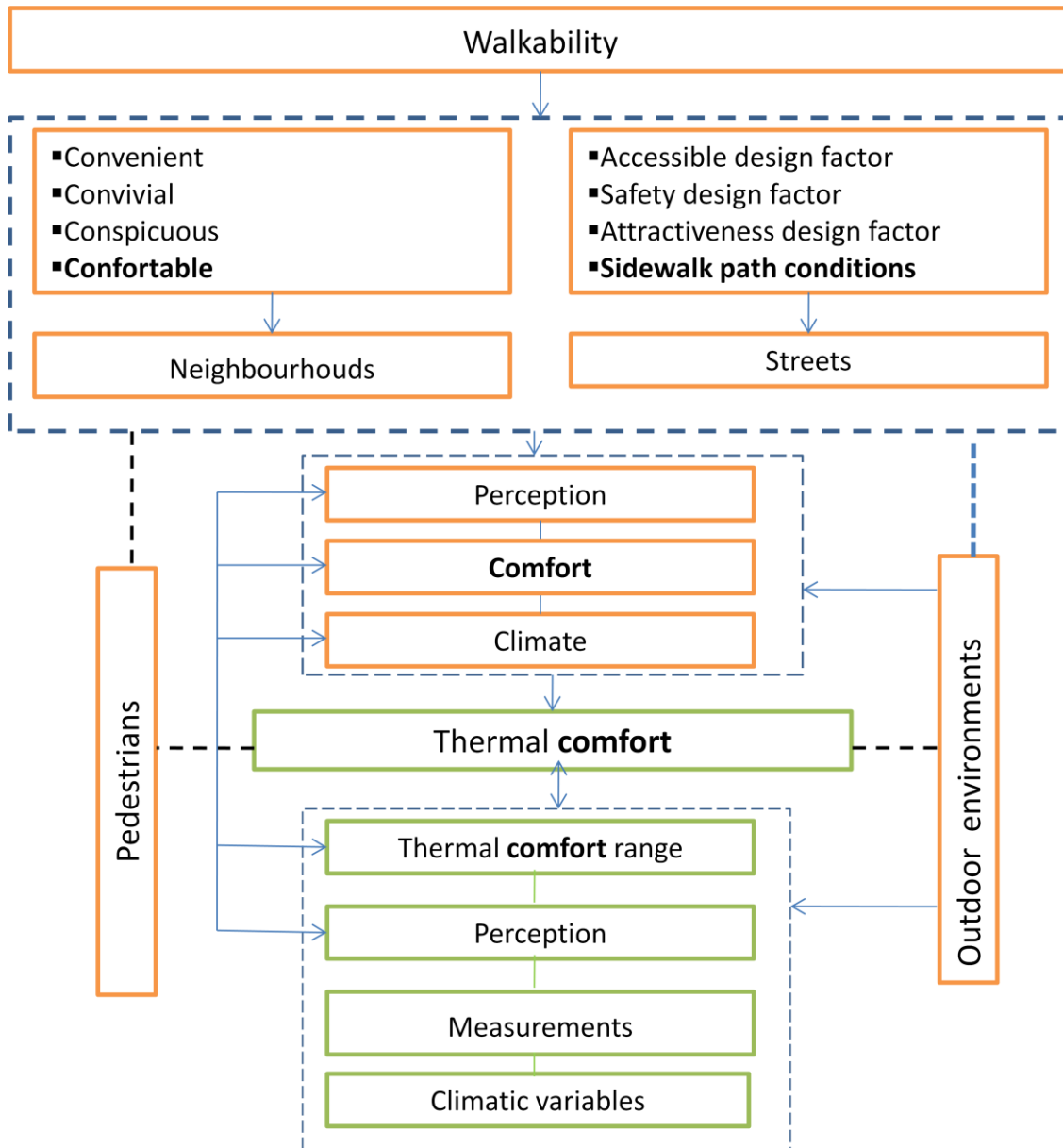


Fig .2. A simplified diagram for understanding the combination of walkability and thermal comfort.

2.7.1 PET as a walkability comfort indicator

The Physiological Equivalent Temperature (PET) and Universal Thermal Climate Index (UTCI) have been advanced as biometeorological indices indicating thermal stress (Lee et al., 2020). According to Chen and Matzarakis (2018), UTCI used 135 W/m^2 as reference activity. It highlights the relevance of the effect of air humidity and wind speed concerns. The initial scaling for UTCI was based on the multi-node dynamic-thermo physiological UTCI - Fiala model

(Błażejczyk et al., 2010). While PET used 80 W/m^2 as a standard stimulating activity, experimental studies showed that people usually feel much heated under brutal metabolism than slight metabolism (Chen and Matzarakis, 2018). The original scaling for PET was based on human energy balance (Matzarakis et al., 2010). PET focuses on radiant and sensible heat loss (Chen and Matzarakis, 2018).

Moreover, according to Lee et al. (2020), PET is more sensitive to thermal sensation variance than UTCI. Indeed, the results showed that thermal sensation was considered in the decrease of PET and UTCI. However, the PET revealed a warm thermal sensation in the shaded area instead of hot and very hot in a sunny location. In comparison, the UTCI expressed a neutral thermal sensation in the shaded zone compared to the sunny area.

PET had been less criticized in comparison with UTCI. According to Potchter et al. (2018), examining the relationship between PET and full scale and outdoor thermal conditions showed a positive relationship and demonstrated a strong correlation. Many field surveys based on questionnaires have been undertaken in different climatic zones, searching to validate those indices against actual people's votes (Cohen et al., 2013; Nikolopoulou et al., 2001; Nikolopoulou and Lykoudis, 2007).

In contrast, exploring the relation between UTCI full scale and outdoor thermal conditions highlighted a positive and weak connection. That is identified as not correlative and significant due to the limited sample size (Potchter et al., 2018). Besides a few studies that tested the subjective method, the results showed a different scale of no stress category (comfort range) for the other climatic conditions that should be examined (Potchter et al., 2018). In comparison, PET had been validated in several climatic zones (Gulyás et al., 2006; Johansson et al., 2014; Matzarakis et al., 1999; Thorsson et al., 2007) and investigated in a wide range of outdoor environments (Ali-Toudert and Mayer, 2007; Andrade et al., 2011; Charalampopoulos et al., 2013; Knez and Thorsson, 2006; Lai et al., 2014; Lin et al., 2013; Lin and Matzarakis, 2008; Matzarakis et al., 2007; Thorsson et al., 2007). The verification of the PET and UTCI indices shows that the perceived comfort zone values are very similar to each other (Potchter et al., 2018).

Lee et al. (2020) explored the influence of biometeorological related factors on pedestrian behaviour by calculating PET and UTCI to express thermal stress in Hong Kong, China. The findings highlighted the correlation between thermal sensation and pedestrian choice

of the shaded zone. However, the selected comfort indices have not been included in the walkability assessment.

Many measurement tools have been advanced to assess the pedestrian environments such as neighbourhoods and streets. However, few studies considered thermal comfort in the assessment of walkability. Indeed, thermal stress could debase the walking experience and indirectly hinder walkability. We focus on universal comfort factors at the neighbourhood micro-scale level and street level. This study seeks to develop an innovative approach towards inclusive design and thermal comfort for a pleasant walking experience. In addition to a broad range of user categories and consider PET as a thermal comfort index. This thesis fills this knowledge research gap by combining thermal comfort and walkability within a quantitative approach. Furthermore, the developed methods were tested in Annaba, Algeria, characterized by the Csa climate.

2.8 Conceptual framework

The conceptual framework of this study depicts the correlation between walkability and thermal comfort. By involving individual perception, neighbourhood and street-scale characteristics considerations and choices, besides objective measurements within Csa. The choice of neighbourhoods and streets depended on the following criteria: walk score averages, urban morphology, street length and orientation, besides pedestrian comfort facilities (available or not). Fig 3 shows a comprehensive summary of this study.

The proposed diagram shows the correlation between walkability and thermal comfort. That was applied and analysed at two major scales: the neighbourhood microscale level and street scale. According to the literature review analysis, the first scale was chosen because of the lack of exploration. Few studies have analysed pedestrian comfort furniture; most of them were associated with safety and attractiveness design factors and usability. Thus, the neighbourhood micro-scale level is more appropriate to evaluate pedestrian comfort. Indeed, the neighbourhood micro-scale concerns the significant walkability channels. Many pedestrian comfort facilities could be involved, possibly improving them, consequently increasing the walkability frequency and enhancing the walking quality experience.

According to the outcome of the literature review, the Street scale has been the focus of several studies because it is the primary measurement unit of walkability. It also appears very interesting within thermal comfort. Indeed, various studies measured PET on streets in different climate zones. Consequently, this scale is considered ideal for exploring new measurement tools by combining current walkability and thermal comfort methods.

This thesis also considers people's perceptions and the importance of pedestrian comfort facilities based on a questionnaire survey, including personal characteristics and socio-demographic categories. Moreover, people's perception is also correlated to thermal perception. The PET assessment is based on two assessment approaches. The first method concerns the neighbourhood microscale based on three climatic variables (weather recorded file): air temperature $T(a)$, Relative humidity (Rh) and wind velocity (V). In this case, PET was computed with RayMan software. The second method concerned the street scale, which required in-situ measurements, the Envi-met software allowed getting four calibrated data: $T(a)$, (Rh), (V), the mean radiant temperature (T_{mrt}), which were used to calculate PET (RayMan).

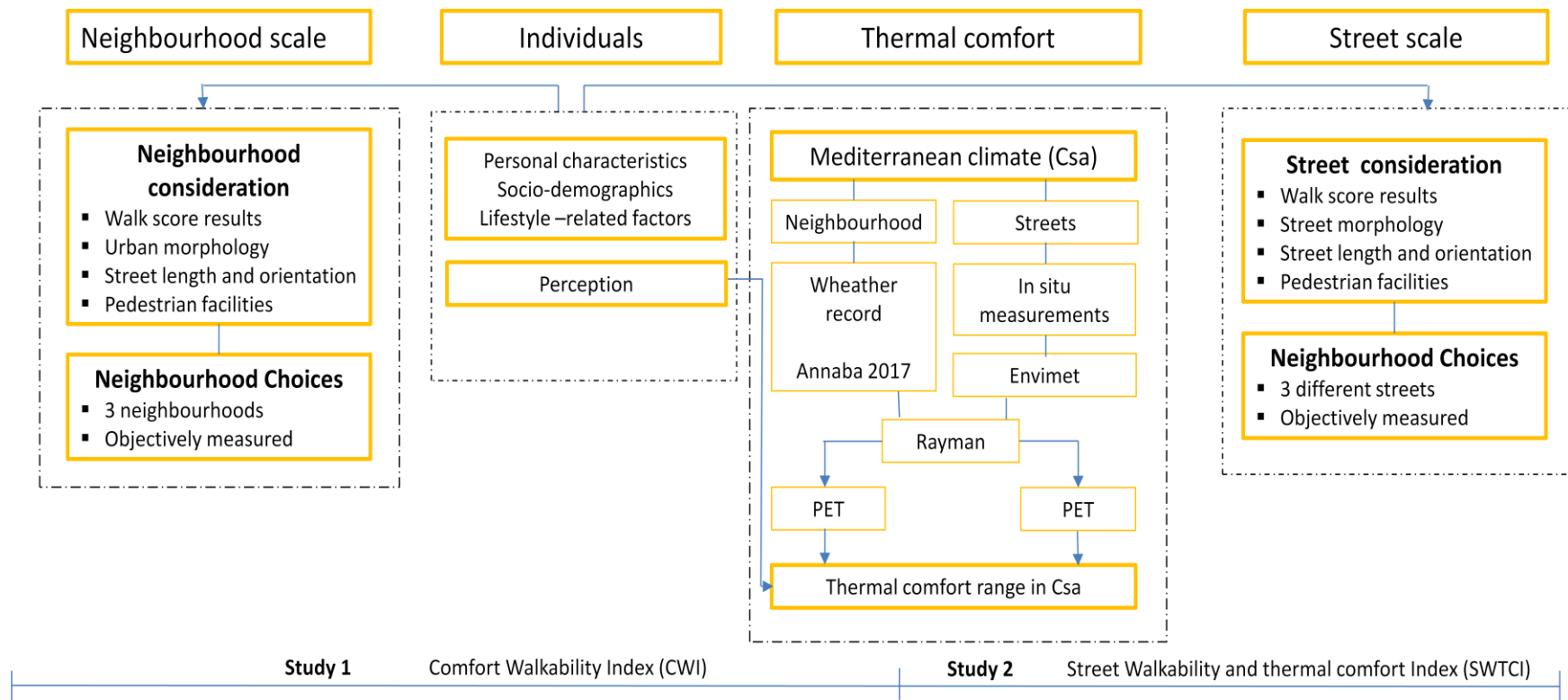


Fig. 3. Explicit summary thesis

2.9 Chapter summary

The purpose of this review was to analyse walkability and thermal comfort concepts and demonstrate the possibility of combining them. The review findings showed that comfort terms, climate, individual perception, and outdoor environment are common in the two research fields. It also highlighted the gaps in considering the micro-level indicators at the neighbourhood scale in walkability evaluation.

Based on this literature review, we strongly support the feasibility of including thermal comfort in walkability assessment. It is clear from the reviewed studies that walkability measurements are overlooked considering thermal comfort.

This study complements the current literature by proposing new assessment tools at the neighbourhood microscale and street level. That involved pedestrian comfort facilities and PET. Which are considered one of the most explored thermal comfort indices in different climate zones. Moreover, relating walkability scores to people's perception regarding the pedestrian environment and thermal sensation in a Csa climate allows a better understanding of the walking comfort rates.

Chapter 3 Method and materials

3.1 Chapter outline

Based on the literature review in chapter 2, we confirm the possibility of combining thermal comfort and walkability. Indeed this correlation could be achieved by developing an innovative method. That included comfort pedestrian facilities and PET at two major scales; the neighbourhood micro-scale rarely explored in previous studies and street scale.

The neighbourhood micro-scale level is consisting of the quality and attractiveness of sidewalks. That can affect the comfort and safety of walkability in urban spaces (Aghaabbasi et al., 2019, 2017; Asadi-Shekari et al., 2013a). Moreover, it is essential to identify pedestrian amenities concerning the quality of the walking environment (Aghaabbasi et al., 2017). Sidewalk amenities conducive to comfortable walking involve main facilities (e.g., kerbs, ramps, sidewalk width), encouragement facilities (e.g., lighting, seating areas, landscape and trees) and convenience facilities (e.g., toilets, drinking fountains) (Asadi-Shekari et al., 2019). Such indicators can transform spaces into accessible, walkable and comfortable areas (Asadi-Shekari et al., 2019; Dixon, 1996; Grahn and Stigsdotter, 2003; Ruiz-Padillo et al., 2018).

The pedestrian level of service (PLOS) is an essential tool for promoting existing infrastructure, managing new investments, and guiding appropriate contributions (Christopoulou and Pitsiava-Latinopoulou, 2012) by identifying the deficiency in the pedestrian street environment and suggesting upgrading for solving the problems. Various studies proved the PLOS' usefulness in assessing street facilities by considering attractiveness, safety and convenience design factors, such as slope, sidewalk width, material, and surface condition

(Asadi-Shekari et al., 2014, 2013b; Christopoulou and Pitsiava-Latinopoulou, 2012; Kang et al., 2013).

An increasing number of studies focused on improving thermal comfort in outdoor urban spaces to enhance citizens' health, well-being and promoting outdoor activities (e.g., walkability, cycling). Many studies have attempted to define thermal comfort conditions to determine the concept of thermal sensation in outdoor urban spaces (Cohen et al., 2013; Elnabawi et al., 2016; Hwang et al., 2011; Kántor et al., 2012; Knez and Thorsson, 2006; Lai et al., 2014a; Tseliou et al., 2010). Accordingly, PET is one of the most used thermal comfort indices. It was related to thermal sensation vote in different climate zones and urban areas (Cohen et al., 2013; Lin and Matzarakis, 2008; Potchter et al., 2018). Considering PET within walkability assessment is a promising quantitative approach. To estimate walkability comfort range at the neighbourhood micro-scale level and street scale.

ENVI-met and Rayman are well-known software models used to calculate outdoor thermal comfort. However, their assessment system is different. While ENVI-met is based on computational fluid dynamics (CFD) and thermodynamics, RayMan is a 3D radiation model. Envi-met simulation predicts the mean radiant temperature, relative humidity, air temperature, wind speed and surface temperature. According to Acero and Herranz-Pascual (2015), these first four microclimatic variables are essential to calculate outdoor thermal comfort, besides metabolic rate and clothing insulation (Watanabe et al., 2014).

This chapter proposes two innovative methods at two urban scales by considering PET as a walkability indicator. The first approach concerns elaborating a new assessment tool, the Comfort Walkability indicators (CWI), at the neighbourhood micro scale. In comparison, the second method explores the street scale by developing The Street Walkability and Thermal Comfort Index (SWTCI). Fig 4 shows the general structure of the present chapter. An extensive analysis of the literature review allowed the selection of twenty-one (21) pedestrian comfort facilities. In addition, PET is considered the most used thermal comfort indices and is also relevant for walkability comfort. The CWI was explored in three (3) neighbourhoods in Annaba city, while the SWTCI index was investigated at three (3) different streets. These two methods had been applied and validated in Annaba city, Algeria, characterized by the Csa climate according to Köppen (2020) classification.

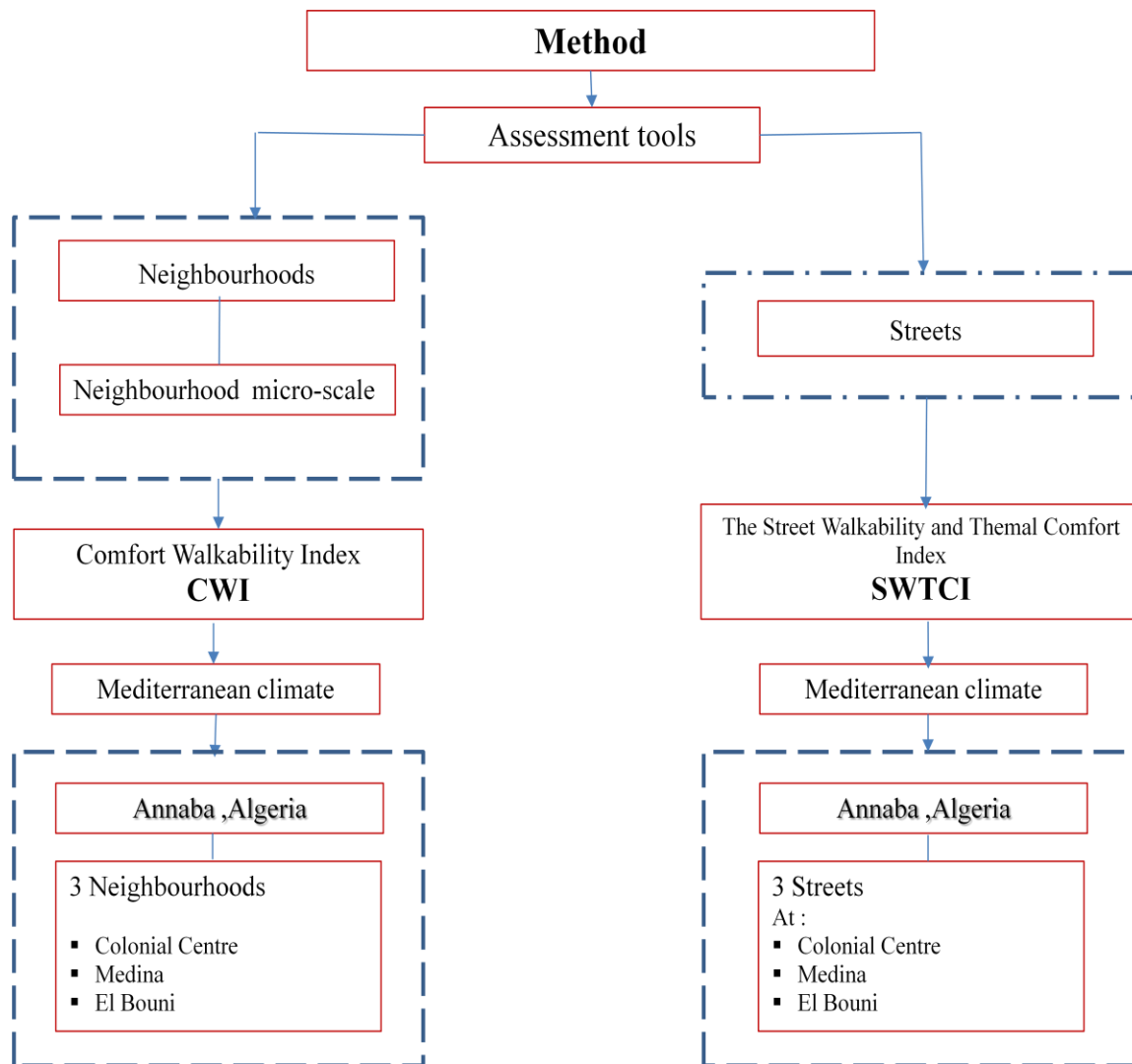


Fig. 4. Explicit outline methods

3.2 The Comfort Walkability Index (CWI) at the neighbourhood micro-scale

Several methodologies have been developed and applied in urban planning to integrate pedestrian audits in transportation system plans and pedestrian planning. To date, however, there are few data gathered using walkability measurement methods that involve the neighbourhood micro scale.

We now briefly present each of the main steps of the CWI procedure. Figure 5 provides a comprehensive description.

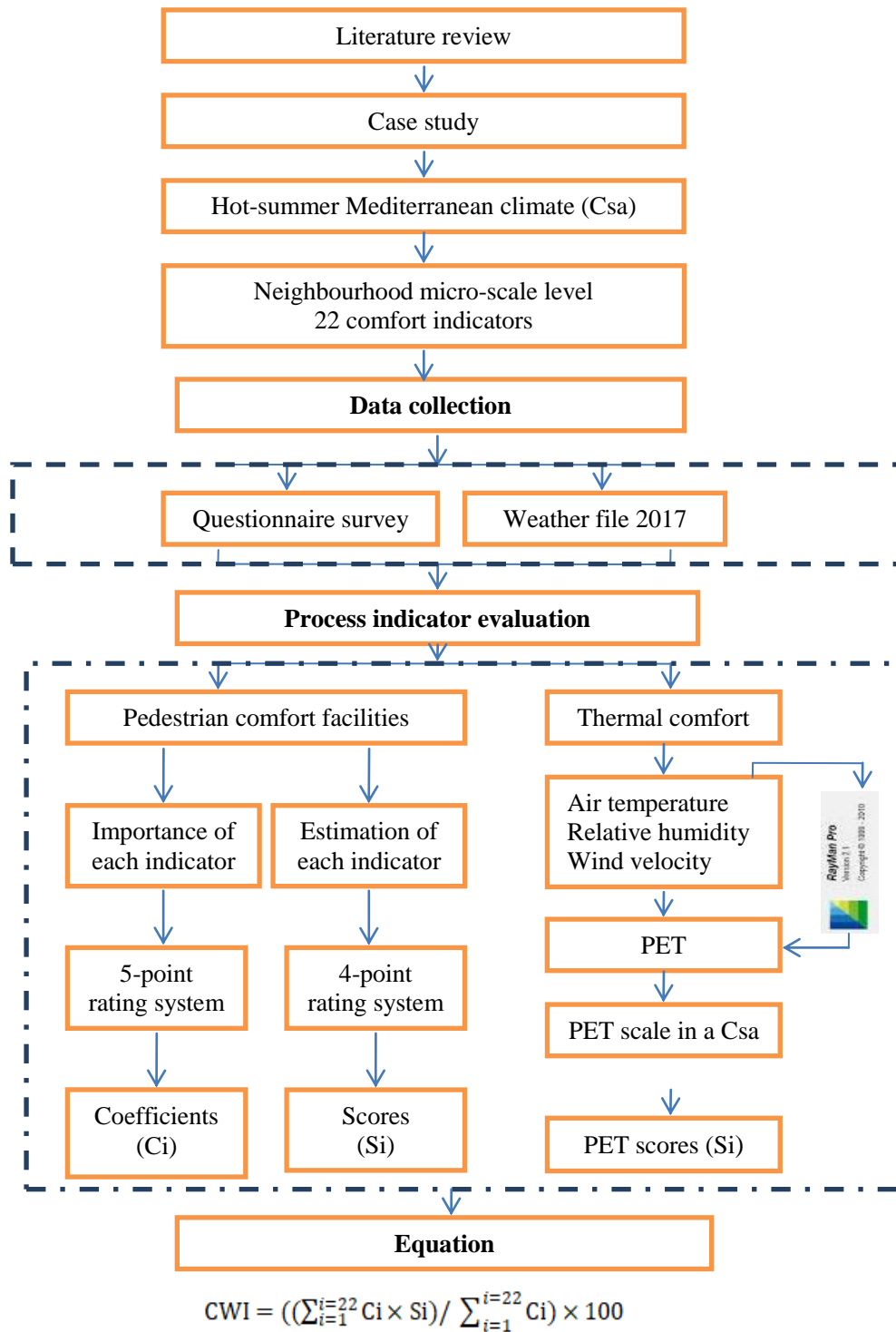


Fig. 5. Conceptual framework of the comfort walkability index (CWI).

3.2.1. Review of effective indicators

This section involved the identification of indicators in full research papers, review articles and standard guidelines, using Google Scholar, the Web of Science and weather records. Keywords included walkability, thermal comfort, assessment tools, streets, neighbourhood and Csa. Some papers were omitted because they focused on collecting data related to the trip level, and as a result, there was a lack of information regarding tool assessment and application. According to our criteria, the selected indicators concerned research conducted between 2002 and 2019, with the aim of defining the comfort indicators that promoted enjoyment of a pleasant walking experience. This concept was analyzed on neighbourhood and street scales, as well as the widely used index of thermal comfort in outdoor environments. The findings highlighted the gap in research on the neighbourhood micro-scale regarding the evaluation of thermal comfort in walkability. The relevant comfort indicators are presented in Table 5.

Table 5 List of pedestrian comfort indicators appropriate for the neighbourhood micro scale.

Pedestrian comfort indicators	References
Slower traffic speed	Asadi-Shekari et al., 2015, 2014
Buffer and barriers (kerb and furnishing zone)	Asadi-Shekari et al., 2015, 2014
Fewer traffic lanes	Asadi-Shekari et al., 2015, 2014
Mid-block crossings	Asadi-Shekari et al., 2015
Landscaping and trees	Aghaabbasi et al., 2019, 2018, 2017; Asadi-Shekari et al., 2019, 2014
Furniture (rubbish bins)	Aghaabbasi et al., 2019, 2017; Asadi-Shekari et al., 2019, 2014
Footpath pavement	Asadi-Shekari et al., 2015; Moura et al., 2017; Nilles and Kaparias, 2018
Marking (crosswalk)	Asadi-Shekari et al., 2015
Sidewalks on both sides	Asadi-Shekari et al., 2015
Width of footpath	Aghaabbasi et al., 2019, 2018, 2017; Asadi-Shekari et al., 2019, 2014
Slope	Aghaabbasi et al., 2018, 2017; Asadi-Shekari et al., 2014
Lighting	Aghaabbasi et al., 2019, 2018, 2017; Asadi-Shekari et al., 2019, 2015, 2014
Ramp	Aghaabbasi et al., 2019, 2017; Asadi-Shekari et al., 2019, 2015, 2014
Parks and spaces for playing	Koh and Wong, 2013; Tsukaguchi et al., 2010
Social spaces (cafés)	Gunn et al., 2017; Moura et al., 2017
Shade	Clifton et al., 2007; Taleai and Taheri Amiri, 2017
Benches and seating areas	Aghaabbasi et al., 2019, 2017; Asadi-Shekari et al., 2019, 2014

Continued Pedestrian comfort indicators	References
Toilets	Aghaabbasi et al., 2019, 2018, 2017
Pedestrian signals	Aghaabbasi et al., 2019, 2018, 2017; Asadi-Shekari et al., 2015, 2014
Shorter crossing distance (kerb extension)	Asadi-Shekari et al., 2015

3.2.2. Data collection

For data collection, we conducted two surveys, one with pedestrians and the other via an online platform (Monkey, Google Forms). It is worth noting that the participants who answered on online platforms were very familiar with the selected neighbourhood as they are residents. Besides general information (age, sex, education), the questionnaire focused on the importance of pedestrian comfort facilities and the status of each indicator in the selected neighbourhoods. The respondents were asked to classify the importance of the chosen factors and estimate their actual condition.

3.2.3 Assessing indicators

To evaluate the indicators, we calculated coefficients and scores from the survey results, as well as a suitable model for designing walkable neighbourhoods. Climate data such as air temperature, wind velocity and relative humidity were used to calculate PET values using RayMan software. We chose two representative summer days to explore the micro differences in the same season characterized by a Csa. Finally, we calculated the CWI using a point system; the related scoring method for PLOS followed Asadi-Shekari et al. (Asadi-Shekari et al., 2015, 2014, 2013a). The CWI score can be calculated from Eq. (1):

$$\mathbf{CWI} = ((\sum_{i=1}^{i=22} C_i \times S_i) / \sum_{i=1}^{i=22} C_i) \times 100, \quad (1)$$

Where C_i is the coefficient of each indicator and S_i is the score of each indicator.

Table 6 shows the different classifications of the CWI percentage rating and their interpretations. CWI A shows the highest comfort quality conditions. CWI B may be acceptable considering the availability of some comfort indicators besides the feasibility of some operational improvements. CWI C requires more attention and improvement. CWI D indicates inferior quality and uncomfortable conditions, requiring considerable improvement. CWI E and F are the

worst comfort quality and lack standard pedestrian facilities; therefore, they need significant improvement.

Table 6 Interpretation of CWI rating.

CWI % rating	Model score	Interpretation
A	80–100	Highest comfort quality (very pleasant), many pedestrian comfort facilities present.
B	60–79	High comfort quality (acceptable), some pedestrian comfort facilities present.
C	40–59	Average comfort quality (rarely acceptable), pedestrian comfort facilities present; however, there is potential to improve pedestrian comfort conditions.
D	20–39	Low quality (uncomfortable), minimal pedestrian comfort facilities.
E	1–19	Lowest comfort quality (unpleasant).
F	0	No standard pedestrian amenities (very uncomfortable).

For thermal comfort, we selected PET for its various benefits in outdoor urban spaces.

- PET was applied and approved in multiple urban areas with detailed shading design; precise averages for thermal environments were thus obtained (Gulyás et al., 2006; Johansson et al., 2014; Matzarakis et al., 2007; Thorsson et al., 2007).
- PET was compared and related to the mean thermal sensation vote (MTSV) scale across multiple climatic zone classifications (Cohen et al., 2013; Elnabawi et al., 2016; Klemm et al., 2015; Lai et al., 2014b; Lee et al., 2013, 2016) and used for improving outdoor thermal comfort ratings in hot and cold climates.
- PET was validated in different climatic zones using multiple field surveys based on population responses (Elnabawi et al., 2016; Lin et al., 2013; Nikolopoulou et al., 2001; Nikolopoulou and Lykoudis, 2006), which makes it reliable. PET was legally approved as a human biometeorological climate assessment tool for urban and regional planning, according to the German standard VDI 3787 (VDI,1998) (Elnabawi et al., 2016).
- PET was calculated using software packages (e.g., RayMan, ENVI-met) and considering climatic/microclimatic data (air temperature, relative humidity, wind speed, average radiant temperature).

- PET had been explored and proved at the street level (Andreou, 2013; Cohen et al., 2013; Elnabawi et al., 2016) and correlated to the pedestrian thermal comfort term.

We validated the relevance of the listed indicators and thermal comfort within the Csa using the method described below.

3.2.4. Data collection

The selected indicators were the subject of two specific questionnaires for data collection: the first focused on the importance of comfort design features at the neighbourhood micro scale, and the second included the participants' evaluation of each indicator.

The climate data (air temperature, relative humidity and wind velocity) were acquired from the Annaba weather records 2017 on two representative summer days (18 July and 8 August 2017) when air temperatures and the relative humidity reach their peak.

3.2.5. Process indicator evaluation

3.2.5.1. Pedestrian comfort facility coefficients and scores

The first questionnaire evaluates the importance of 21 indicators at the neighbourhood micro-scale level using a five-point Likert scale ranging from 1 (least important) to 5 (very important). In total, 330 respondents from different cities in Algeria, including Annaba answered the first questionnaire using an online platform. The outputs of this questionnaire are used to generate the relative coefficient for each comfort indicator (Cis). The second questionnaire (282 respondents) assesses the scores of the selected factors (Sis) using a simple random sampling technique. The randomized information allowed us to define the respondents' characteristics (e.g., sex, age, residential origin), while participants evaluated each indicator using a scale ranging from 0 (awful) to 4 (very good).

3.2.5.2. Calculating and scoring PET

3.2.5.2.1. Calculating PET

This study used RayMan software to calculate PET values from 7 am to 8 pm (every hour) on two representative summer days. This software, which was developed in accordance with guidelines of the German Engineering Society (VDI, 1998) at the University of Freiburg, Germany, is regarded as one of the most reliable radiations and bioclimate models (Cohen et al., 2013a; Elnabawi et al., 2016) to predict thermal comfort and has been approved for use in urban spaces and several climatic zones (Cohen et al., 2013; Gulyás et al., 2006; Hwang et al., 2011; Lin et al., 2013; Matzarakis et al., 2007).

RayMan measures PET based on air temperature, air humidity, wind speed, mean radiant temperature, clothing and human activity. The period of the year, time of day and environmental obstacles allow the sky view factor (SVF) to be calculated. It can also be adjusted to account for other variables, such as the albedo of the surrounding surfaces, altitude and location, the Bowen ratio of the ground surface and the related air turbidity (Elnabawi et al., 2016; Hwang et al., 2011; Matzarakis et al., 2007). The software manufacturer recommends that for the assessment of thermal sensation, constants should be adjusted based on a man with a height of 1.75 m and a weight of 75 kg (Cohen et al., 2013; Mayer and Höpfe, 1987). PET calculation is based on representative segments of each neighbourhood (8-10 segments for each neighbourhood), with every street having a PET calculating point. The PET value in each neighbourhood is the average of the calculated points (Fig 9).

3.2.5.2.2. Scoring PET

To score PET in a Csa, a scale from 0 to 1 was adopted according to the TSV defined in Tel Aviv, which is characterized by a Csa. The thermal comfort range that reflects a neutral sensation of the TSV classification is estimated at between 19°C and 25°C for winter, and between 20°C and 26°C in the summer (Cohen et al., 2013). For cold and hot and very hot the score of PET is 0; for cool and warm, 0.25; for slightly cool and slightly warm, 0.5; and for the neutral thermal sensation, 1 (See Tables 7 and 8).

Table 7 Thermal sensation and PET range for Tel Aviv (Csa) (Cohen et al., 2013; Lin and Matzarakis, 2008; Matzarakis et al., 1999).

TSV	Thermal sensation	PET range for Tel Aviv (°C)	Tel Aviv climatic zone (Köppen classification)
-4	Very cold	-	Csa
-3	Cold	8	
-2	Cool	12	
-1	Slightly cool	15	
0	Neutral	19	
1	Slightly warm	26	
2	Warm	28	
3	Hot	34	
4	Very hot	40	

^aSubtropical (Csa) ; TSV, thermal sensation vote scale.

Table 8. PET scores according to thermal sensation and PET range in a Csa.

PET range	PET scores
8–12°C	0
12.1–15°C	0.25
15.1–19°C	0.5
19.1–26°C	1
26.1–28°C	0.5
28.1–34°C	0.25
34.1–40°C	0

3.3 The Street Walkability and Thermal Comfort Index (SWTCI)

The current study aims to measure walkability at the street level by considering pedestrian comfort-related facilities and thermal comfort. For this purpose, we developed a new assessment tool, the Street Walkability and Thermal Comfort Index (SWTCI).

The presented method comprises some main steps that are summarized in Fig 6. The first one is reviewing effective indicators to identify pedestrian facilities and thermal comfort variables in research papers and standard guidelines, using Google Scholar, the Web of Science. Keywords included walkability, thermal comfort, street, Envi-met, simulation, assessment tools, street furniture policy and Csa. This research was conducted between 2002 and 2019 to select all the indicators that improve the walking experience. The finding emphasizes the lack of consideration for thermal comfort in the walkability assessment at the street scale. The microclimatic variables are also missing in the evaluation of walkability comfort.

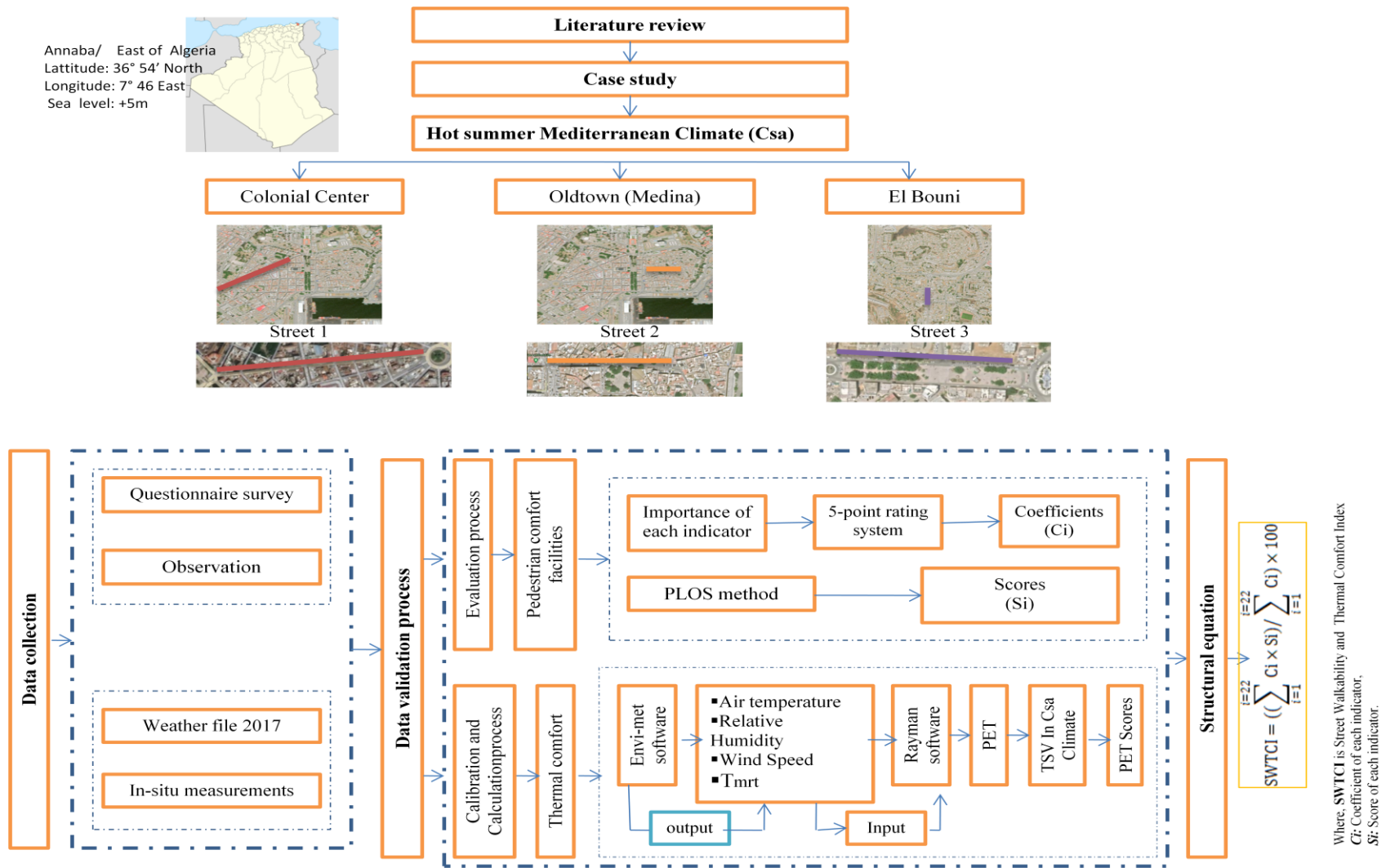


Fig. 6. Conceptual framework of the STWCI.

The proposed SWTCI tool is based on compiling 21 pedestrian comfort facilities extracted from the current literature (Table 9). That includes a wide range of sidewalk-related factors and facilities, considering people with different needs and abilities.

Table 9 Pedestrian comfort facilities on street level

Pedestrian comfort facilities	References
Slower traffic speed	Asadi-Shekari et al. 2015, 2014; Lee and Kim, 2019; Retting et al. 2003)
Buffer and barriers (curb and furnishing zone)	Asadi-Shekari et al. 2015; Jaskiewicz 2000; Labdaoui et al. 2021
Fewer traffic lanes,	Asadi-Shekari et al., 2015, 2014; Labdaoui et al. 2021
Mid-block crossing	Diogenes and Lindau, 2010; King et al. 2009
Landscape and tree	Aghaabbasi et al. 2019; Labdaoui et al. 2021; Lee et al. 2016; Todorova et al. 2004
Furniture (trash receptacles)	Aghaabbasi et al. 2019, 2017; Asadi-Shekari et al. 2019, 2014; Labdaoui et al. 2021
Footpath pavement	Kelly et al. 2011; Moura et al. 2017; Nilles and Kaparias, 2018
Marking (crosswalk)	Kelly et al. 2011; Labdaoui et al. 2021; Moura et al. 2017; Ruiz-Padillo et al. 2018
Sidewalk on both sides	Asadi-Shekari et al. 2015; Cain et al. 2014; Labdaoui et al. 2021
Width of footpath	Landis et al. 2001; Nilles and Kaparias, 2018
Slope	Asadi-Shekari et al. 2014; Kim et al. 2014; Koh and Wong, 2013; Labdaoui et al. 2021
Lighting	Asadi-Shekari et al. 2019; Crews and Zavotka, 2006; Nilles and Kaparias, 2018
Ramp	Aghaabbasi et al. 2019; Christopoulou and Pitsiava-Latinopoulou, 2012
Park and space for playing	Gehl et al. 2006; Labdaoui et al. 2021; Lamour et al. 2019
Social space (café)	Gunn et al. 2017; Koh and Wong, 2013; Labdaoui et al. 2021; Moura et al. 2017
Shade	Clifton et al., 2007; Jaskiewicz, 2000; Taleai and Taheri Amiri, 2017
Bench and seating area	Asadi-Shekari et al. 2019; Galanis and Eliou, 2011; Kihl et al. 2005; Troped et al., 2006
Toilet	Aghaabbasi et al. 2018; Asadi-Shekari et al. 2019; Labdaoui et al. 2021
Pedestrian signal	Aghaabbasi et al. 2018; Asadi-Shekari et al. 2014; Boisseau, 1999
Shorter crossing distance (curb extension)	Asadi-Shekari et al. 2015; Johnson, 2005; Labdaoui et al. 2021

The second step included the online survey conducted between June and August 2019 via Survey Monkey and Google Forms with 330 participants. The purpose of this survey was to measure the importance of pedestrian facilities according to people's perceptions. It included general information (age, gender, education) and highlighted street facilities' importance. People were asked to classify the importance of the selected indicators according to a scale of less important (1) to very important (5). Before the accurate data collection in June-August 2019, a pilot test with ten persons was carried out to verify the process and ensure the straightforwardness and clarity of all questions. The sample size is 330, based on the city population of 640,050, with a 95% confidence level and 5.4% margin of error. The survey's main purpose was to estimate the importance of pedestrian comfort features in general and not specially related to a specific street.

3.3.1 Microclimatic measurements

Three different streets were selected according to the following criteria: street morphology, slight slope, buildings' height, street orientation, length of the sidewalk, vegetative species, and distribution. We used microclimate monitoring instruments LM 8000 (Thermo-Anemometer, Hygrometer, Thermometer & Illuminometer) at the height of 1.10 m from the ground, at specific points on the 26th and 28th of August 2017. Air temperature (T_a), relative humidity (R_h), and wind speed (v) were measured and recorded at the one-second interlude. The measurement precision of microclimatic variables was ± 0.2 °C, 3% (%) and 0.2 (m/s). Every street has a specific measurement point near the sidewalk border to reduce the effect of unmeasured parameters and curtail interference with pedestrian observation and behaviour. Finally, the third step involves the assessment of street facilities and PET.

To estimate these indicators, we calculated the coefficients using the survey results, scores with observation results, and PET based on the in situ measurement (to validate simulation by Envi-met tool and to get T_{mrt}). The calibration process results allowed air temperature, wind speed, relative humidity, and T_{mrt} considered in the PET calculation with the RayMan program. The SWTCI is based on the PLOS method. It can be calculated from Eq (1)(Labdaoui et al., 2021):

$$SWTCI = ((\sum_{i=1}^{i=22} C_i \times S_i) / \sum_{i=1}^{i=22} C_i) \times 100 \dots \dots \dots \text{Eq. (1)}$$

Where *C_i*: Coefficient of each indicator, *S_i*: Score of each indicator.

Table 10 shows the suggested categories of (SWTCI) from A to F, in line with other point system studies related to pedestrians(Aghaabbasi et al., 2017; Asadi-Shekari et al., 2014; Moeinaddini et al., 2015). Thus, class (A) presents the highest comfort quality with 80-100 scores while the (F) category is the lowest class, estimated very uncomfortable with 1-19 scores.

Table 10 SWTCI % interpretation

SWTCI % rating	Model score	Interpretation
A	80-100	The highest quality (very comfortable); reflecting the existence of many comfort pedestrian facilities.
B	60-79	High-quality (acceptable), some comfort pedestrian facilities present.
C	40-59	Average quality (rarely comfortable), pedestrian comfort facilities present. However, the potential to improve pedestrian comfort conditions is omnipresent.
D	20-39	Low-quality (uncomfortable), minimal pedestrian facilities.
E	1-19	Lowest quality (unpleasant).
F	0	There are no standard pedestrian amenities (very uncomfortable).

3.3.2 Sidewalk measurement in the pedestrian level of service (PLOS) methods

Pedestrian level of service (PLOS) methods are extensively used in urban and transportation models. The macro and micro design methods are relevant in measuring pedestrian environments (Aghaabbasi et al., 2017). Although the micro design factors are crucial to analyze the walking environment's quality (Asadi-Shekari et al., 2019; Southworth, 2005), many existing PLOS models explored just the macro-scale approach. The latter approach considers macro design factors such as density, diversity, design, destination accessibility, and distance to transit (Kim et al., 2014).

Since the current study's scope is street level, the focus is on PLOS models at the street scale (considering micro design factors). These PLOS models have different techniques and characteristics. However, each one has its benefits and drawbacks regarding sidewalk measurement. Fig 7 shows the primary indicators and scopes included in these PLOS models for the sidewalk assessment.

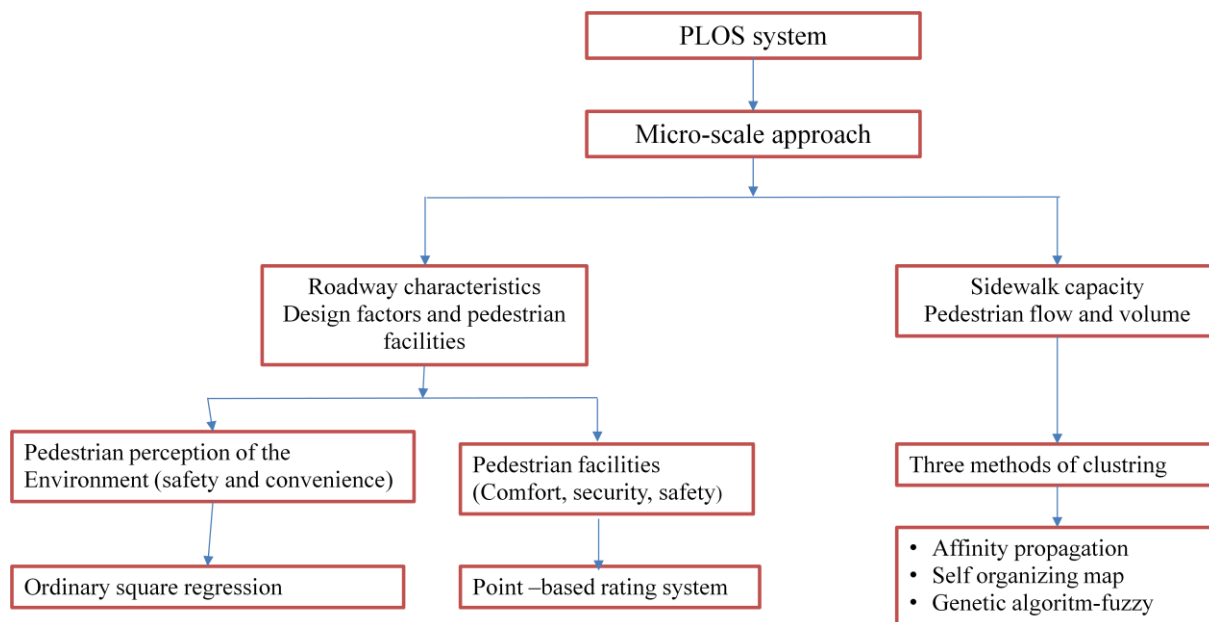


Fig. 7. Main scopes for PLOS models at the street level (Asadi-Shekari et al., 2013)

Some studies characterized the PLOS as a classification question. For example, Sahani and Bhuyan (2014) investigated three clustering methods, counting affinity propagation, self-coordinating map in artificial neural networks, and the genetic algorithm-fuzzy (GA-Fuzzy) approach. Despite clarifying that GA-Fuzzy is the most relevant clustering, this method only focused on capacity and met some related indicators such as pedestrian space, flow, volume to capacity ratio, and pedestrian speed, rather than the principal aim of PLOS for sidewalk facilities (Asadi-Shekari et al., 2019).

According to Asadi-Shekari et al. (2019), the PLOS method at the street level could be categorized into two major categories (Asadi-Shekari et al., 2013a, 2013b). The first category includes capacity-based tools that concentrate on sidewalk capacity, pedestrian flow, and volume. Ignoring micro-level design factors in walkability evaluation (e.g., Fruin, 1971; Manual, 2000), such as curb ramp, accessible drinking fountain, lighting, seating area, landscape, and trees. The second category includes the roadway aspects-based model that emphasizes design factors and pedestrian facilities (e.g., Asadi-Shekari et al., 2014, 2013b, 2013a; Landis et al., 2001; Sarkar S., 1993; Tan et al., 2007). The first method was criticized because pedestrians were comparable to cars and not users with special needs (Asadi-Shekari et al., 2013a, 2013b). Therefore, the second approach is more suitable for measuring walkability based on comfort-related factors that focus on this study.

Miller et al. (2000) suggested a point system in their PLOS evaluation. However, the restrained number of street facilities and users was inadequate for assessing inclusive streets. Landis et al. (2001) and Jensen (2007) explored more street factors to measure the PLOS. However, they applied an ordinary squares regression and found a few significant indicators that

exclude people with disabilities. Asadi-Shekari et al. (2013b) suggested a point system suitable for their PLOS model to explore micro-level design factors for all people, including people with disabilities. Although they consider weights and different measurement scores to include all possible conditions and avoid subjectivity in their evaluation, they did not consider PET in their proposed point system.

3.3.3 Thermal comfort indices

We selected PET to represent thermal comfort because it was applied and validated in multiple climates and urban areas (Gulyás et al., 2006; Johansson et al., 2014; Matzarakis et al., 2007; Thorsson et al., 2007) based on field surveys (Elnabawi et al., 2016; Lin et al., 2013a; Nikolopoulou et al., 2001; Nikolopoulou and Lykoudis, 2006). Besides, PET was associated with the Mean Thermal Sensation Vote (MTSV) within the hot and cold climate. Therefore, the assignment scores of PET are related to the human thermal sensation scale in the Mediterranean climate based on Potchter et al. (2018) findings.

Many studies explored PET based on in situ measurements using Envi-met or RayMan software. The Envi-met model is a three-dimensional micro-meteorological program (Bruse and Fler, 1998) and is considered one of the few micro-scale models that meet the required precise simulation standards. It verifies the correlation between the physical processes and the resulting micro-meteorological conditions in the urban canopy and thermal boundary layer (Lee et al., 2016). Also, it has been applied in simulations of the micro-climate and human-bio-meteorological influence of street design, building, and urban greening (Ali-Toudert and Mayer, 2007, 2006; Lee et al., 2016). Therefore, Envi-met was used in our study to calibrate data and get the Mean radiant temperature (T_{mrt}).

RayMan is considered one of the most successful radiations and bio-climate models (Cohen et al., 2013; Elnabawi et al., 2016). This software was developed according to the German Engineering Society's guidelines (VDI, 1998), University of Freiburg, Germany. It assesses PET according to different parameters (e.g., air temperature, air humidity, wind velocity, cloud cover, time of the day and year), and human clothing (0.9 clo), and activity (80 W) (Matzarakis et al., 2010, 2007).

Few studies combined the two programs to get more accurate results. Recent works adopt this approach in distinct outdoor environments (e.g., streets, parks, squares) within different climate zones, despite their rarity in the Mediterranean climate (Table 11).

1 **Table 11** Overview of PET calculations method in outdoor environments

Authors	Thermal comfort indices	Area/climate	Urban layout	Climatic /Microclimatic indicators	Method
Andreou, 2013	PET	Tinos, Greece	Streets (geometry, orientation)	Basic meteorological data	Calculation of PET using the Rayman v.1.2 tool Calculation of T_{mrt} Calculation Solar access and shading Calculating PET
Salata et al. 2016	PET	The Mediterranean climate, Csa	Street, square.	In-situ measurements	Calculating T_{mrt} Questionnaire for (MTSVs)
Klemm et al. 2015	PET	Netherlands	Parks (size, tree canopy, upwind vegetation cover)	In-situ measurements	PET Calculation using Rayman software. Calculating T_{mrt} Questionnaire for inhabitants' long-term perception of thermal comfort on warm summer days
Taleghani and Berardi, 2018	PET	Toronto	square	Climatic data In-situ measurements	ENVI-met simulations Simulated results (Air temperature, T_{mrt} , and surface temperature)
Liu et al. 2016	PET	Changsha, China	Park, square, grassland, 3kind of the sidewalk.	In-situ measurements	PET Calculation using Rayman software. Surveys during 4 seasons
Lee et al. 2016	PET	Freiburg, Germany	Residential district	In-situ measurements Climatic data	PET and T_{mrt} are calculated using ENVI-met Calculating PET using Rayman
Cohen et al. 2013	PET	The Mediterranean climate	Park, Square, Street	In-situ measurements	Statistical data analysis of the in-situ Subjective thermal sensation voter records on the questionnaires with PET values Calculating PET using Rayman
Elnabawi et al. 2016	PET	Hot Arid Climate of Egypt	Streets In Medieva lCairo	In-situ measurements	Subjective thermal sensation records the questionnaires with PET values Calculating PET using Rayman
Morakinyo et al. 2017	PET	Hong Kong	Street canyon.	In-situ measurements	Calculating T_{mrt} using Envi-met software Shades ENVI-met simulations, its impact on thermal comfort

The main aim of this study is the application of the SWTCI at different street morphologies. The survey is also designed to estimate the importance of the indicators for available street types. However, for particular street types like tiny streets, some indicators such as slower traffic speed, marking (crosswalk), mid-block crossing, and slower traffic speed, could be freeze. Therefore, the proposed method can be used for general street types in different cities and particular streets and cities. The included indicators and weights need to be justified and localized. The SWTCI within Csa is applied according to the following method.

3.4 Assessing indicators

One of the main limitations for PLOS point systems like Asadi-Shekari et al. (2013b) is ignoring the perceptions and PET. This study fills this gap by using people's perceptions and viewpoints as weights and coefficients for the indicators and including the PET effects. In addition, a series of in situ observations is also used to evaluate each comfort indicator's state objectively and measure their scores (Asadi-Shekari et al., 2014).

3.4.1 Pedestrian comfort facilities coefficients and scores

The questionnaire survey measured 21 street design indicators' importance, using a five-point Likert scale ranging from 1 (least important) to 5 (very important). This survey explored people's perceptions regarding the matter of pedestrian facilities. In total, 330 respondents in Annaba completed the survey online. The survey data are used to achieve each comfort indicator's relative weight (coefficient) (Cis).

Using the observation technique seeks to quantify every pedestrian comfort indicator as a score (Sis), indicating a number between 0 and 1. The score (1), considered the best score, reveals a relevant match between the existing street condition and the guideline requirements. In

contrast, the score (0) means no link or the indicator is not existing in the case study. There are also some scores between 0 and 1 to cover the semi-fitness situations. For more details, refer to Appendices A and B.

2.4.2 Calculating and scoring PET

To understand thermal comfort impact on pedestrians, PET was computed on the selected streets using RayMan (Matzarakis et al., 2010, 2007). This study also used the spatial height performance and temporal microclimate resolution model, the Envi-met 4 software that can generate simulations by designing the building's architecture and vegetation model (Wu and Chen, 2017). Before PET calculation, the T_{mrt} was measured through the calibration process using the full forcing command (24h) with Annaba weather records data (26th and 28th of August 2017).

We validated the calibrated model based on the difference between simulated and measured air temperature, which showed a good performance between the two data sets (Elnabawi et al., 2013; Taleghani and Berardi, 2018) $Y=0.862x+3.909$, $R^2=0.84$ (Fig3). Consequently, we got four calibrated data: air temperature, wind velocity, relative humidity, and T_{mrt} . Therefore, based on these calibrated data (Klemm et al., 2015; Lobaccaro and Acero, 2015; Morakinyo et al., 2017; Taleghani and Berardi, 2018), we calculate PET from 8 am to 8 pm (Fig 8).

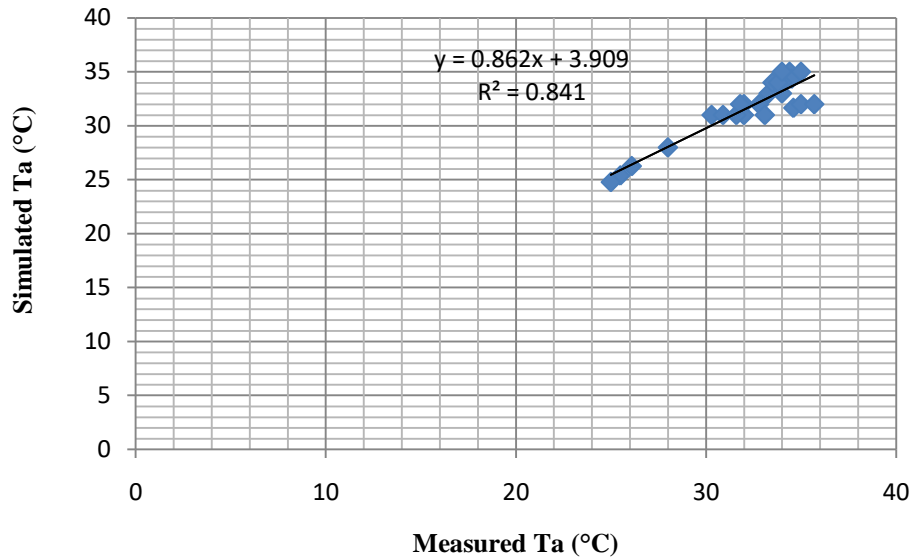


Fig. 8. Correlation between simulated and measured air temperature.

To score PET in the Mediterranean climate, we applied a scale from 0 to 1 (Labdaoui et al., 2021), considering the defined thermal sensation vote (TSV) in Tel Aviv, characterized by a Csa. Thus, despite the same climate classification, both cities have the same level from the sea +5m. According to Potchter et al. (2018), the thermal comfort range in TelAvivis between 19°C - 25°C in winter and 20°C - 26°C in summer. Therefore, for cold, hot, and very hot thermal sensations, the PET score is 0. For cool and warm thermal perception, the score is 0.25; for slightly cool and slightly warm, the score is 0.5. Finally, the neutral thermal sensation reaches the score of 1. (Refer to Tables 12 and 13).

Table 12 Thermal sensation and PET range for Tel Aviv (Csa climate) (Cohen et al., 2013; Lin and Matzarakis, 2008; Matzarakis et al., 1999; Potchter et al., 2018)

TSV	Thermal sensation	PET range for Tel Aviv (°C)	Tel Aviv Climatic zone (Koppen classification)
-4	Very cold	-	Csa
-3	Cold	8	
-2	Cool	12	
-1	Slightly cool	15	
0	Neutral	19	
1	Slightly warm	26	
2	Warm	28	
3	Hot	34	
4	Very hot	40	

^aVote scale (TSV), Warm Mediterranean Climate (Csa).

Table 13 PET scores according to the Thermal sensation and PET range in Csa Climate (Labdaoui et al., 2021).

PET range	PET scores
>8°C	0
8° C-12° C	0.25
12.1°C-15°C	0.5
19.1° C-26°C	1
26.1°C-28° C	0.5
28.1° C-34° C	0.25
34.1° C-40° C	0

3.5 Case study

The field study was conducted in the city of Annaba, Algeria (36°54'N, 7°46'E; +5 m above sea level) with a population of 640,050 (National Office of Statistics, 2008). Annaba is characterized by a hot-summer Mediterranean climate (Csa) according to the Köppen (1931) classification. In the 2015–2019 period, the air temperature varied from 12°C to 22°C (maximum) and 4°C to 11°C (minimum) in winter, and the maximum summer air temperature varied from 26°C to 36.5°C. The minimum summer temperature varied from 15°C to 24°C.

In order to have an idea about the de walkability in the city of Annaba, we applied Walk Score®. However, it doesn't concern all the neighbourhoods of the city. Indeed, only a few neighbourhoods had the scores (principal communities of Annaba city). The results showed that the walkable neighbourhood with the highest scores (60%-65%) involved three neighbourhoods: European center, Medieval town, Champs de Mars. In comparison, low scores characterised the other districts, varying between 18% and 40%.

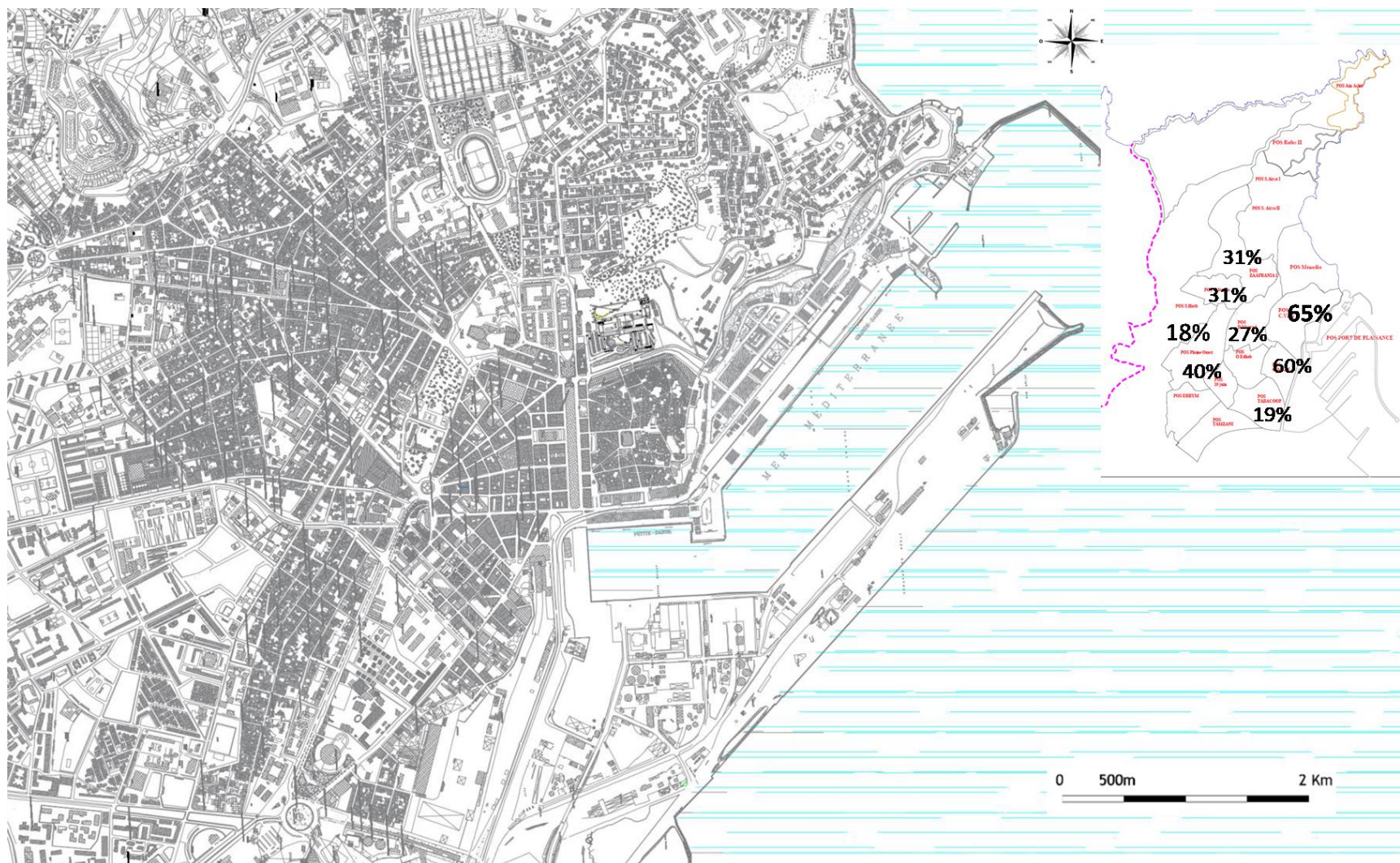


Fig.9. Walk scores in main streets at Annaba city.

3.5.1 Case study 1 Neighbourhood micro scale

Three neighbourhoods were selected in Annaba city, The European Center, the Old Town (Medina), and El Bouni (suburban). The first two neighbourhoods located in Annaba city centre are rated as the most walkable neighbourhoods (66% and 64% walking scores, respectively, based on (Walkscore.com, 2010)). In addition, this area is characterized by dense commercial activities that play a significant role in the city centre. The third neighbourhood is El Bouni, having an 18% walking score (Walkscore.com, 2010).

Despite the differences in walk scores, the three selected neighbourhoods have many variances: urban morphology, high buildings, vegetative distribution, length and width of streets beside the pedestrian facilities. Considering thermal comfort , the PET calculation is based on representative segments of each neighbourhood (8-10) according to the following criteria: street hierarchy, street width, standard sidewalks, slight slope, the height of buildings, street orientation, street length, and vegetative species and their distribution (Fig 10)



— selected streets at European Centre — Selected streets at Old Town (Medina) — Selected streets at El Bouni.

Source: Google images, 2020

Fig .10. Selected streets at Annaba city centre and El Bouni.

3.5.2 Case study 2 Street scale

We selected three different streets in three diverse neighbourhoods in Annaba city (Fig 11). The first segment in European Centre is a regular and furnished street (Having minimum pedestrian features) with North-East, South-West orientation, and $h/w = 2$. The second Case in the medieval neighbourhood (Medina) with East-West orientation has an irregular morphology and a ratio h/w equivalent to 1.83. The last street was in El Bouni neighbourhood (Suburban area), with a North-South direction characterized by a regular morphology with $h/w=0.29$, but unfurnished (Table 14). These selections are just for testing the proposed STWCI in different types of streets, and the proposed STWCI can be used to measure walkability for other streets.

Table 14 The characteristics of the selected streets

Streets' characteristics	Street1	Street2	Street3
Length	512.9 m	323.22m	299.68m
Orientation	NE/SW	E/W	N/S
High of building	16m	11m-13m	12m - 15.5m
Ratio h/w	2	1.83	0.29
Vegetative elements (Trees)	0	3	0
Building's material	stones	Stones/Solid bricks	Precast concrete walls
Building's color	White	White	Yellow
Footpath material	Pavement	Concrete	Unfurnished+concrete stranded tiles.

NE/SW: North East/South West, E/W: East/West, N/S: North/South



— Street 1 in European Center, — Street 2 in Medina neighbourhood, — Street 3 in El Bouni



Fig.11. Location of selected streets at three distinct neighbourhoods.

Source: Google images, 2020

3.6 Chapter summary

This chapter explored how to combine walkability and thermal comfort according to the research objectives and hypotheses. Accordingly, two scales have been investigated by using PET in the assessment of walkability comfort. The neighbourhood micro-scale is considered a more suitable scale for measuring walkability comfort. The street scale was identified as the primary channel for pedestrians. Twenty-one (21) selected pedestrian comfort facilities besides PET were considered to assess CWI and SWTCI.

The CWI tool is based on two questionnaires' surveys that measure the pedestrian comfort coefficients and scores. PET was calculated with Rayman software based on three climatic variables (air temperature, wind velocity, and relative humidity) in two summer days 2017.

In comparison, the SWTCI involved additional techniques. PET assessment combines two software. Envi-met was used to calibrate data and get four microclimatic variables (air temperature, wind velocity, relative humidity and T_{mrt}). Rayman used these four data to calculate PET. Indeed, this measurement tool considered in situ measurements besides one questionnaire survey and observation to calculate pedestrian facilities scores and coefficients. It is essential to mention that both methods were explored, analyzed and validated in Annaba, Algeria, within the Mediterranean climate.

Using such methods, by considering hypotheses allowed to:

- Verify the relevance of correlating walkability and thermal comfort at two significant urban scales.
- Analyzed the difference in using three or four climatic variables.
- Analyze people's perceptions.
- Calculate objectively pedestrian comfort scores, and finally, analyze the tools finding interactions.

Chapter 4 Results

4.1 Chapter outline

The main question of our research was how to combine thermal comfort and walkability. To this end, we developed two innovative methods at the neighbourhood microscale and the street level. Two measurement tools were explored in Annaba City, characterized by the Mediterranean climate. The CWI was applied within three neighbourhoods: the European center, Old Town (Medina) and El Bouni having 66% and 64% and 20%, respectively, based on walk score results. The SWTCI was applied at three streets.

This chapter presents the results of applying the two measurement tools on two representative summer days. The first section defines the CWI results, while the second shows the SWTCI finding. This chapter also includes a comparison between the developed tool and the walk score.

4.2 The results of applying the CWI model in Csa

Regardless of their characteristics, distinct neighbourhoods can be evaluated using the CWI model, as the indicators and standards are from leading models and current research. We studied two areas to test the CWI model; the PET values of each neighbourhood are taken from the average PET values of selected streets.

4.2.1 Pedestrian comfort facility coefficients and scores

Table 15 shows the results of coefficients and scores at the neighbourhood micro scale. Each neighbourhood had four representative streets characterized by their length varying between 230 m and 510 m in the European Center, 116 m and 428 m in the Old Town and between 158 m and 613 m in El Bouni along different orientations: North, South, East, West, North-west–South-east and North-east–South-west. However, the selected streets in each neighbourhood had identical scores, according to the survey results. The coefficients of the designated areas were also the same, so every neighbourhood was represented by average scores. In total, 21 pedestrian facilities in addition to thermal comfort were tested at the neighbourhood micro scale.

According to the survey results, 95% of the indicators were considered very important and necessary, with coefficients of 0.80–0.93 and 0.67–0.77, respectively (e.g., landscaping and trees, footpath pavement ramps, pedestrian signals, footpath width, slope). The exception was one indicator (rubbish bins) that was viewed as less critical (coefficient of 0.32). Participants' perception varied from very good, good, some problems, many problems to awful, with respective scores of 0.79, 0.52–0.65, 0.4–0.47, 0.2–0.39 and 0.14–0.18. The European center scores were higher than those for the Old Town and El Bouni (Fig 12).

Most of the pedestrian facilities in the European Centre scored highly, indicating their pleasant condition (0.60-0.79) (e.g., benches and seating areas, slope, social spaces, landscaping and trees, footpath pavements). However, there were some exceptions (facilities such as lighting, ramps). In contrast, few indicators were estimated as good in the Old Town, with the highest score assigned to shade. Most pedestrian facilities received low scores of 0.18–0.23 (e.g., benches and seating areas, footpath width, landscaping and trees, ramps, parks, spaces for playing), reflecting their awful condition (Table 15).

Considering El Bouni neighbourhood, all the pedestrian facilities scores are much lower than the European center but remain closer to the Medina scores. For example, some pedestrian comfort facilities such as landscaping and trees, shade and thermal comfort, benches and seating areas have 0.09,0.2 and 0.15 scores in El Bouni, and 0.23,0.54, 0.39 in the Medina, while in the European center, the scores reached 0.62,0.52 and 0.79 (Fig 12). The highest score in El Bouni was 0.49 (pedestrian signal). In contrast, many indicators have very low scores varying between 0.09 and 0.15, such as landscaping and trees, footpath pavement, parks and spaces for playing, toilets and sidewalks on both sides (Table 15).

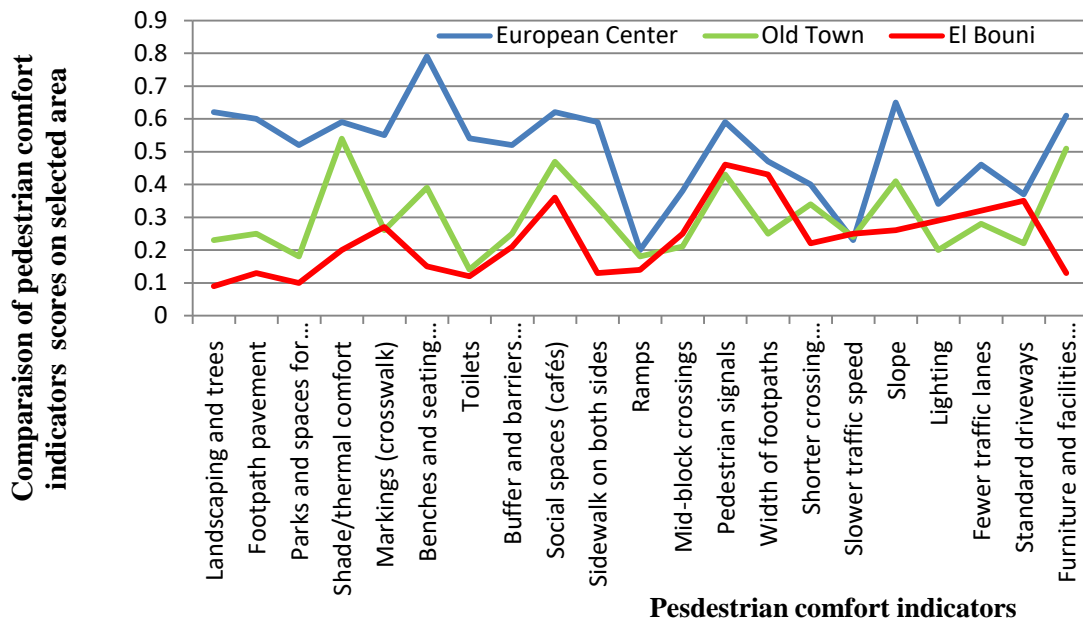


Fig. 12. Comparison of the pedestrian comfort indicators scores in the selected neighbourhoods.

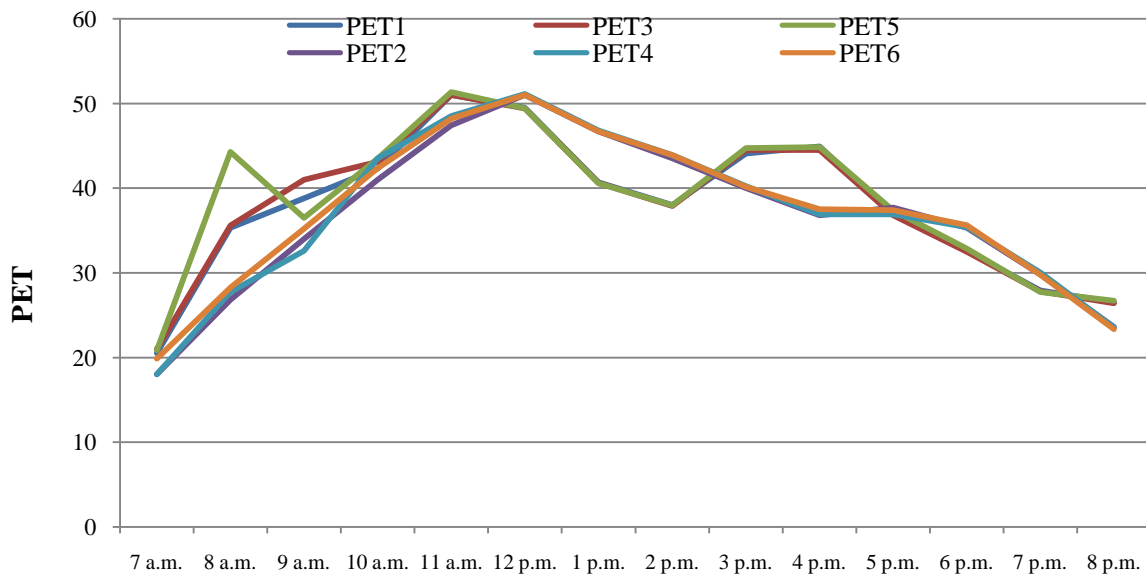
Analysis of the comfort indicator scores in the European center shows that PET values achieved both the maximum score of 1 and the lowest score of 0, compared with pedestrian comfort facilities where benches and seating areas earned the highest score of 0.79 versus ramps, which were evaluated with the lowest score of 0.2 (Fig 13). In the Old Town, PET values also achieved the maximum score of 1 and the lowest score of 0, compared with shade, with a score of 0.54, and toilets, with a score of 0.14 (Fig. 14). In addition, PET in El Bouni also reached the maximum score of 1 and the lowest score of 0. In comparison, the highest score of pedestrian facilities was 0.46 (pedestrian signal) versus 0.09 for landscaping and trees (Fig 15).

Table 15. Scores and coefficients of walkability comfort indicators in two selected areas.

	European center				Old Town (Medina)				El Bouni							
	Street 1	Street 2	Street 3	Street 4	Street 5	Street 6	Street 7	Street 8	Street 9	Street 10	Street 11	Street 12				
Orientation	NE/SW	E/W	N/S	NW/SE	N/S	E/W	NE/SW	NW/SE	E/W	N/S	E/W	NW/SE				
Street length	510 m	435.43 m	410.26 m	230.46 m	427.66 m	239.21 m	115.84 m	163.96 m	613.08 m	261.04 m	334.83 m	158.45 m				
Indicators	Coefficients				Scores average in Colonial Centre				Scores average in Old Town (Medina)				Scores average in El Bouni			
Landscaping and trees	0.93				0.62				0.23				0.09			
Footpath pavement	0.92				0.6				0.25				0.13			
Parks and spaces for playing	0.85				0.52				0.18				0.1			
Shade/thermal comfort	0.85				0.59				0.54				0.2			
Markings (crosswalk)	0.84				0.55				0.26				0.27			
Benches and seating areas	0.84				0.79				0.39				0.15			
Toilets	0.82				0.54				0.14				0.12			
Buffer and barriers (kerbs and furnishing zone)	0.80				0.52				0.25				0.21			
Social spaces (cafés)	0.80				0.62				0.47				0.36			
Sidewalk on both sides	0.80				0.59				0.33				0.13			
Ramps	0.77				0.2				0.18				0.14			
Mid-block crossings	0.76				0.38				0.21				0.25			
Pedestrian signals	0.76				0.59				0.43				0.46			
Width of footpaths	0.75				0.47				0.25				0.43			
Shorter crossing distances (kerb extension)	0.73				0.4				0.34				0.22			
Slower traffic speed	0.72				0.23				0.24				0.25			
Slope	0.71				0.65				0.41				0.26			
Lighting	0.69				0.34				0.2				0.29			
Fewer traffic lanes	0.68				0.46				0.28				0.32			
Standard driveways	0.67				0.37				0.22				0.35			
Furniture and facilities (rubbish bins)	0.32				0.61				0.51				0.13			

N: North, **S:** South, **E:** East, **W:** West, **NW/SE:** North-west/South-east, **NE/SW:** North-east/South-west.

The results reflected two significant differences at two specific hours; 8 am with warm thermal sensation instead of slightly warm besides hot thermal sensation rather than warm at 10 am. However, at 8 am, two PET scores of 1 and 0.5 indicate differing thermal perceptions, one neutral and the other slightly warm, respectively. At 9 am and 7 pm, the value of 0.25 indicates a warm thermal sensation. Between 10 am and 6 pm, the PET score is 0, showing a hot or very hot thermal perception (Table 16).



PET1 and PET2 (European center), PET3 and PET4 (Medina), PET5 and PET6 (El Bouni)

Fig. 16. Changes in PET values in the two selected areas on the two representative summer days.

Table 16 PET scores according to the TSV scale in a Csa.

Date/Time	European Center		Old Town		El Bouni		Date/Time	Colonial Centre		Old Town		El Bouni	
	PE T1	Score	PE T3	Score	PE T5	Score		PE T2	Score	PE T4	Score	PET 6	Score
7 am.	20.5	1	21	1	20.85	1	7 a.m.	18	1	18	1	18.85	1
8 am.	35.3	0	35.6	0	44.27	0	8 a.m.	26.8	0.5	27.7	0.5	28.25	0.25
9 am.	38.8	0	41	0	36.5	0	9 a.m.	34	0.25	32.6	0.25	35.2	0
10 am.	42.3	0	43.1	0	43.47	0	10 a.m.	41	0	43.5	0	42.325	0
11 am.	51	0	51	0	51.32	0	11 a.m.	47.4	0	48.5	0	48.2	0
12 pm.	49.5	0	49.4	0	49.4	0	12 p.m.	51	0	51.1	0	51	0
1 pm.	40.7	0	40.6	0	40.57	0	1 p.m.	46.7	0	46.8	0	46.675	0
2 pm.	38	0	37.9	0	37.95	0	2 p.m.	43.5	0	43.9	0	43.875	0
3 pm.	44.1	0	44.5	0	44.72	0	3 p.m.	40	0	40.2	0	40.15	0
4 pm.	44.9	0	44.5	0	44.82	0	4 p.m.	36.8	0	36.9	0	37.5	0
5 pm.	36.9	0	36.8	0	37.35	0	5 p.m.	37.7	0	36.9	0	37.4	0
6 pm.	32.6	0.25	32.5	0.25	32.87	0.25	6 p.m.	35.3	0	35.4	0	35.6	0
7 pm.	27.9	0.5	27.8	0.5	27.72	0.5	7 p.m.	29.8	0.25	30	0.25	29.75	0.25
8 pm.	26.5	0.5	26.4	0.5	26.72	0.5	8 p.m.	23.6	1	23.5	1	23.325	1

4.2.3 The CWI

We used Equation (1) to calculate the CWI in the three selected areas on the two representative summer days (18 July and 8 August 2017). Our estimated model explains the contributions of thermal comfort and pedestrian facilities to a pleasant walking experience.

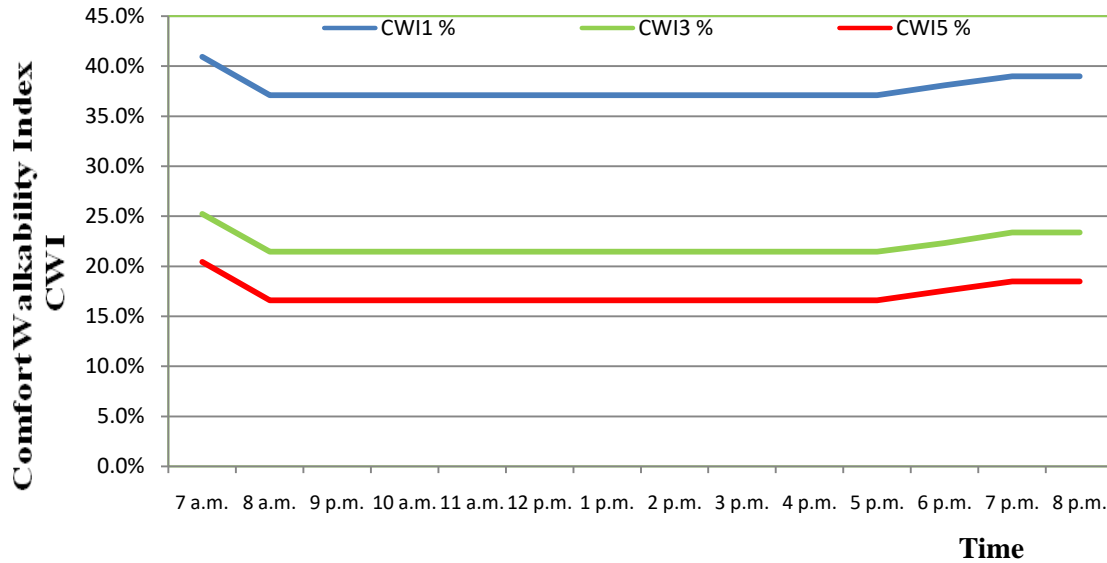
The highest CWI value was 40.95% in the European centre on both representative days at 7 am (Fig 17), when the thermal sensation was neutral, defining a rarely acceptable average comfort quality that necessitates improvements (Table 7). The minimum CWI value was 37.09%, that is, a hot thermal sensation, which indicated an uncomfortable walking experience. CWI reached new scores (38% and 39%) when the thermal perception was warm and slightly warm, respectively, with a lower classification which reflected uncomfortable conditions and low comfort quality (Fig 17).

For the Old Town, the recorded scores were lower than for the European center. The highest CWI value was 25.23% at 7 am when the thermal sensation was neutral, illustrating uncomfortable comfort conditions and minimal pedestrian facilities. CWI reached its minimum value (21.45%) when the thermal perception was hot, with increasing scores (22.32% and 23.36%) with a warm and slightly warm thermal sensation (Fig 18). Despite these reported differences in thermal sensation, the CWI remained between 20% and 39%, which indicates a low comfort quality level and needed improvements.

Considering the CWI in El Bouni, the highest score (20.45%) was reached when the thermal sensation was neutral at 7 am on the two representative summer days. This score revealed low quality and minimal pedestrian comfort facilities. However, most CWI ratings recorded in this area varied between 16.59% and 18.50%, which means unpleasant walking and the lowest comfort quality. Moreover, most of these rates (16.59%) are correlated with hot and very hot thermal sensation, while 17.54% and 18.50% reflected a warm and slightly warm thermal sensation (Fig 19).

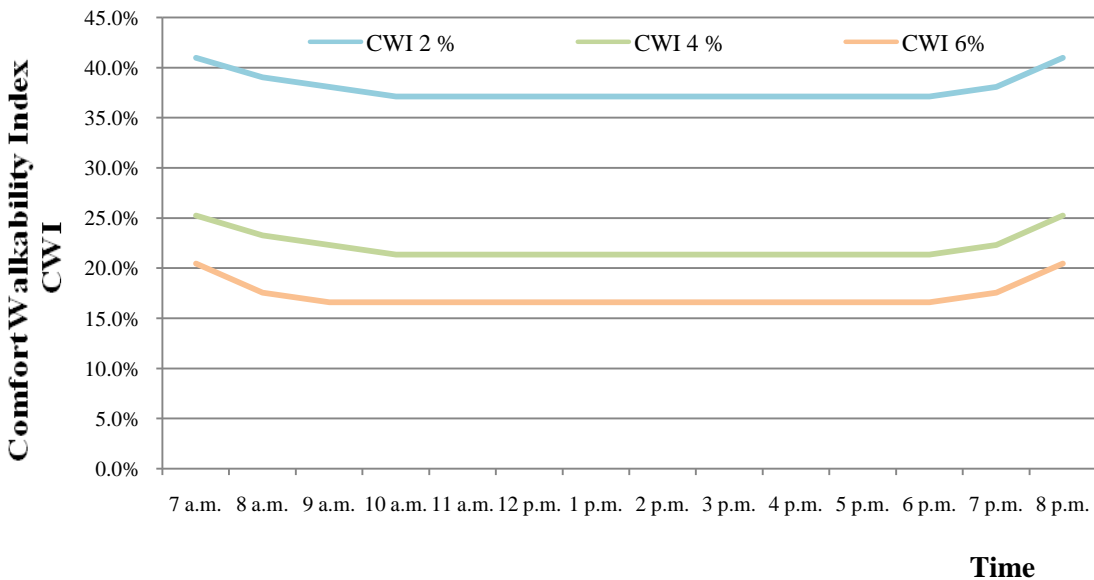
The results also showed that the CWI scores were almost identical over the two days, although thermal perception differed marginally depending on the time of day. For example, on 8 August, a neutral thermal sensation was recorded at 7 am and 8 am, compared with only 7 am on 18 July, giving the highest CWI value in the selected neighbourhoods (40.95%, 25.23% vs 20.45%).

The minimum CWI ratings (37.09%, 21.36% and 16.59%) occurred from 10 am and remained constant until 6 pm on 8 August, compared with 9 am to 5 pm on 18 July hot thermal sensation (Fig 19).



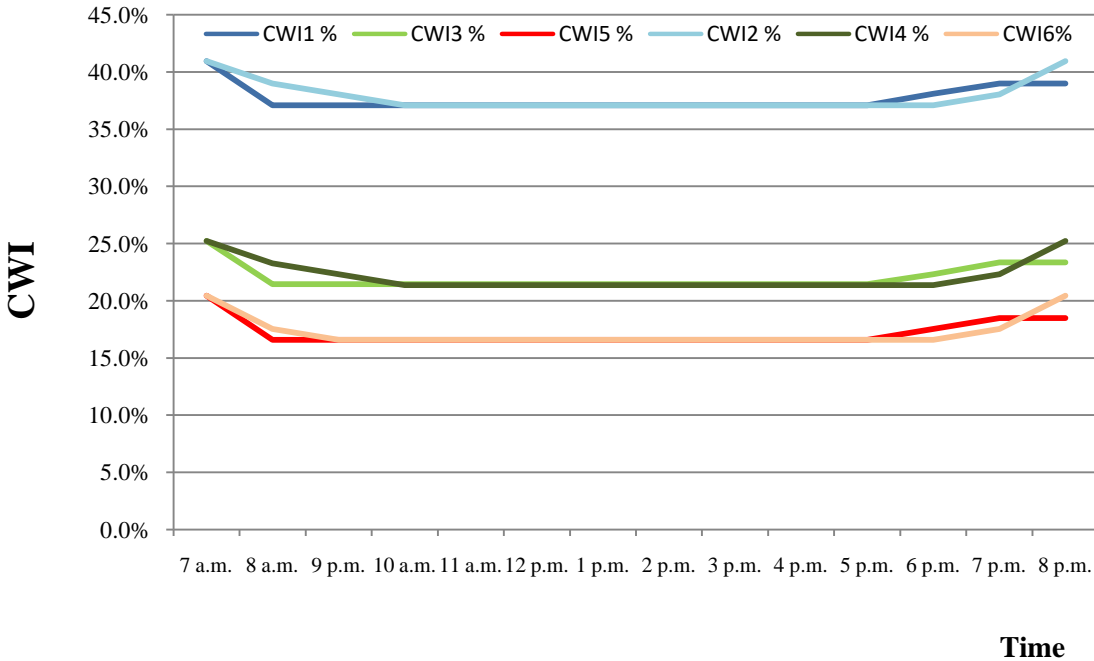
CWI 1 Comfort Walkability Index in European center, CWI 3 Comfort Walkability Index in Old Town, CWI5 Comfort Walkability Index in El Bouni.

Fig. 17. Changes in CWI in the neighbourhoods on 18 July 2017.



CWI 2 Comfort Walkability Index in European center, CWI 4 Comfort Walkability Index in Old Town, CWI6 Comfort Walkability Index in El Bouni.

Fig. 18. Changes in CWI in the neighbourhoods on 8 August 2017.



CWI 1: Comfort Walkability Index in European center, CWI3 Comfort Walkability Index in Old Town and CWI5 Comfort Walkability Index in El Bouni (18/07/2017).

CWI2: Comfort Walkability Index in European center, CWI4 Comfort Walkability Index in Old Town, CWI6 Comfort Walkability Index in El Bouni (08/08/2017).

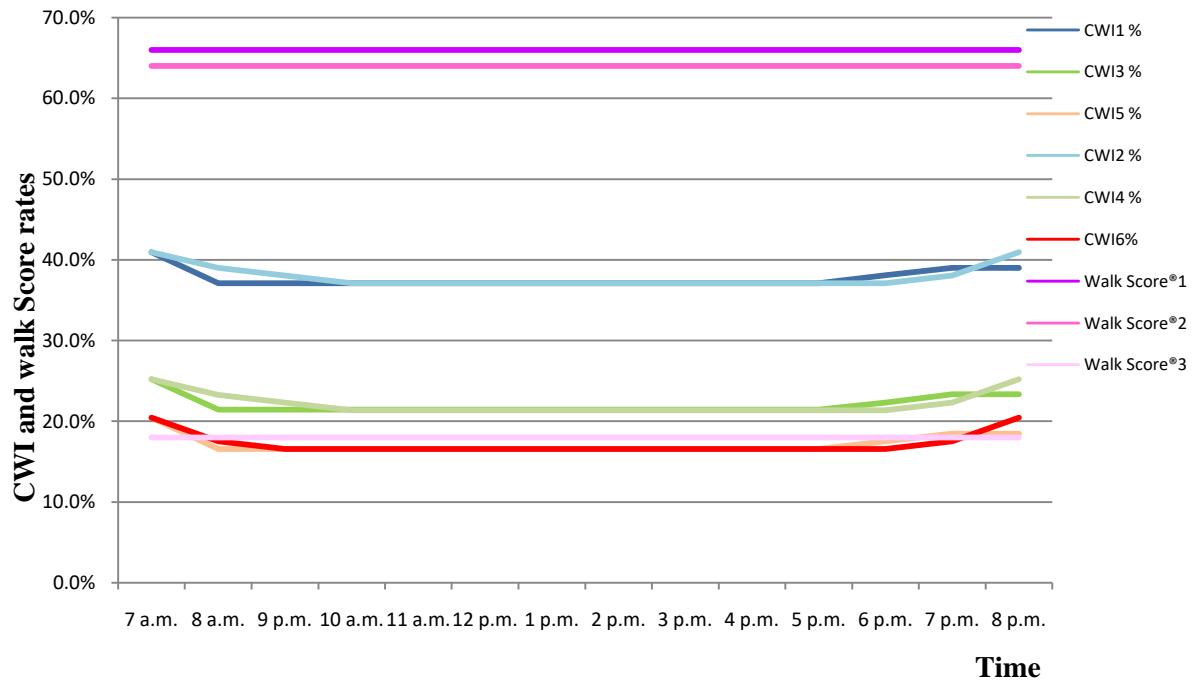
Fig. 19. Changes in CWI in the two neighbourhoods on the two representative summer days.

4.2.4 CWI and Walk score rates

According to section 3 in chapter 3, the Walk Score® was one of the principal criteria to select the neighbourhoods. The comparison of CWI and Walk Score® rates still relevant. Indeed, the walk score® rates in the Colonial centre, the Old Town and El Bouni were 66% and 64%, and 18%, respectively. Accordingly, the European center and Old Town are somewhat walkable, which means that some tasks could be achieved on foot. In contrast, El Bouni is a car-dependent neighbourhood.

In comparison, the CWI recorded 41% and 25% and 20% as the highest scores in the two representative days (Fig 19). A simple analysis of this figure shows the differences between the two tools. The walk score results are not depending on summer hours' day. It gave stable and unchanging results during the day, compared to the CWI results, which highlighted various scores depending on thermal comfort hours.

Moreover, the walk score® rates at European center and Old town are much higher than CWI best scores. Considering El Bouni, the rates of CWI and walk score® were close. Indeed Walk Score® defined a rate of 18%, while CWI identified 20% as the highest score (Fig 20).



CWI 1: Comfort Walkability Index in European center, CWI3 Comfort Walkability Index in Old Town and CWI5 Comfort Walkability Index in El Bouni (18/07/2017).

CWI2: Comfort Walkability Index in European center, CWI4 Comfort Walkability Index in Old Town, CWI6 Comfort Walkability Index in El Bouni (08/08/2017).

Walk Score®1: Walk Score in European Center, Walk Score®2: Walk Score in Old Town, Walk Score®3: Walk Score in El Bouni.

Fig.20. Comparison between CWI and Walk Score® rates in the selected area.

4.3. The results of applying the SWTCI tool in the Csa

4.3.1 Pedestrian comfort facilities coefficients and observation scores

4.3.1.1 Sample characteristics

The sample comprised 330 respondents, 53% male and 47% female. Some age categories were more involved than others. The results showed 64% of the response are related to the 25-34 category, followed by the 35-44 years group. In comparison, the youngest group (18-24 years old), and 45-54 years and 55-64 years, represented only 8%, 3%, 5% survey responses. Two categories, 65-74 years and +75 years old, didn't take part in the survey. Since this survey's main purpose is to estimate just the importance of the indicators, the scores are calculated using objective measurement methods. Therefore, the differences in age categories, mainly because of the online data collection, cannot affect the scores. In addition, the 25-44 age categories can represent the majority of the pedestrian population in the city, and the estimated weights can represent the opinions of the majority of the pedestrian population.

4.3.1.2 Coefficient results

The first column in Table 17 presents the coefficients of comfort walkability indicators. Over 95% of the suggested factors such as landscape and trees, footpath pavement, shade, bench and seating area, and social space (café) are considered very important and highly significant (0.80 and 0.93). Other indicators such as the ramp, pedestrian signals, footpath width, and slope are estimated as essential (0.67-0.77). However, a single indicator (trash receptacle) was supposed less critical, having a score of 0.32.

4.3.1.3 Observation scores result

From the data presented in the second column of Table 17, six pedestrian comfort indicators had a score of 1. This value demonstrated an actual presence of factors on the street in a European center (e.g., social space (café), the sidewalk on both sides, slower traffic speed, few traffic lanes). On the other hand, footpath pavement, the width of the footpath, and buffer /barriers (curb and furnishing zone) have 0.8, 0.8, and 0.5 scores, respectively, estimated present

on the street. Still, they are not meeting the recommended standard. However, a score of 0 suggests the non-existence of the pedestrian comfort facilities in the street segment.

The third column shows the observation scores of Street 2 in the medieval neighborhood (Medina). The highest score (1) is assigned to social space (café), slower traffic speed, few traffic lanes, so they are available and correspond to the referred methodological calculations. Alternatively, the ramp and standard driveway are not existing in the street. Other indicators to which scores are 0.13, 0.12 reflect no weight (e.g., footpath pavement and width of the footpath). In comparison, the sidewalk on both sides and buffer/barriers (curb and furnishing zone) indicators, with respectively 0.39 and 0.5 scores, highlight a failure with the required standards. However, the rest of the comfort walkability indicators having a score equivalent to 0 showed their total absence on the street.

The last column exhibits the observation scores at street 3 (El Bouni neighborhood). Most of the street comfort facilities had a 0 score, reflecting their lack on the street. Other indicators such as buffer and barriers, having a score of 0.5, indicated a deficiency with the recommended standard. However, social space (café), slower traffic speed, fewer traffic lanes scored the highest value 1, which implies their standard appearance on the street, while ramp and standard driveway are not available.

Table 17 The scores and coefficients of street comfort indicators

		Street1	Street2	Street3
	Length	512.9 m	323.22m	299.68m
	Orientation	NE/SW	East/West	N/S
Indicators	Coefficients	Scores	Scores	Scores
Landscape and trees	0.93	0	0.13	0
Footpath pavement	0.93	0.8	0.12	0
Marking (crosswalk)	0.85	0	0	0
Park and space for playing	0.85	0	0	0
		1	1	1
		1	1	1
Shade/Thermal comfort	0.85	0.5	0.5	0.25
		0.25	0.25	0.5
		0.25	0.25	0.25
		0.5	0.5	0.25
		1	1	1
Benches and seating area	0.84	0	0	0
Toilet	0.82	0	0	0
Buffer and barriers (curb and furnishing zone)	0.81	0.5	0.5	0.5
Social space (café)	0.8	1	1	1
Sidewalk on both sides	0.8	1	0.39	0
Ramp	0.77	1	1	1
Mid-block crossing	0.76	0	0	0
Pedestrian signal	0.76	0	0	0
Width of footpath	0.75	0.8	0.12	0
Shorter crossing distance (curb extension)	0.73	0	0	0
Slower traffic speed	0.72	1	1	1
Slope	0.71	0	0	0
Lighting	0.69	0	0	0
Fewer traffic lanes	0.68	1	1	1
Standard driveway	0.67	1	1	1
Furniture and facilities (trash receptacle)	0.32	0	0	0

NE/SW: North East/South West, E/W: East/West, N/S: North/South

4.3.2 Thermal comfort results and scores

It is essential to mention that PET was computed based on four calibrated microclimatic data (Air temperature, Relative humidity, wind velocity, and Mean radiant temperature) at the three selected streets on the 26th and 28th of August 2017 (Table 18). The purpose of this study is to estimate PET for the general population and not individuals. Therefore, some parameters like clothing and activity are used to represent the general population (clothing: 0.9 clo and activity: 80 W).

4.3.2.1 Microclimatic data

The results show a significant difference in air temperature in the three streets. The lowest temperature was recorded in Street 2 (Medina) at 8 am, 24.9 °C, compared to Street 1 (25.2°C) and Street 3 with 26°C. Although many hours reflected a high temperature (12 pm, 2 pm, 4 pm), the T (a) at Streets 1 and 2 are similar at 10 am (30.5°C -30.6°C). However, Street 2 showed the lower temperature at noon (31.1°C -31.5°C), 2 pm (33.2°C -33.5°C), 4 pm (34.3°C - 34.5°C) in comparison to Street1 with (31.6°C -32°C),(33.9°C -34.2°C), and (34.6°C -34.9°C). At the same time, the highest temperature was recorded in Street 3 at noon (34.7°C). Considering relative humidity, Streets 1 and 2 recorded a higher percentage during the entire hours of the day. For example, at 8 pm, Street 1 has (81%-83%), Street 2 (below 83%), while Street 3 has 57% (Table 18).

The T_{mrt} emphasized noticeable differences. The lowest values were recorded at 8 am for the three streets. For example, Street 1 has 13.3°C -13.5°C, Street 2 recorded 13.6°C -13.8°C, and Street3 has 12.8°C. However, at noon, street 1 has a lower T_{mrt} value than Street 2 (19.1°C - 19.3°C) and Street 3 with 21.6°C. Finally, the wind velocity recorded common low values at the three streets (Table 18).

Table 18 Microclimatic data and PET results using Envi-met and RayMan software.

Time (H)	Calibrated data (Envi-met)				RayMan	Calibrated data (Envi-met)				RayMan	Calibrated data (Envi-met)				RayMan
	Ta1 (°C)	Rh1 (%)	V1 (m/s)	Tmrt1 (°C)	PET1 (°C)	Ta 2 (°C)	Rh 2 (%)	V 2 (m/s)	T _{mrt} 2 (°C)	PET2 (°C)	Ta 3 (°C)	Rh 3 (%)	V 3 (m/s)	T _{mrt} (°C)	PET3 (°C)
8:00 AM	25.2- 25.3	below 94%	0.2- 0.4	13.3- 13.5	20.1	24.9- 25.1	96%	0.3-0.4	13.6-13.8	20	26	48%	0	12.8	19.9
10:00 AM	30.5- 30.6	68%	0.5- 0.9	17.7- 17.9	25.2	30.5- 30.6	below 73%	0.9-1.2	18.3-18.5	25.6	33.4	32%	0	19.9	26
12:00 PM	31.6-32	57%-59%	0.9- 1.9	18.7-19	26.5	31.1- 31.5	58%- 61%	2-2.6	19.1-19.3	26.4	34.7	28.50%	0.2	21.6	28.4
2:00 PM	33.9- 34.2	71%	0.8- 1.5	21.2- 21.5	29.4	33.2- 33.5	70%- 74%	1.6-1.9	21.7-22	29.5	31.6	50%	2.4	20.5	27.3
4:00 PM	34.6- 34.9	31%-32%	1-2.	23.9- 24.3	30.5	34.3- 34.5	below 33%	2.4-2.9	24.5-24.8	31	33.2	25%	2.6	23.8	29.5
6:00 PM	31-31.2	65%	1-1.97	22.6- 22.8	27.5	30.9- 31.1	65%- 69%	2.1-2.5	22.5-22.8	26.6	31.6	44%	0.5	23.6	28
8:00 PM	27.5- 27.6	81%-83%	0.7- 1.4	19	23.6	27.3- 27.4	below 83%	1-1.3	below 19.07	23.1	28.8	57%	0.5	20.1	24.8

The PET values at Streets1 and 2 are almost the same, especially during the hottest hours of the day. For example, at noon, the PET at Street 1 is 26.5°C, compared to Street 2 (26.4°C). However, at 8 pm, Street 2 recorded a lower temperature (23.1°C) than Street 1 (23.6°C). However, Street 3 registered the highest values of PET at all the hours of the day, compared to Street 1 and Street 2 (Table 17), except for 8 am where PET (19.9°C) was like Street 1 (20.1°C), and Street 2 (20°C). The results also showed a positive correlation between street orientation PET values and h/w. Indeed, Street 1 and Street 2 showed relative values of PET at the hottest hours of the day despite the difference in orientation (Street 1 NE/SW, Street 2 E/W). However, the h/w at Street 2 (1.89) is lower than Street 1 (equivalent to 2), showing a good level of shade. In contrast, Street 3 has N/S orientation, with h/w equivalent to 0.29, highlighting a deficient shade level.

4.3.2.2 PET coefficient and scores

The PET coefficient was derived from the questionnaire survey. There is a specific question about indicating the importance of thermal comfort for people during the walking experience in the questionnaire. To define an "acceptable thermal range" for PET in summer, TSVs were within the three major categories (Neutral, slightly warm, warm). We summarised PET values and scores from 8 am to 8 pm according to thermal comfort ranking in TelAviv with a Csa climate (Table 19). The PET is reaching its highest score (1) at 8 am, 10 am, and 8 pm, denoting a neutral thermal sensation. The lowest score is 0.25 at 4 pm on the three streets, showing a warm thermal perception. PET had the same score of 0.5 and 0.25 at noon and 6 pm on Streets 1 and 2. Versus a warm thermal perception, with a score of 0.25 simultaneously on Street 3 (See Fig 21).

Table 19 PET values and score results in the selected streets.

Time	PET Street1	Scores	PET Street 2	Scores	PET Street 3	Scores
8:00 AM	20.1	1	20	1	19.9	1
10:00 AM	25.2	1	25.6	1	26	1
12:00 PM	26.5	0.5	26.4	0.5	28.4	0.25
2:00 PM	29.4	0.25	29.5	0.25	27.3	0.5
4:00 PM	30.5	0.25	31	0.25	29.5	0.25
6:00 PM	27.5	0.5	26.6	0.5	28	0.25
8:00 PM	23.6	1	23.1	1	24.8	1

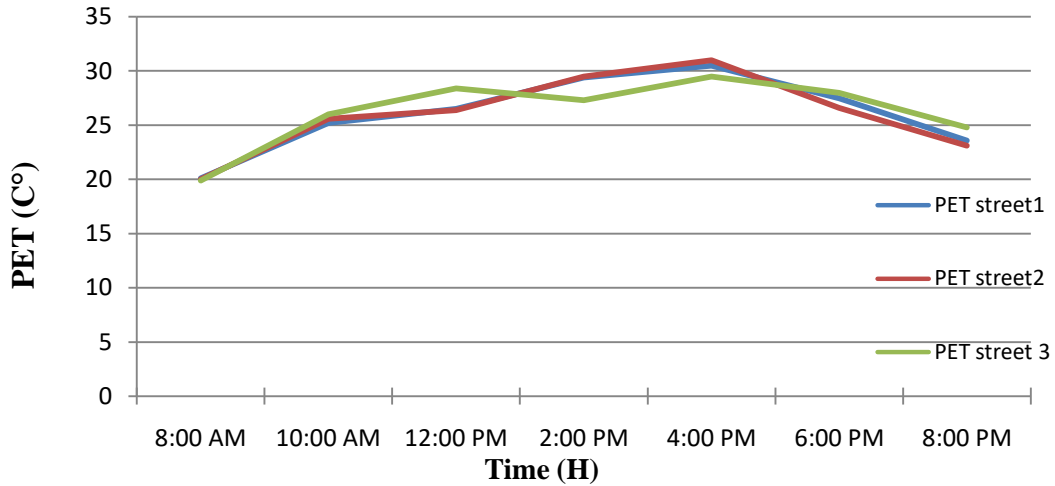


Fig. 21. Comparative analyses of PET results on three selected streets.

A straightforward analysis of the scores reveals that the same pedestrian facilities (e.g., social space (café), slower traffic speed, and fewer traffic lanes) besides PET reached the maximum scores of 1 at the three selected streets. However, the minimum values for the street facilities (e.g., parks and spaces for playing, toilet, benches and seating area) were equivalent to 0, while for the PET, the lowest score was 0.25 (See Fig 22).

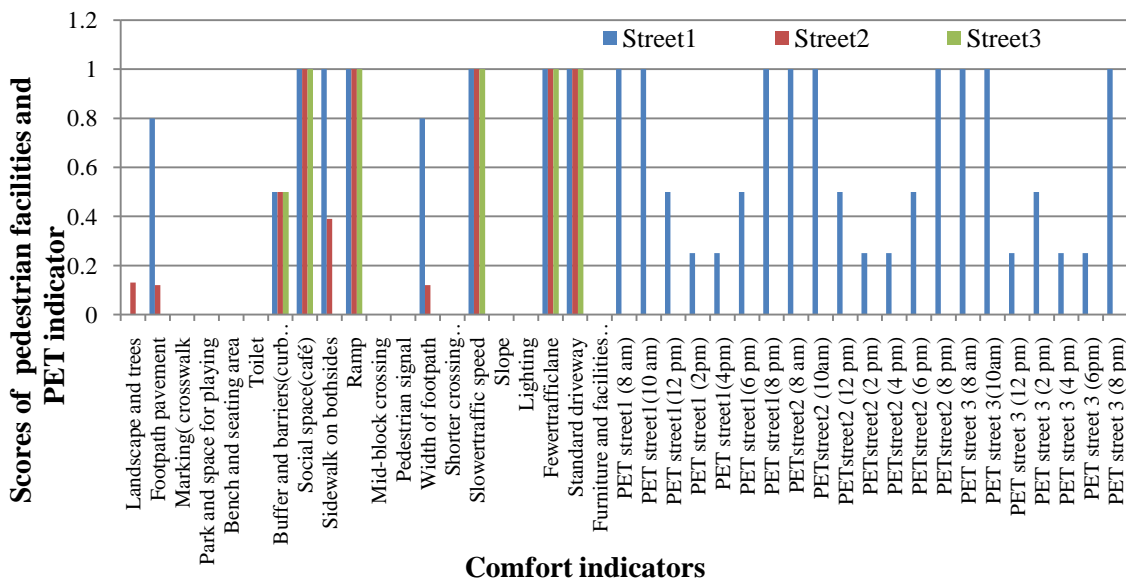
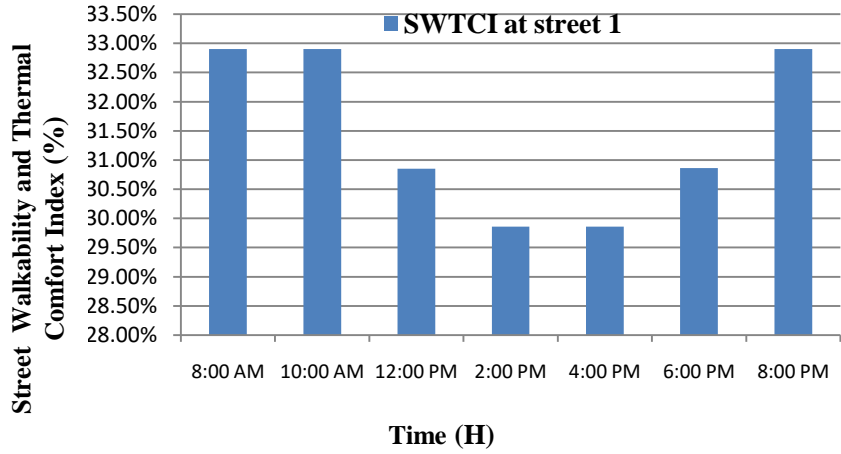


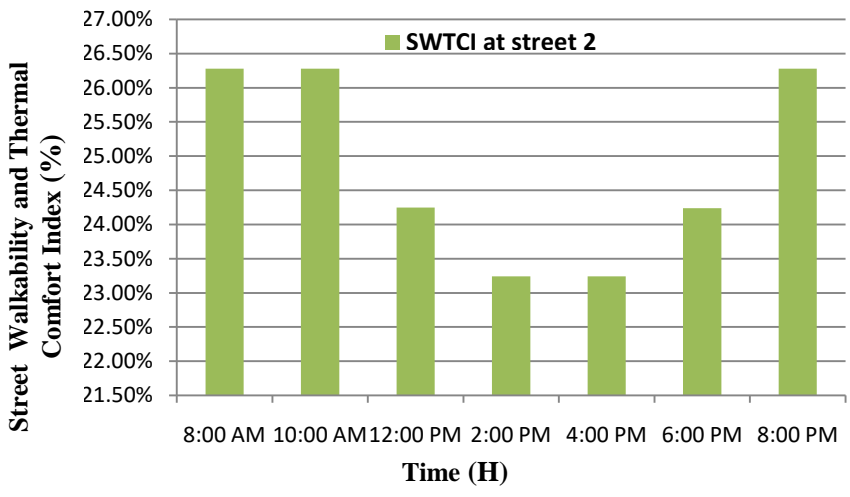
Fig. 22. Comparative analysis of comfort indicator scores on street level.

4.3.3 Street Walkability Thermal Comfort Index (SWTCI)

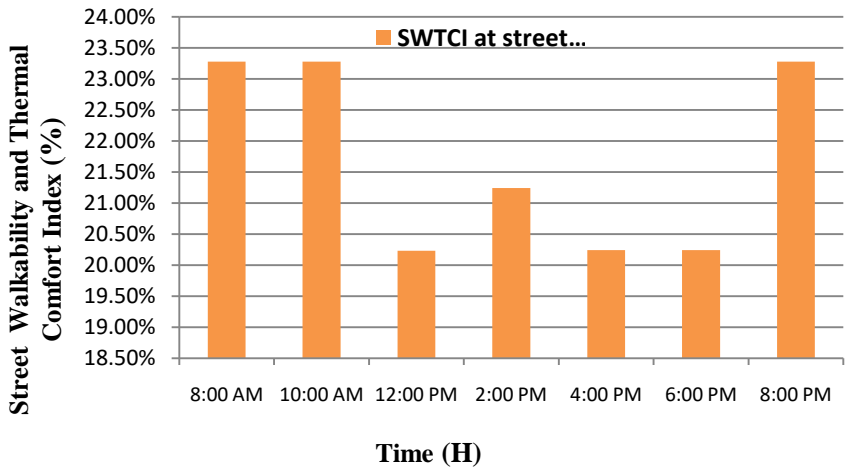
The application of equation (1) allowed us to have the (SWTCI). The comparative analysis of SWTCI outcomes showed low-quality comfort walkability indicators specified by minimal pedestrian street design, which does not comply with international standards (Table10). For example, the SWTCI in Street1 was between 30%-33%. In Street 2, SWTCI was included in the average of 23%-26%, and finally, the lowest scores were at Street 3 ($20 \% < CWTCI < 23\%$) (Fig 23). Most of the comfort walkability indicators are not existing. The selected streets are considered uncomfortable to use and unpleasant to walk (Table 20).



a



b



c

Street 1 in the European center, Street 2 in Medievalneighborhood (Medina), Street 3 in El Bouni

Fig. 23. Street walkability Thermal Comfort Index at the selected streets

According to the results, SWTCI reaches its highest score on the three streets at three hours a day, 8 am, 10 am, and 8 pm, when the thermal sensation is neutral with 32.90%, 26.28%, and 23.28%, respectively. However, SWTCI gets the minimum rating at 4 pm when the thermal perception is warm, showing 29.86%, 23.24%, and 20.23%, respectively (Fig 24).

The corresponding SWTCI values at street1 got 30.85% and 29.86% by increasing from noon to 4 pm. That is reflecting a slightly warm and warm thermal sensation, respectively. STCWI was rising from 6 pm to 8 pm with 30.8% and 32.90% (Fig 23.a). The variation of STCWI was similar in the two streets (Colonial Center and Medina) (Fig 23.a, b); however, the STCWI rating on Street 1 was higher than Street 2 (Fig 24).

Regarding Street 3 (El Bounineighborhood), the results show a noticeable difference comparing to the previous STCWI rating. Three hours a day (12 am, 4 pm, and 6 pm) characterized by a warm thermal sensation get the lowest STCWI rating (20.23%, 20.24%) respectively (Fig 23.c). However, STCWI ranking at Street 3 is inferior to both previous STCWI results (Fig 24)

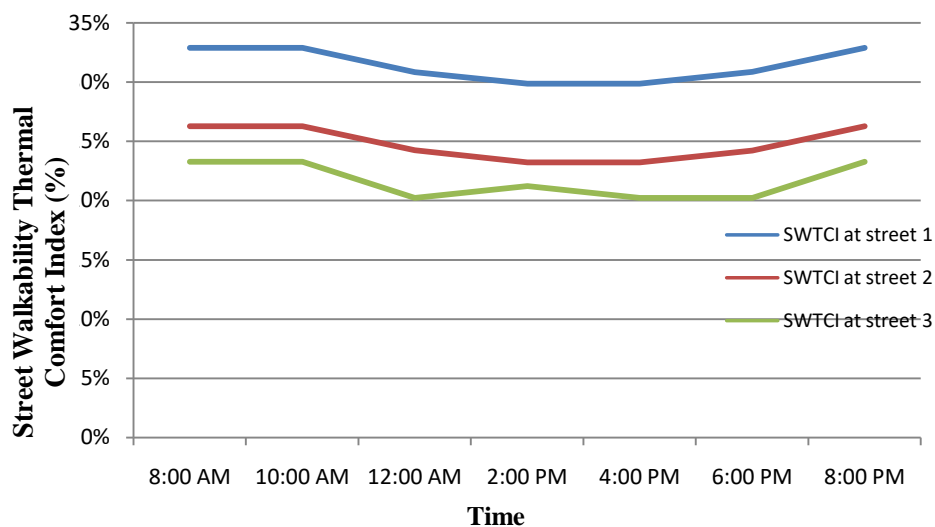


Fig. 24. Comparatives analysis of the SWTCI on the selected streets

4.4 Chapter summary

The presented chapter sought to address measurement tools by considering thermal comfort in the assessment of walkability.

The application of the CWI at three neighbourhoods (European center, Old Town and El Bouni) revealed interesting discrepancies. That can confirm the applicability of the method within different neighbourhood morphology, characteristics and walk score ratings. Moreover, minor divergences were recorded in each neighbourhood on the two representative days, confirming the importance of thermal comfort in walkability assessment.

The SWTCI had been applied within different streets depending on several characteristics such as length, morphology, the height of buildings. The findings showed a noticeable difference in SWTCI scores depending on the street characteristics. The results show an apparent difference in the PET values with considering or not the T_{mrt} variable. These results showed the suitability and relevance of the two assessment model in the Mediterranean climat

Chapter 5 Discussion

5.1 Chapter outline

To answer the prerogatives of our central research question. That involves how to combine walkability and thermal comfort. This study presented an innovative method by combining pedestrian comfort facilities and PET with a quantitative approach. Two measurement tools had been proposed, the CWI and SWTCI, based on 21 pedestrian comfort indicators besides PET. The CWI concerned with the neighbourhood micro scale, while the SWTCI is related to the street scale. The two assessment models were applied and validated in Annaba City, characterized by the Csa climate.

This chapter focuses on the discussion part. Every measurement tool explored a comparison with the previous studies' findings regarding pedestrian comfort facilities and thermal comfort. On how to view the thermal comfort affects walkability, the discussion continues with the interactivity of CWI and PET besides SWTCI and PET.

This chapter also includes specific sections exploring CWI and Walk Score® findings to understand the micro-level indicator's currency on the neighbourhood scale. We also presented how to optimize the SWTCI scores by identifying pedestrian comfort failure and calculate improvements. Another section discussed the overview interactivity of the proposed tools to analyze each method's currency.

5.2 The CWI

Few studies have examined sidewalks at the neighbourhood scale. The proposed model presents an easy-to-follow method for assessing walkability comfort indicators on the neighbourhood micro scale.

5.2.1. Coefficients and scores of pedestrian comfort facilities

As revealed by the survey, landscaping and trees were estimated as the most significant indicator for respondents of the questionnaire (0.93), which highlighted their role in providing pleasant and attractive streets (Aghaabbasi et al., 2018; Asadi-Shekari et al., 2019), with a shady environment and landscaped views (Taleai and Taheri Amiri, 2017), thereby promoting rain infiltration and improving the local microclimate (Battista and Manaugh, 2018), as well as enhancing pedestrian safety (Aghaabbasi et al., 2018; Lamour et al., 2019; Landis et al., 2001; Todorova et al., 2004). Shades, parks and spaces for playing were also rated as very important in providing relaxation areas for inhabitants.

Furthermore, these characteristics improve the attractiveness and security of walkways (Adkins et al., 2012; Battista and Manaugh, 2018; Giles-Corti et al., 2005; Owen et al., 2004), enhancing wellbeing, comfort and health. Our results are also consistent with those of Aghaabbasi et al. (2018), which emphasized the contribution of seating areas and benches to the attractiveness of sidewalks, and the convenience and comfort for pedestrians (Kihl et al., 2005), especially for improved access for people with disabilities (Troped et al., 2006). Moreover, these indicators can be considered as fundamental factors that affect pedestrian safety (Aghaabbasi et al., 2019; Boisseau, 1999). Mid-block crossings, slope and slower traffic speed are also considered important indicators because their absence generates an unpleasant effect on comfort and safety. Pedestrian signals had a weighting of 0.76, which shows that they are the principal comfort indicator that ensures usability and safety (Aghaabbasi et al., 2019).

Another important walkability indicator is path width, with a weighting of 0.75; clearly, path width can affect the comfort, attractiveness and safety of the walking experience (Aghaabbasi et al., 2018, 2017). However, some sidewalk features, such as lighting, fewer traffic

lanes and standard driveways with a weighting of 0.67–0.71, drew less attention than other comfort indicators. Rubbish bins had the lowest weighting of 0.32.

The scores for each neighbourhood are related to people's perception of the area. Notably, the obtained scores corroborate the fact that these perceptions are in line with actual conditions. For instance, in the European center, furniture and facilities, rubbish bins, footpaths, sidewalks on both sides and pedestrian signals have high scores because this area is well maintained by the local authorities as a popular tourist location. The European center also has a sufficient number of sitting areas and benches, social spaces (cafés), landscaping and trees, and a shade (courts and squares), all of which are essential for the pedestrian comfort level. El Bouni scores are lower than the Old Town and European center for all comfort indicators (Table 15). For example, shade and thermal comfort besides furniture and facilities (rubbish bins) have high scores in the European center (0.59,0.54) and Old Town (0.61,0.51), compared to El Bouni, which has a score of 0.2 and 0.13 respectively, reflecting the current state of neighbourhoods.

5.2.2 CWI and PET

As presented in Table 3, the TSV considered in the summer period was varying between neutral, slightly warm, warm, hot and very hot. Our analysis shows that PET values vary depending mainly on the time of day on the two representative days. The highest CWI values were neutral for the lowest category of thermal sensation, followed by slightly warm and warm. The lowest CWI values were hot and very hot for the highest category of thermal sensation.

The highest CWI values represent a neutral thermal sensation, which is considered an acceptable thermal comfort satisfaction level (ASHRAE Standard, 2004) during the summer period. Moreover, a neutral temperature is always related to a comfortable feeling (Elnabawi et al., 2016). The changes in the CWI during the two representative days in each neighbourhood reflect their dependence on the user's thermal sensation and comfortable weather conditions. Our findings are supported by those of Cohen et al. (Cohen et al., 2013) and Givoni, B et al. (2003), and confirm the importance of the climatic conditions in outdoor urban spaces and highlight their impact on the quality of life and wellbeing in cities. Thus, a neutral thermal sensation characterizes the recommended walking hours in the summer ($18 < PET < 23.6$), followed by a slightly warm ($26.8 < PET < 27.9$) and a warm ($29.8 < PET < 34$) thermal sensation. In contrast, hot

and very hot thermal sensations ($35.3 < PET < 51$) can be taken as uncomfortable walking conditions. It is of note that urban greening reduces daytime heat in the outdoor environment, and provides large areas of shade from tree canopies (Lee et al., 2016a), thereby promoting walking even in the hot hours of the day.

To our knowledge, this study is the first to evaluate the walkability comfort level by including thermal comfort indices. The CWI tool has been developed to assess the standard pedestrian comfort features in neighbourhoods together with PET in a Csa. Comfort facilities and the thermal comfort of pedestrians encourage inhabitants to walk, thereby contributing to a healthy life. Moreover, the CWI indicated a good match with the real-life conditions in the two study areas.

5.2.3 CWI and Walk Score®

The results emphasized noticeable differences in CWI and Walk Score® (Fig 19). The most significant variance was identified at the European center and Old Town, where Walk Score® recorded 65% and 64% versus 41% and 23% by CWI. Considering El Bouni, the results showed a marginal difference, 18%-20% with walk Score®, versus 20% with CWI.

This difference is related to the computing parameters of the two measurement tools. Indeed according to Hall and Ram (2018), the Walk Score® calculation process associates three parameters: shortest path to many prequalified landings (e.g., commerce/services such as public transport, restaurants, shopping, parks/green spaces, and schools), the block distance beside the intersection density all over the first location (origin).

In comparison, the CWI is measured based on 21 pedestrian comfort indicators, including social spaces (e.g., café, restaurants), length of the sidewalk, parks and playing area besides PET. That involved a wide range of walkability indicators compared to Walk Score®. Accordingly, considering few walkability attributes is one of its principal weaknesses (Wang and Yang, 2019).

The CWI assessment includes coefficients and scores based on people's perceptions (Aghaabbasi et al., 2017), which can define the current state and conditions of the area. This measurement tool is related to the micro-scale level of the neighbourhoods, estimated suitable

and significant for pedestrian comfort. Moreover, this approach helps measure walking environment quality (Aghaabbasi et al., 2017).

In comparison, the Walk Score® also correlates distance accessibility with street connectivity, based on one mile (1.60 km) Euclidean length buffer (Carr et al., 2010) for the Walk Score® algorithm (2010), while the recent version resolved buffer by the network (Hall and Ram, 2018; Vale et al., 2016). Besides, the lack of many pedestrian indicators can effectively show the actual conditions of the neighbourhoods and give precise scores. The Walk Score® ignores people's perception and comfort. It correlates walkability to car dependence.

The CWI considered thermal comfort in the walkability assessment. The results highlighted the variance of CWI during the summer hours compared to Walk Score®, which gave a constant score. The CWI scores depend on thermal comfort range hours, emphasising climatic conditions effects on walking activity. These findings are strongly supported by (Lorraine Fitzsimons, 2013; Mehta, 2008; van der Ploeg et al., 2010), who highlighted the importance of suitable climatic conditions and their effect on outdoor activities (walkability, biking). Accordingly, the outdoor environment should provide pleasant conditions for users (Marcus and Francis, 1997). That includes comfortable weather conditions such as air temperature, sunlight, winds (Pedro Gomes, 2012), relative humidity. In addition, the height of buildings is affecting the hours' shades on streets. Indeed, the small buildings and sinuous streets positively affect wind protection (Gehl et al., 2006b).

Based on these points, we can confirm the usefulness and the currency of the CWI tool. Indeed it can measure the walkability index based on a wide range of pedestrian comfort facilities and people's perceptions besides thermal comfort, which allowed achieving more current and precise scores. Moreover, the CWI tool could be applied to different kinds of neighbourhoods.

Applying these comfort indicators can enhance comfort quality and allow people to have a more pleasant walking experience in an urban environment. The CWI model would also help municipalities improve the quality of life and increase sustainable development strategies and health promotion. Our assessment tool indicated a strong correlation with the current real-life conditions of the two neighbourhoods studied, thereby confirming its reliability and reflecting the model-based performance.

5.3. The SWTCI

To make the walking experience pleasant and more suitable, we need a pertinent rating system that can evaluate the existing pedestrian comfort environment and identify the problems that can be used for suggesting solutions. In this aim, the current research intended to examine 22 comfort walkability indicators on the sidewalk scale, using an innovative method including pedestrian comfort facilities and PET. The proposed model was tested in Annaba, Algeria. This model fulfilled the need for rating pedestrian comfort and enhancing walkability scores by combining street comfort design and thermal comfort.

5.3.1 Impact of the pedestrian comfort facilities

This study's findings showed the relevance of the selected indicators. Indeed, most themes are valued as very relevant for pedestrian comfort. Besides offering convenience, the requested factors included a potential sign of safety, attractiveness, and usability. For example, besides suitable signage and sufficient time for crossings, the speed limit provides comfort and safety (Lamour et al., 2019; Mateo-Babiano, 2016). Street lighting provides a pleasant and secure pedestrian setting at night (Loukaitou-Sideris, 2006). Also, the results reveal some other crucial comfort attributes such as a sidewalk on sides, foot pavement, the width of the footpath, benches, and seating area. Those define pedestrian convenience and ensure a pleasant walking experience (Aghaabbasi et al., 2018) for all categories, including children, older adults, and people with disabilities. Moreover, these indicators allowed enjoying the social life (Jacobs, 1993; Marcus and Francis, 1997). Slope, toilets, curb ramps are necessary for pedestrian comfort and ensure usability and accessibility (Asadi-Shekari et al., 2019).

5.3.2 The PET effect on walking comfort

The Envi-met model allows human thermal comfort simulation for the current and future climatic conditions estimated by regional climate models. The calibrated model was successfully validated based on the difference between measured and simulated air temperature, showing a good correlation between set data (Acero and Herranz-Pascual, 2015; Chen and Ng, 2013; Müller et al., 2014). This study also used the Rayman software to calculate the PET based on calibrated data to provide more accurate data of the existing thermal comfort model. For example, simulated T_a and T_{mrt} values agree much better with measurement data (Lee et al., 2016; Tan et al., 2016). Moreover, the results highlighted the h/w ratio and orientation on thermal comfort conditions (Andreou, 2013). For example, Street 3 (h/w of 4) has higher air temperature, T_{mrt} , and PET values in comparison to Street1 (h/w of 2) and Street 2 (h/w of 1.83).

As introduced in Tables 12 and 13, the thermal sensation advised for the summertime in the Csa climate are neutral, slightly warm, and warm. Formerly PET ranked amid 19.9°C and 31°C. The inquiry of results PET scores fluctuated according to the time of day in summer. The PET results at the three selected streets showed the similarity of PET ratings in Street1 and Street 2 from 8 am to 4 pm. However, PET in Street 2 is lower than PET at Street1 from 6 pm to 8 pm. We noted that the thermal sensation in both streets (Streets 1 and 2) is almost the same (Table 19, Fig 21). Alternatively, PET at Street 3 is higher than the previous streets, which involve a warm sensation in three significant hours of the day (12 am, 4 pm; 6 pm) with a harmful effect on pedestrian comfort.

Those findings are strongly supported by Wu and Chen (2017), confirming the importance of the High-rise building on both sides of streets; their shades significantly impact the

thermal near-surface surrounding environment. Indeed, the concrete pavement surface temperatures shaded by buildings were relatively 16 °C lower than those bared to solar radiation during mid-day in the summer. Besides being significantly crucial to citizens, trees provide shade, allow walking during the hottest hours of the day. Indeed trees generate the cooling effect by reducing air temperature and T_{mrt} (Bowler et al., 2010; Lee et al., 2016, 2013; Lee and Mayer, 2015; Mullaney et al., 2015). Moreover, the urban green cover can massively absorb high amounts of solar radiation (Shortwave and long-wave radiation) (Oke, 1982) and add aesthetic value (Sousa et al., 2016).

5.3.3 Interactivity of PET and pedestrian comfort facilities on SWTCI

Among the many output possibilities derived from the SWTCI tool, we extracted those aiming to illustrate the PET assessment's usefulness. In this optic, we can confirm the importance of PET in the assessment of the SWTCI process. The highest SWTCI at the three streets (33%,26%, and 23%) was correlated to neutral thermal sensation, reflecting the lowest amounts of PET followed by slightly warm. On the other hand, the lowest SWTCI rate in the selected streets (30%, 23%, and 20%) was related to the warm category of thermal sensation. Thermal comfort is considered a vital comfort walkability factor in improving pedestrian activity and a healthy environment, confirming the importance of the climatic conditions in outdoor urban spaces and the quality of life and wellbeing in cities (Cohen et al., 2013; Givoni, B et al., 2003).

Furthermore, the results recommended walking hours activity at 8 am,10 am, and 8 pm defined as thermally comfortable hours in summer with a neutral thermal sensation ($20 < PET < 26$), followed by 6 pm with a slightly warm thermal perception ($26.84 < PET < 27.5$). However, the warm thermal sensation is not recommended for walking and made an

uncomfortable condition ($28 < PET < 31$) at 12 am and 2 pm. Thus, the pedestrians walking in the shaded zone could improve thermal sensation (Lee et al., 2020). For example, the thermal sensation scale is expressed as slightly warm instead of warm for subtropical climates (Huang et al., 2017).

Some walkability indicators such as landscape and trees, parks and playing areas, shade, and footpath pavement have an important effect on thermal comfort. Indeed, previous studies approved the positive impact of trees in parks, streets and squares on thermal comfort (Todorova et al., 2004) and walkability (Asadi-Shekari et al., 2019; Labdaoui et al., 2021; Taleai and Taheri Amiri, 2017). Indeed, many studies proved that people in the hottest hour of the day prefer walking in the shaded area (Bowler et al., 2010; Donovan and Butry, 2009; Gillner et al., 2015; Lee et al., 2020). The rest of the walkability indicators, such as benches and seating area, toilet, Buffer and barriers (curb and furnishing zone, ramp, mid-block crossing, pedestrian signal, the width of the footpath) have no impact on thermal comfort (see Table 21).

The proposed model can improve the pedestrian street comfort design by enhancing the indicators scores and comparing existing conditions with standards. Some pedestrian facilities such as landscape and trees and footpath pavement have a dual role; first, they improve the sidewalk's comfort conditions, and second; they increase pedestrians' thermal comfort. Landscape and trees are considered the principal component of attractiveness, safety, and usability on street level (Aghaabbasi et al., 2019, 2017). Adding vegetation can reduce mid-daytime heat by shading ground and evapotranspiration (Donovan and Butry, 2009; Gillner et al., 2015; Wu and Chen, 2017) and promoting walking hot hours of the day. Also, some paving materials such as cement tiles facilitate the accessibility of wheelchairs and strollers. The tiles with lighter pigmentation can absorb less heat and permit better thermal comfort (Synnefa et al., 2006).

Regarding the evaluated streets in this study, enhancing some pedestrian comfort facilities scores such as landscape and trees, benches and seating area, lighting, the width of the footpath, footpath materials can significantly improve the SWTCI rates. We can enhance the pedestrians' comfort by analyzing the existing variable's quality standards (See Table 17 and Appendix A and B and C). The comfort indicators could achieve the ideal score of 1 by performing current scores. Thus, applying the suggested improvements in Appendix C leads to a relevant upgrade to SWTCI 3. Indeed, it increased from 23% to 38% but still included in the same category (D).

Although the SWTCI results correlate to the PET, improving other pedestrian comfort indicators can significantly affect the SWTCI. For example, for a street without a sidewalk, most of the scores will be zero regardless of PET. In addition, some pedestrian facilities, such as footpath pavement (pavement type material) as well as landscape and trees, could have a dual role in improving the walkability and thermal comfort scores. Furthermore, including additional parameters such as building material and colour, besides analyzing the effect of adding vegetation and comparing the pavement material on thermal comfort, could be other interesting perspectives on the dual role factors for future research.

It is worthy to note the possibility of improving all the pedestrian comfort indicators by considering the standard guidelines (See Appendix A) and following the same method of Asadi-Shekari et al.(2019) (See Appendix B). Using the SWTCI method would help authorities improve comfort walkability conditions on the street level and enhance citizens' comfort potential. This design model can transform uncomfortable streets into pleasant and convenient environments within different street morphology and length. Indeed, the selected streets have fulfilled

Table 21 Walkability indicators relevance on PET based on previous studies

Walkability indicators	High relevant	Less relevant	Previous studies statement
Landscape and trees	1	0	Aghaabbasi et al., 2019; Kaplan and Kaplan, 1989; Klemm et al., 2015; Labdaoui et al., 2021; Lee et al., 2016; Taleai and Taheri Amiri, 2017; Todorova et al., 2004
Footpath pavement	1	0	Synnefa et al., 2006; Taleghani and Berardi, 2018
Marking (crosswalk)	0	0	/
Park and space for playing	1	0	Lin et al., 2013b
Shade	1	0	Bowler et al., 2010; Donovan and Butry, 2009; Gillner et al., 2015; Wu and Chen, 2017
Benches and seating area	0	0	/
Toilet	0	0	/
Buffer and barriers (curb and furnishing zone	0	0	/
Social space (café)	0	0	/
Sidewalk on both sides	0	0	/

Continued Walkability indicators	High relevant	Less relevant	Previous studies statement
Ramp	0	0	/
Mid-block crossingramp	0	0	/
Pedestrian signal	0	0	/
Width of footpath	0	0	/
Shorter crossing distance (curb extension)	0	0	/
Slower traffic speed	0	0	/
Slope	0	0	/
Lighting	0	0	/
Fewer traffic lanes		0	/

1:existing impact on PET. 0: absence of impact

5.4 Overview interactivity of CWI and SWTCI

The previous sections have investigated the discussion concerning the CWI and SWTCI separately. Every tool had been analyzed and examined. Indeed, most of the results had been strongly supported by previous research. That confirms the reliability and relevance of the proposed assessment tools.

This study proposed two measurement tools based on the PLOS model at two different scales: the neighbourhood micro-scale and street level. However, the interactivity of the proposed methods seems very interesting because it allows identifying the most influential parameters in the walkability assessment (Fig 25).

This interactivity is based on the cross-referencing of variables used to assess coefficients, scores and PET. Accordingly, we confirm the usefulness and currency of the selected 21 pedestrian comfort facilities. The findings of the two tools showed the relevance of those indicators at the neighbourhood micro-scale and street level. Indeed, those indicators were strongly supported by previous studies such as Aghaabbasi et al.(2018, 2017), Asadi-Shekari et al.(2019) and Lamour et al. (2019) (See sections 5.2.1and 5.3.1).

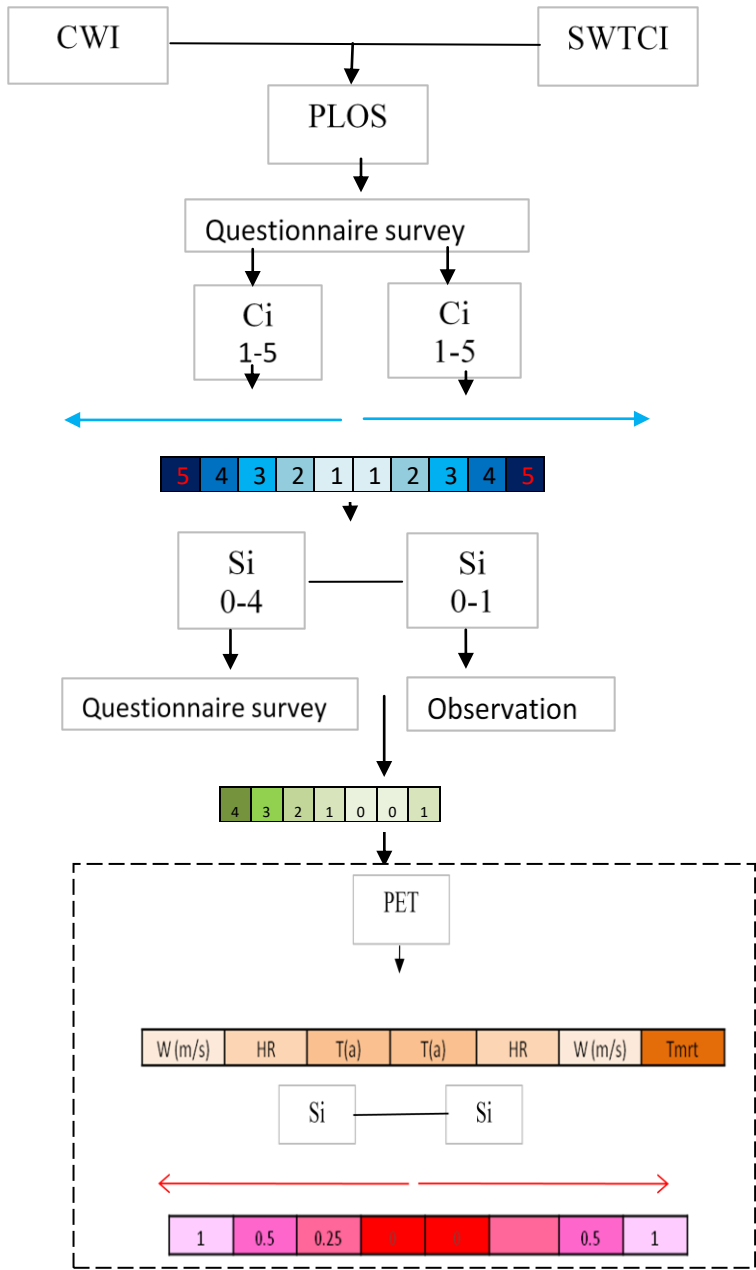
The assessment of coefficients in both tools was based on people's perception (questionnaire survey) using a five-point Likert scale ranging from 1 (least important) to 5 (very important). This approach is considered very useful and supported by previous studies (Aghaabbasi et al., 2017) (See sections 5.2.1, 5.2.3). The CWI is based on a questionnaire survey) using a simple random sampling technique concerning the evaluations of scores. The participants evaluated each indicator using a scale ranging from 0 (awful) to 4 (very good). While the SWTCI used observation, the scores had been defined according to the guideline requirements. Using people's perception and evaluation is more appropriate for the neighbourhood scale, while combining people's perception and observation is required for the street level because it allows for more accuracy. Accordingly, we confirm the usefulness of every method for each scale.

This thesis proposed two innovative methods by considering thermal comfort in the walkability assessment. We selected PET as a thermal comfort index for both measurement tools that had been argued, explained. We proved how it is firmly by other studies such as Cohen et al.

(2013), Potchter et al. (2018), Lin and Matzarakis (2008). However, the difference between the two methods was in the microclimatic variables consideration. Indeed the CWI assessed PET based on three climatic variables (air temperature, relative humidity and wind velocity).

In comparison, the SWTCI used four climatic (air temperature, relative humidity and wind velocity and T_{mrt}). Despite calculating PET in two representative summer days, considering T_{mrt} allowed getting more currency in the PET values. Many studies support these findings, such as (Lee et al., 2016) and (Tan et al., 2016) (See sections **5.2.4,5.3.4**).

Despite using people's perceptions, this does not sufficiently represent how people with multiple perceptions and cultural values affect walkability assessment in urban environments (Ruiz-Padillo et al., 2018). Indeed, people's thermal perceptions can vary from one climate to another and from one zone to another within the same climate. That implies pedestrians are susceptible to adaptation to thermal comfort conditions. In our case, the PET scores were evaluated according to the thermal sensation in the Mediterranean climate Annaba, Algeria, during the summer season.



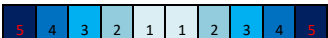
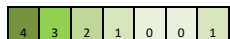

- 
 Same scale for coefficients 1-5 less important to very important
- 
CWI questionnaire survey from 0 to 4(Awful-very good), **SWTCI** Observation from 0 to 1 (0= no match, 1= existe according to the guidelines requirements).
- 
 0:very hot, hot thermal sensation, 0.25 warm, 0.5 slightly warm, 1:Neutral thermal sensation.

Fig. 25. CWI and SWTCI interactivity

5.4 Chapter summary

This chapter presented CWI and SWTCI dissertations. That involved two different scales, the neighbourhood micro-scale and the street level. The discussion included a variety of sections focusing on the pedestrian comfort facilities and the effect of PET on the proposed models. Besides comparing CWI and Walk Score tools. The last section included a crossover dissertation of CWI and SWTCI characteristics.

The CWI and SWTCI used successful and current techniques such as PLOS system point, questionnaire survey, observation, and well-known software (e.g., Rayman, Envi-met). These two methods were applied and approved in the Csa climate. Accordingly, we confirm the originality of the proposed method by combining a wide range of pedestrian comfort indicators (21) and thermal comfort. Thus, verify their reliability and be applied in different neighbourhoods and streets, which involves their usefulness for urban designers and architects. Moreover, using these tools can help authorities evaluate the current communities and streets for proposing improvements that strongly support sustainable strategies.

This chapter also highlighted the importance of considering T_{mrt} in the PET assessment, enhancing PET results accuracy. It also allows achieving a more accurate estimation of thermal comfort range, which implies precise CWI results.

Chapter 6 Conclusions and future research

6.1 General conclusion

Before delivering conclusions, the author draws attention to the research contributions related to architecture, urban planning, climate, transport and health. The proposed approaches could bring additional findings to the present work.

Based on successful and current techniques, this thesis conceptualized new assessment tools by combining walkability and thermal comfort, the CWI and SWTCI. These tools used a multitude of walkability indicators and climatic variables for optimal reliability.

The study aimed at: (i) Understand how to combine walkability and thermal comfort. Four principal solid objectives were specified to achieve these aims: (i) Identifying walkability indicators related to pedestrian comfort. (ii) Developing assessment tools to quantify this correlation. (ii) Inform urban planners, architects and municipalities, about the usefulness of these tools, by integrating them into environmental approaches and sustainable perspectives. (ii) Identifying the most used and validated thermal comfort index (iii) achieving the correlation through measurement tools, and finally (iv) verifying the applicability and reliability of the proposed tools in the Mediterranean climate (as an example).

This concluding chapter first recaps the responses to research questions before emphasizing the research contributions, effective recommendations, and thesis limitations. This chapter ends with prospects for future research.

6.1.1 Response to the research questions and beyond

This section presents the responses to the four comprehensive research questions and the results from the empirical investigation in line with the approved methods.

Before summarizing the answers, it is worthy to recall comfort as a significant key for walkability. Indeed, the walkability comfort appoints pedestrians' convenience level, and several factors, including climate, can also affect it. Accordingly, hot temperature and cold weather significantly influence outdoor activities, which justifies the importance of correlating walkability and thermal comfort. A range of indicators is relevant for both concepts. The first one is related to pedestrians comfort, which is the leading interest for walkability and thermal comfort studies. The second point is the urban scale, walkability, and thermal comfort explored the main urban components (outdoor environments; streets, neighbourhoods, squares). Every concept has been objectively measured based on quantitative approaches.

The research questions were addressed based on an in-deep analysis of three key elements; Walkability, Comfort and thermal comfort. An embedded case study within comparative research was carried out in the Mediterranean climate (Annaba), which concerned the primary urban structures, neighbourhoods, and streets characterized by different morphologies. Every case study has a specific pedestrian condition.

The questions are re-examined in what follows.

Q1 How to combine thermal comfort and walkability

This research question is very crucial since very few studies explored combining walkability and thermal comfort. Understanding how to combine the two concepts is an innovative approach. A critical analysis of the literature review strongly confirmed the feasibility of associating walkability and thermal comfort. It also highlighted the gap in considering thermal comfort in walkability assessment.

The most effective method to make it tangible into concrete form was to adopt a quantitative approach by developing new measurement tools to quantify walkability and thermal comfort objectively. Accordingly, the PLOS system was entirely consistent with the required method. Moreover, applying the PLOS method delivered rates. That is based on calculating

walkability indicators and scores and coefficients. That included pedestrian comfort facilities and the Physiological Equivalent Temperature (PET).

$$\mathbf{CWI} = \left(\frac{\sum_{i=1}^{i=22} C_i \times S_i}{\sum_{i=1}^{i=22} C_i} \right) \times 100$$

$$\mathbf{SWTCI} = \left(\frac{\sum_{i=1}^{i=22} C_i \times S_i}{\sum_{i=1}^{i=22} C_i} \right) \times 100$$

Where *C_i*: Coefficient of each indicator, *S_i*: Score of each indicator.

Many successful techniques were used, such as observation questionnaire surveys. Adopting this approach allowed developing two assessment tools, the Comfort Walkability Index (CWI) and the Street Walkability and thermal comfort index (SWTCI), at two different scales; the neighbourhood microscale and the street level.

It is worthy to note that every assessment tool had various categories (from A to F). That reflects the meaning of each score. For example, class A(80%-100%) describes the highest quality of comfort, which involves many comfortable pedestrian facilities. In comparison, category F (0%) reflected a very uncomfortable environment and confirmed the total absence of standard pedestrian amenities.

Q2 What are the indicators that define walkability comfort?

This question was addressed based on the interaction of walkability and comfort. To answer this question, we explored the literature review in full research papers, reviewed articles and standard guidelines, using Google Scholar, the Web of Science and weather records between 2002 and 2019. That allowed identifying two main elements of the analysis model. The first reveals the appropriate scale for assessing walkability comfort. Therefore, two urban components were assigned to the neighbourhood microscale and street level. The second involved the pedestrian comfort facilities. Accordingly, 21 comfort amenities were designed at the suggested scales (e.g., Slower traffic speed, Fewer traffic lanes, Landscaping and trees, Sidewalks on both

sides, Lighting), which concerned all users, including older adults, children, and people with disabilities.

Q3 What is the most appropriate thermal comfort index for walkability?

Two main phases had been carefully undertaken to answer the third question. The first concerned an inventory of the most used outdoor thermal comfort indices. The results showed many indices such as Perceived temperature (Pt), and its outdoor variant OUT-SET* Universal thermal Climate Index (UTCI), and the physiological Equivalent Temperature (PET). Thus, we correlated its assessment to the principal walkability measurement scales (Streets, squares, neighbourhoods) to select the most appropriate index. In addition, we analyzed how the assessment tool was associated with people's thermal perception. That includes several criteria such as survey's number and quality, climate variety and finally, the comfort range that a wide range had approved of studies. It also concerned selecting the relevant thermal comfort indices that are relevant for the walking activity. This means taking into consideration the metabolism rate for a slight physical activity and human energy balance. The cross-referencing allowed selecting PET as the most appropriate thermal comfort index for walkability.

Q4 Does thermal comfort affect the walking scores.

In order to answer that question, it was necessary to measure PET from 8 am to 8 pm and apply the required equation for each selected scale. Considering the neighbourhood micro-scale, CWI was calculated based on the scores and coefficients of the pedestrian comfort facilities and PET within three neighbourhoods. To understand the effect of thermal comfort on walkability efficiently, PET was assessed from 8 am to 8 pm on two representative summer days in each neighbourhood. Accordingly, the CWI was calculated from 8 am to 8 pm. The results highlighted a significant difference in the CWI depending on the thermal comfort range. The highest score of CWI was correlated to the neutral comfort sensation where $20 < PET < 26$. In contrast, the lowest score of CWI was related to a hot and very hot thermal sensation where $(35.3 < PET < 51)$.

The Street scale involved a similar process, by measuring PET and SWTCI from 8 am to 8 pm on three different streets. The results also emphasized a relevant variance in the SWTCI, depending on the PET scores. The highest score of SWTCI was reached when the thermal sensation was neutral. That implies a PET comfort range of $18 < PET < 23.6$. In contrast, the lowest SWTCI score was associated with the lowest scores of PET ($28 < PET < 31$).

Based on these findings, we strongly confirm the impact of thermal comfort on walking scores. Indeed, noon, 2 pm and 4 pm are defined as uncomfortable hours for walking because they are considered the hottest hours of the day and reflect the lowest PET scores.

We approve that considering people's estimation and perception is very important when evaluating safety attractiveness, especially pedestrian comfort. Indeed by using this quantitative approach, we are taking into consideration the most relevant pedestrian comfort that can efficiently improve the walking experience. Moreover, combining people perception and objective measurement is the best way to transform streets into ideal walkable paths. The CWI is an innovative method. It is designed as a dynamic tool involving the neighbourhood micro-level (rarely considered in the literature review), 21 pedestrian facilities, and thermal comfort.

Finally, combining the CWI and SWTCI tools can significantly affect the operational urban project. Indeed, the first tool (CWI) can identify the lowest scores of pedestrian facilities and thermal comfort at the neighbourhood microscale. In comparison, the second tool (SWTCI) will enhance these scores according to standard guidelines. Thus, associating these two methods is a new revolutionary approach that meets the prerogatives of a comprehensive sustainable project.

6.2 Research contributions

This thesis makes research contributions at different levels. The current section summarizes these contributions during various stages of PhD dissertation

6.2.1 The Combination of Pedestrian Comfort Facilities and Thermal Comfort

This innovative method involved an extensive literature review in selecting the most significant factors for pedestrian comfort. Few studies combined walkability with thermal

comfort. To complement the current literature by considering PET in the walkability measurement. Thus, new assessment tools are proposed, the CWI was and SWTCI at two major urban scales, the neighbourhood microscale and the street level. These tools are based on the PLOS system, and every model involved suitable techniques (questionnaire survey, observation, in situ measurement) for the practical scale. Twenty-one (21) pedestrian comfort facilities, besides PET, were selected, which provides a wide range of indicators suitable for all users (e.g. older adults, children, people with physical disabilities).

Considering PET assessment, two different methods have been used. The first concerned the neighbourhood micro-scale (CWI), and the second concerned the street level (SWTCI). Using the questionnaire survey allowed having PET for both measurement tools. In comparison, the scores of PET have been related to people thermal perception within the Mediterranean climate. For example, score 1, the perfect score, is related to neutral thermal sensation, while 0.5 and 0.25 reflect a slightly warm and warm thermal sensation. In contrast, the score 0 shows a hot or very hot thermal sensation.

6.2.2 Assessment of outdoor thermal comfort (PET)

At this stage, the PET assessment required a suitable method on both scales. Thus, Rayman software met the desired objectives since it was used in different climate zones and outdoor environments. The CWI considered three climatic variables (air temperature, wind velocity and relative humidity) used as input data for the PET assessment on two representative summer days from 8 am to 8 pm. This informed choice allowed analyzing the significant effect of PET on CWI.

The street scale involved in-situ measurements, Envi-met and Rayman models. Indeed Envi-met allowed having four calibrated data (air temperature, wind velocity and relative humidity and T_{mt}). This process, approved by several climate research, helped to reach more accurate PET results. In addition, SWTCI was measured from 8 am to 8 pm according to the PET computing hours. Which significantly emphasized the effect of PET on walking rates.

6.2.3 Accurate measurement tools

The CWI and SWTCI have been applied and validated in Annaba City, characterized by the Csa climate. The CWI was carried out in three neighbourhoods, characterized by different urban morphologies, street length, urban density, building's high, street hierarchy, street width, standard sidewalks, street length, vegetative species, and distribution.

It is worthy to note that applying these tools allowed having a new vision of considering pedestrian comfort facilities and PET within a quantitative approach. Every walkability indicator was based on coefficients and scores within objective assessments. Indeed, the results at the neighbourhood micro-scale highlighted a significant difference depending on the pedestrian facilities conditions and the thermal comfort range. The results also emphasized relevant variance in the selected streets, regulated by street conditions and PET comfort range concerning the street level. The recorded variances based on the validated process can only confirm the reliability and accuracy of the developed tools.

6.2.4 New assessment tools for operational urbanism

This thesis combined two sustainable fields of research, walkability and thermal comfort. The CWI and SWTCI allowed measuring walking rates according to thermal sensation, human energy balance, and stimulating activity, which underline the tools' reliability because these parameters are crucial for both fields. Every measurement tool is defined according to categories. Accordingly, five (5) classes were organized from A to F by providing the significance of each score. For example, Class A (80%–100%) defines the highest comfort quality scores (very pleasant), which confirm many pedestrian comfort facilities.

In contrast, Class E (1%–19%) reflects the Lowest comfort quality (unpleasant). Moreover, Class F (0%) highlighted the total absence of standard pedestrian facilities. Furthermore, the F category, which reflects (0%), highlighted the complete absence of common pedestrian facilities.

Applying these measurement tools help municipalities, designers, architects, urban planners to evaluate the current conditions of neighbourhoods and streets. Moreover, combining these measurement tools is an innovative approach that allows a comprehensive operational

urban project. This association provides a link between two complementary urban scales enabling the evaluation of pedestrian comfort.

These innovative methods can improve streets by identifying low indicators and proposing improvements, transforming streets and neighbourhoods into ideal walkable areas. The CWI and SWTCI are suitable for several neighbourhoods and streets. Accordingly, they could be involved within sustainable urban strategies.

The SWTCI includes a perspective guide to give enlightened decisions supports for the professional of space and environment by improving the current conditions of streets and neighbourhoods for a comfortable walking experience. This guide is based on a wide range of pedestrian comfort facilities (21), including vegetation (e.g., landscaping and trees, parks and playing area), sidewalk conditions (e.g., sidewalks on both sides, Footpath pavement, Footpath width), besides thermal comfort. The SWTCI is easy to use and understand. It provides an accurate evaluation for a wide range of walkability comfort indicators, allowing a complete diagnostic of the existing streets. By following the STWCI, the streets' improvements meet the standard. Some indicators have a dual effect that meets thermal comfort and pedestrian facilities (landscaping and trees, footpath material). Indeed optimizing the standard trees numbers and/or footpath material improves thermal comfort.

Further, this tool helps architects, urban designers and municipalities, to strengthen walkability comfort. That can effectively and efficiently promote the existing environments. Moreover, these tools offer a new sustainable vision of the urban area.

6.3 Limitations

Walkability and thermal comfort are two significant research domains. This thesis is relevant and innovative because it associated two original concepts within a quantitative method. This research focused on specific aims and objectives to provide a straightforward and extensive process. Thus, the research study excluded some aspects, which can be explained in the following.

1. Some methods were not considered because they focused on compiling data associated with a trip level, including a lack of information regarding tools assessment and application.
2. The PET scores were based on the people's perception of Tel Aviv city, characterized by the Mediterranean climate (same climate in Annaba). However, it could be interesting to have the citizen's thermal perception in Annaba. It is worthy of informing that measuring the PET comfort range has already been completed, but it is not the purpose of this study. We can confirm the similarities of the PET comfort range in the two cities (Annaba and TelAviv).
3. In this study, we just average the weight of the PET indicator. Indeed it was calculated based on the PLOS system. Future researches can follow more details by using the Supervisory formula approach (SFA) and the Structural equation modelling (SEM). To estimate the weight and validate them.
4. This study used the observation technique to quantify the coefficients of pedestrian facilities. Future researchers can also use this technique to quantify people's numbers and correlate them with PET measurements and thermal perception.
5. Other methodological limits consist of considering the (T_{mrt}) in the PET assessment at the neighbourhood micro scale.
6. . This study used the people's preferences in calculating the scores of walkability design factors and thermal comfort. Future studies can include pedestrians' sensitive and cultural dimensions in the estimation of walkability indicator's weight. Indeed, people's evaluation depends on the existing conditions. For example, in medieval cities, sidewalks on both sides can be obsolete because the street is tiny, and they don't need sidewalks on both sides.
7. By selecting a wide range of pedestrian comfort facilities, this thesis aimed to ensure comfortable walking for all users, besides developing assessment tools, which can be used in a different urban context. However, some pedestrian facilities, such as Mid-block crossings, Pedestrian signals, Markings (crosswalks) are not adequate for tiny and narrow streets.
9. The CWI is an innovative tool highlighting the correlation between pedestrian facilities and thermal comfort at the micro-scale neighbourhood. However, this dynamic method

has to be adjusted to other climates because the thermal comfort range varies from cold to hot climates. In comparison, the walk score is considered universal. However, it is only based on three factors. Moreover, the walk score is not taking into account pedestrian comfort. Finally, performing the CWI by exploring additional requirements such as microclimate measurement and shade. Besides, testing the UTCI index may provide an interesting alternative on walkability assessment and offer a further comparative method analysis.

10 Despite the novelty of the proposed method (CWI and SWTCI), there are some limitations, such as the absence of some comfort indicators (e.g., drinking fountains, tactile pavements, elevators next to a sky-bridge) considering their rareness in the selected area, besides the lack of building's characteristics (e.g., materials, colours). Thus, combining these factors in people's perceptions and analyzing the vegetation and footpath material effects on thermal comfort could be an added value for the SWTCI. In addition, using the fisheye technique can facilitate the quantitative interpretation of results. Improving the SWTCI tool for each type of street, besides comparing different cities with different climates, could be an interesting topic for future research. In addition, further studies can use similar methodologies to develop user-friendly software for the SWTCI estimation.

6.4 Perspectives for future researches

This thesis concludes with perspectives for future research in the light of additional questions posed during the investigations. Walkability and outdoor thermal comfort are in perpetual development. Alternative methods, tools and databases are expected to ensure more accuracy soon. Sustainable strategies highlighted the importance of promoting walkability and reducing car use. Thus, the usefulness of developing alternative methods to optimize pedestrian comfort and improve the walking experience. Applying the CWI and SWTCI in the Cold climate will positively impact sustainable urban planning for a hot and cold environment.

Considering the UTCI index instead of PET is an interesting perspective for future research. Indeed, the UTCI and PET have a closed comfort range within the various climates. However, the difference comprises the required metabolism of physical activity. The UTCI used 135 W/m² as reference activity, while PET used 80 W/ m² as standard stimulating activity.

Furthermore, developing an accurate design guide for the street, including climate typology, constitutes an excellent alternative for sustainable urban strategies. Indeed, this accurate guide can measure the walkability comfort in different climates and different urban environments. It will specify each urban climate zone according to standards, modelling and people's perceptions. This perspective is relevant for various research domains, including urban planning, smart cities, transport and green mobility, and health. In addition, Future research can include sensitivity studies consisting of plotting the alteration of one or many variables vs a controlled variable. This future perspective is helpful within the ponderation of PET weight

Climate change and heat islands have a significant impact on outdoor activities. Indeed, projected increasing gases provided changes in minimum/maximum temperatures, evapotranspiration, and precipitation. That can have a crucial effect on walkability rates. Thus, future perspectives can take into consideration these changes in walkability assessment. However, the CWI and SWTCI could be performed to adapt to climate changes.

Finally, the current situation resulting from the COVID-19 has emphasized the relevance and need of physical activities, especially walkability. Several countries in the world allow outdoor activities for a few hours, which do these practices necessary for citizen health. This thesis method and results can help the community choose suitable hours for walking. In addition, using accurate assessment tools that combine pedestrian comfort facilities and thermal comfort is a new form of conceptualizing cities, neighbourhoods, and streets, raising further research questions to be investigated.

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Appendix A The pedestrian comfort facilities standards

Sources Asadi-Shekari et al. (2019, 2014), Ellen Vanderslice (1998), and Centre (n.d.)

Pedestrian comfort facilities	Standards
Slower traffic speed	<i>30km /H based on the street standard.</i>
Buffer and barriers (curb and furnishing zone)	<ul style="list-style-type: none"> ✓ <i>Curb standard: the lowest width of curb is equal to 0.15m, the minimal high is equivalent to 0.10-0.15m</i> ✓ <i>2. Furnishing zone: the lowest acceptable width is 1.2m; however, the Interval (1.8m-2.4m) is recommended.</i>
Fewer traffic lanes,	✓ <i>Standard 2 lanes.</i>
Mid-block crossing	<ul style="list-style-type: none"> ✓ <i>1. Crosswalk number is changing, but not farther apart 60-90m, besides not contiguous than 45m and does not ban crossing further than 120m.</i> ✓ <i>2. The representative width of the mid-block crossing is 3 m. However, if the sidewalk is more extended than 3.7 m, the crosswalk should be larger than the width.</i>
Landscape and trees	<ul style="list-style-type: none"> ✓ <i>Trees Limb must have a clear vertical high of a minimum of 2.4 m (1)</i> ✓ <i>Trees must be distant from intersections with a minimum of 7.6 m (2)</i> ✓ <i>Trees interval must not exceed 9 m to ensure an extended trees canopy.</i> ✓ <i>Trees must be implanted on both sides of the sidewalk</i>
Furniture (trash receptacles)	<ul style="list-style-type: none"> ✓ <i>It must be in the furnishing zone within 0.9 m wide or more extensive.</i> ✓ <i>It must be far from the intersection with 9m of distance.</i> ✓ <i>A distance of 0.6m, at least from the curb border, should be respected.</i> ✓ <i>One receptacle should be provided in each playground, which has to be near benches.</i> ✓ <i>It must have at least 1.2 m clear out concerning bus facilities.</i> ✓ <i>It must be placed every 200-400 m.</i>
<i>Footpath pavement</i>	<ul style="list-style-type: none"> ✓ <i>It must be solid, anti-slip, not rough, and extended.</i> ✓ <i>The area of discontinuities should not be more than 1.25 cm; besides, the thickness differences must be including 0.6-1.25</i>
Marking (crosswalk)	<p><i>The first type (Ladder or longitudinal)</i></p> <ul style="list-style-type: none"> ✓ <i>The minimal width of a crosswalk is 3 m, but the suggested width is 5 m</i> ✓ <i>The strips interval is 0.3-1.5 m</i> ✓ <i>The width of the bands is between 0.3-0.6m</i> <p><i>The second type (Parallel or standard transverse)</i></p> <ul style="list-style-type: none"> ✓ <i>The minimal crosswalk width is 1.9m, but the suggested width is between 3-4.5 m</i> ✓ <i>The width of the two bands is 0.15-0.30m</i>
Sidewalk on both sides	✓ <i>Every side of the street must have a sidewalk.</i>
Width of footpath	<i>The footpath zone must be at least 1.5 m. However, the preferred width is between 1.8m-2.4m</i>
Slope	<i>The sidewalk slope $\leq 2\%$</i>
Lighting	<ul style="list-style-type: none"> ✓ <i>Sufficient light must be furnished.</i> ✓ <i>The pedestrian dimension is relevant for providing lighting.</i> ✓ <i>The light pole must be based at least 0.9 m from the curb beside any other approachable structure (e.g., shelter).</i> ✓ <i>The lighting fixtures with full-cut off must provide a descended light in the streets.</i> <p><i>The light pole interval must be 9 m maximum to ensure sufficient light.</i></p>

Continued Pedestrian comfort facilities	Standards
Ramp	<p><i>A pedestrian surface characterised by a running slope superior to 5%</i></p> <ul style="list-style-type: none"> ✓ <i>Maximal value of the slope is 8.3%</i> ✓ <i>The minimal width is 1.2m</i> ✓ <i>An appropriate handrail must be furnished.</i>
Park and space for playing	<ul style="list-style-type: none"> ✓ <i>Parks and the public area must be effortlessly accessible on foot or by bike for the user's categories (e.g., people with different abilities besides children and alder).</i> ✓ <i>Parks and public spaces require to be safe, accessible, and age-friendly.</i>
Social space (café)	<ul style="list-style-type: none"> ✓ <i>They should be located every 200-400 m</i>
Benches and seating area	<ul style="list-style-type: none"> ✓ <i>They must be provided in the frontage zone.</i> ✓ <i>They must be implanted with a minimal distance of 0.6m from the curb.</i> ✓ <i>They must be implanted with a minimal distance of 9m from the intersection.</i> ✓ <i>They must be furnished at all bus stops.</i> ✓ <i>They should be implanted every 200-400 m.</i> ✓ <i>An area of 1.2 m should be given at the end of the seats to allow strollers and wheelchairs station.</i> ✓ <i>Every seat must be furnished with a minimal distance of 0.6 m from the pedestrian traffic roads.</i> ✓ <i>A distance of 1.5 m should be respected between the seat and any immobile furniture such as a drinking fountain, trash receptacle or signpost.</i>
Toilet	<ul style="list-style-type: none"> ✓ <i>The public toilet must be implanted close to the bus stop and at each Rapid Transit Station. Besides being adjoining to parks and playing area.</i> ✓ <i>Toilet interval implementation must be every 500- 800m.</i> ✓ <i>For wheelchair users, a minimal distance of 1.7*1.8 m should be respected.</i>
Pedestrian signal	<ul style="list-style-type: none"> ✓ <i>Reachable pedestrian signals should have an interval of 3m at a crossing besides respecting a distance of 1.5 m from other signals (1)</i> ✓ <i>The pedestrian signal must be implanted no closer than 0.75m and with a maximal distance of 3m from the curb (2)</i> ✓ <i>It must be far less than 1.5 m from the crosswalk (3)</i> ✓ <i>An appropriate countdown must be furnished (4)</i> ✓ <i>People with disabilities (wheelchair user) must be able to achieve the button (5)</i> ✓ <i>An audio signal is necessary (6)</i>
Shorter crossing distance (curb extension)	<ul style="list-style-type: none"> ✓ <i>Curb extension reduces the crossing distance, furnishes an additional area to the corner, and permits pedestrians' visibility before crossing.</i> ✓ <i>They should be at any mid-block crossing or marked crosswalk defined by a parking lane (where the curb could be extended).</i> ✓ <i>They are the favoured elements for corner except in extenuating design consideration (e.g., turning radius of the design vehicle).</i> ✓ <i>The curb extension could comprise transit stops, which can omit buses need to pull out of the travel lane for loading and unloading pass.</i>

Appendix B Scores calculation, Source Asadi-Shekari et al. (2019, 2015, 2014, 2013b)

Facilities	scores
Slower traffic speed	$S = \begin{cases} =1 & \text{if the speed of 30km/h (pedestrian zone) is respected} \\ =0 & \text{if the of 30km/h is not mentioned and respected.} \end{cases}$
Buffer and barriers (curb and furnishing zone)	$C = \text{Number of standard curb ramps}$ $N = \text{Total number of curb ramps the street needs}$ $P = C/N$ $S = \begin{cases} = 1 & \text{if } P \geq 1 \\ = P & \text{if } P < 1 \\ = 0 & \text{if the curbs are not required} \end{cases}$
Fewer traffic lanes,	$S = \begin{cases} = 0 & \text{if } N^{\circ} \text{ of lanes } > 2 \\ = 1 & \text{if } N^{\circ} \text{ of lanes } \leq 2 \end{cases}$
Mid-block crossing	$S = \begin{cases} = \sum P_i / \text{The entire number of sections with an extend over 120m} \\ = 0 & \text{if, the whole extend of the street, is under 120m and } c_i = 0 \\ P_i = \begin{cases} = 1 & \text{if } P_{ci} \geq 1 \\ = P_{ci} & \text{if } P_{ci} < 1 \end{cases} \\ P_{ci} = c_i / n_i \\ i = 1, 2, 3, \dots, k \text{ (Various segments of streets between crossroads greater than 120m)} \\ c_i = \text{Numeral of standard mid-block crossing in segment } i \\ n_i = \text{extend of trees in segment} / 120. \end{cases}$
Landscape and trees	$D = \text{Interval of the distance between trees (m)}$ $C = \begin{cases} = \text{Extend of a street with trees - entire extend of crossroads and their considered standard} \\ \text{restrictions} / D \text{ If } D > 9 \\ = \text{Extend of a street with trees - entire extend of crossroads and their considered standard} \\ \text{restrictions if } D \leq 9 \end{cases}$ $N = \text{Extend of the street (both sides) - entire extend of crossroads and their considered standard restrictions}$ $P1 = C/N$ <p>If D is varying within different segments of the street</p> $C_i = \begin{cases} = \text{Extend of a street with trees in segment } i - \text{entire extend of crossroads and their considered standard} \\ \text{restrictions} / D \text{ If } D > 9 \\ = \text{Extend of street with trees in segment } i - \text{complete distance of intersections and their considered} \\ \text{standard restrictions if } D \leq 9 \end{cases}$ $i = 1, 2, 3, \dots, k \text{ (Various segments of streets with a different interval of trees)}$ $N_i = \text{Extend of a street (in segment } i) - \text{considered standard restrictions (m)}$ $P1 = \sum_{i=1}^k C_i / \sum_{i=1}^k N_i$ $F = C - \text{Extend of a street that does not have a clear vertical height}$ $N = \text{Extend of the street (both sides) - entire extend of intersections and their considered standard restrictions}$ $P2 = F/N$ <p>If D is varying in different segments of the street.</p> $F_i = C_i - \text{Extend of a street that does not have clear vertical height in section } i$ $N_i = \text{Extend of the street (section } i) - \text{considered standard restrictions (m)}$ $P2 = \sum_{i=1}^k F_i / \sum_{i=1}^k N_i$ $N_i = \text{Number of crossroads with considered standard restrictions for trees.}$ $I = \text{Number of the hole crossroads}$ $P3 = NI/I$ $S = (P1 + P2 + P3) / 3$
Furniture (trash receptacles)	$C = \text{Extend of a street with guideline trash receptacle area + their support distance (m)}$ $N = \text{Extend of street (both sides) (m)}$ $S = C/N$
Footpath pavement	$W = \text{Width of footpath (m)}$ $C = \text{Area of standard pavement (m}^2)$ $N = \begin{cases} = \text{Extend of street (both sides) - extend of crossroads} \times 1.8 & \text{if } W < 1.80 \text{ m} \\ = \text{Extend of a street (both sides) - extend of crossroads} \times W & \text{if } W \geq 1.80 \text{ m} \end{cases}$ $S = C/N$ <p>If W is varying in a different segment of street</p> $W_i = \text{Width of footpath in segment } i$ $i = 1, 2, 3, \dots, k \text{ (various segments of a street with different width of the footpath)}$ $C_i = \text{Area of guideline pavement in segment } i \text{ (m}^2)$ $N_i = \begin{cases} = \text{Extend of a street (in segment } i) \times 1.8 & \text{if } W_i < 1.80 \text{ m} \\ = \text{Extend of a street (in segment } i) \times W_i & \text{if } W_i \geq 1.80 \text{ m} \end{cases}$ $P_{Ci} = C_i / N_i$ $L_i = \text{Extend of street in segment } i \text{ (m)}$ $S = \sum_{i=1}^k P_{Ci} \times L_i / (\text{Extend of a street (both sides) - extend of crossroads}).$

Continued Facilities	scores
Marking (crosswalk)	<p>C = Number of guideline crosswalk markings N = Number of crosswalks that street requires (mid-block and cross walk at intersections) $P = C/N$</p> $S = \begin{cases} = 1 & \text{If } P \geq 1 \\ = P & \text{If } P < 1 \end{cases}$
Sidewalk on bothsides	$a = \begin{cases} = 1 & \text{if } P \geq 1 \\ = P & \text{if } P < 1 \end{cases}$ $P1 = l1/N1$ $l1$ = Extend of sidewalk in one side (m) $N1$ = Extend of street – Extend of crossroads in one side (m) $m = \begin{cases} = 1 & \text{if } P2 \geq 1 \\ = P2 & \text{if } P2 < 1 \end{cases}$ $P2 = l2/N2$ $l2$ = Extend of footpath in opposite side (m) $N2$ = Extend of street – Extend of crossroads in other side (m) $S = (a + m)/2$
Width of footpath	W = Width of sidewalk (m) C = Area of guideline sidewalk (m ²) $N = \begin{cases} = (\text{Extend of street (both sides)} - \text{extend of crossroads}) \times 1.8 & \text{if } W < 1.80 \text{ m} \\ = (\text{Extend of a street (both sides)} - \text{extend of crossroads}) \times W & \text{if } W \geq 1.80 \text{ m} \end{cases}$ $S = C/N$ If W is varying in a different segment of street Wi = Width of sidewalk in segment i $i = 1, 2, 3, \dots, k$ (various segments of street with different width of the sidewalk) Ci = Area of guideline sidewalk in segment i (m ²) $Ni = \begin{cases} = (\text{Extend of a street (in segment } i) \times 1.8 & \text{if } Wi < 1.80 \text{ m} \\ = (\text{Extend of a street (in segment } i) \times Wi & \text{if } Wi \geq 1.80 \text{ m} \end{cases}$ $PCi = Ci/Ni$ Li = Extend of street in segment i (m) $S = \sum_{i=1}^k PCi \times Li / (\text{Extend of a street (both sides)} - \text{extend of crossroads}).$
Slope	C = Area of footpath with the guideline slope (m ²) $N = \begin{cases} = (\text{Extend of street (both sides)} - \text{extend of crossroads}) \times 1.8 & \text{if } W < 1.80 \text{ m} \\ = (\text{Extend of a street (both sides)} - \text{extend of crossroads}) \times W & \text{if } W \geq 1.80 \text{ m} \end{cases}$ W = Width of the footpath (m) $S = C/N$ If W is varying in a different segment of street Wi = Width of footpath in segment i $i = 1, 2, 3, \dots, k$ (various segments of street with different width of the sidewalk) Ci = Area of the footpath with guideline slope in segment i (m ²) $Ni = \begin{cases} = (\text{Extend of a street (in segment } i) \times 1.8 & \text{if } Wi < 1.80 \text{ m} \\ = (\text{Extend of a street (in segment } i) \times Wi & \text{if } Wi \geq 1.80 \text{ m} \end{cases}$ $DCi = Ci/Ni$ Li = Extend of footpath (in segment i) (m) $S = \sum_{i=1}^k DCi \times Li / (\text{Extend of a street (both sides)} - \text{extend of crossroads}).$
Lighting	D = interval of distance between light poles (m) $C = \begin{cases} = (\text{Extend of street with pedestrian lighting} - \text{entire extend of crossroads}) \times 9 / D & \text{if } D > 9\text{m} \\ = \text{Extend of street with pedestrian lighting} - \text{entire extend of crossroads} & \text{if } D \leq 9\text{m}. \end{cases}$ N = (Extend of street (both sides) – crossroads extend) (m) $P = C/N$ $S = 1$ if $P \geq 1$ $= P$ if $P < 1$ If D is varying in a different segment of street $S = \sum_{i=1}^k Ci / \sum_{i=1}^k Ni$ $i = 1, 2, 3, \dots, k$ (various segments of street with different Interval of distances between light poles) $C = \begin{cases} = (\text{Extend of street with pedestrian lighting in segment } i) \times 9 / D & \text{if } D > 9\text{m} \\ = (\text{Extend of street with pedestrian lighting in segment } i) & \text{if } D \leq 9\text{m}. \end{cases}$ Ni = Extend of street in segment i (m)

ContinuedFacilities	Scores
<i>Ramp</i>	<p>C = Number of guideline ramps N = Number of ramps that street requires $P = C/N$ $S \begin{cases} = 1 & \text{if } P \geq 1 \\ = P & \text{if } P < 1 \end{cases}$ 1 if the street does not require ramp.</p>
<i>Park and space for playing</i>	<p>$S \begin{cases} = 1 & \text{If there are a park and space for playing} \\ = 0 & \text{If there is no park and space for playing} \end{cases}$</p>
<i>Social space (café)</i>	<p>C = Extend of a street with social spaces + their support distance (m) N = Extend of a street (in both sides) (m) $S = C/N$</p>
<i>Bench and seating area</i>	<p>C = Extend of a street with guideline seating area + their support distance (m) N = Extend of a street (in both sides) (m) $S = C/N$</p>
<i>Toilet</i>	<p>C = Extend of a street with guideline toilets + their support distance (m) N = Extend of a street (m) $S = C/N$</p>
<i>Pedestrian signal</i>	<p>$SPI \begin{cases} = 1 & \text{if } P1 \geq 1 \\ = P1 & P1 < 1 \end{cases}$ $P1 = SP/N$ SP = Signals with first, second and third quality N = Entire number of signals that street requires. $CPI \begin{cases} = 1 & \text{if } P2 \geq 1 \\ = P1 & P2 < 1 \end{cases}$ $P2 = C/N$ C = Signals with fourth quality $WPI \begin{cases} = 1 & \text{if } P3 \geq 1 \\ = P1 & P3 < 1 \end{cases}$ $P3 = W/N$ W = Signals with fifth quality $API \begin{cases} = 1 & \text{if } P4 \geq 1 \\ = P4 & \text{if } P4 < 1 \end{cases}$ $P4 = A/N$ A = Signals with sixth quality $S = (SPI + CPI + WPI + API)/4$ $S = 0$ If there is no signal</p>
<i>Shorter crossing distance(curb extension)</i>	<p>$P = C/N$ C = Number of guidelines curb extensions N = Entire number of curb extensions that street requires $S \begin{cases} = 1 & \text{if } P \geq 1 \\ = P & \text{if } P < 1 \\ = 0 & \text{if there is no point in requiring curb extension and there is no footpath.} \end{cases}$</p>

Appendix C Improving scores

We can improve the pedestrians' comfort condition by analyzing the existing variable's qualities with standards (See Table 17 and Appendices A, B). The comfort indicators could achieve the ideal score of 1 by performing current scores.

Example 1 Developing pedestrian facilities scores at street 1

1.1 Landscape and trees (current score $S=0$, improved score $S_1=0.62$ with trees interval distance of 15 m, $S_2= 1$ with trees interval distance of 9 m).

Where:

$$C \begin{cases} (Extend\ of\ a\ street\ with\ trees-entire\ extend\ of\ crossroads\ and\ their\ considered\ standard\ restrictions) \times 9/D \text{ If } D > 9 \\ (Extend\ of\ a\ street\ with\ trees-entire\ extend\ of\ crossroads\ and\ their\ considered\ standard\ restrictions) /D \text{ If } D \leq 9 \end{cases}$$

$N=Extend\ of\ the\ street\ (both\ sides)-entire\ extend\ of\ crossroads\ and\ their\ considered\ standard\ restrictions)$

$F = C - Extend\ of\ a\ street\ that\ does\ not\ have\ a\ clear\ vertical\ height$

$NI = Number\ of\ crossroads\ with\ considered\ standard\ restrictions\ for\ trees).$

$I = Number\ of\ the\ hole\ crossroads.$

$P1=C/N$

$P2 = F/N$

$P3 = NI/I$

$S=(P1+P2+P3)/3$

1. D=15

$C = ((515 \times 2) - 72) \times 9/15 = 574.8$, $N = (515 \times 2) - 72 = 958$, $P1 = 574.8/958 = 0.60$, $F = 958 - 0 = 958$,

$P2 = 974.8/958 = 0.60$, $NI = 8$, $I = 12$, $P3 = 8/12 = 0.66$; so, $S_1 = (0.60 + 0.60 + 0.66)/3 = 0.62$

2. D=9

We can have the ideal score of 1 ($S_2=1$) of landscape and trees by considering the interval distance between trees 9m instead of 15 m, besides eliminating the standard length at two intersections.

1.2 Benches and seating area

C = Extend of a street with guideline seating area + their support distance (m)

N = Extend of a street (in both sides) (m)

$S = C/N$

1. The minimal required distance between benches ($D=200m$)

$$(C= 500+200=700, N= (515 \times 2) =1030, S=700/1030=0.67)$$

2. It is also possible to achieve the ideal score of 1 by considering the benches' furniture along 330m (Which included 200-400 m).

By improving only these two factors scores and maintaining PET scores, the SWTCI (at Street1) increases from 33% (category D) to 42% (category C). That allows a better comfort level.

Example 2 Developing pedestrian facilities scores at Street 3

Street 3 recorded the lowest scores. However, developing some pedestrian facilities scores such as landscaping and trees, footpath pavement can enhance the scores and improve the walking experience.

2.1 Width of the footpath (current score $S= 0$, improved score $S1'0.83=$ with $W=1.5$ m, $S2'= 1$ with $W=2.4$ m or 1.80 m).

Where:

W = Width of sidewalk (m)

C = Area of guideline sidewalk (m²)

$$N \begin{cases} = (\text{Extend of street (both sides)} - \text{extend of crossroads}) 1.8 \text{ if } W < 1.80 \text{ m} \\ = (\text{Extend of a street (both sides)} - \text{extend of crossroads}) W \text{ if } W \geq 1.80 \text{ m} \end{cases}$$

$$S = C/N$$

1. W=1.50

$$C = (299.68-5) \times 1.50, N = (299.68-5) \times 1.80, S = C/N, S_2' = 442.02/530.42 = 0.83$$

2. W=2.40 m or 1.80m

$$C = (299.68-5) \times 2.40, N = (299.68-5) \times 2.40, S = C/N, S_2' = 707.23/707.23 = 1.$$

Combining footpath pavement and width of the footpath could be an excellent choice for enhancing the pedestrian comfort facilities scores. In this case, it is easy to enhance the footpath pavement because it is not existing. So it is possible to reach the score (1) directly.

Where

W = Width of footpath (m)

C = Area of standard pavement (m²)

$$N \begin{cases} = (\text{Extend of street (both sides)} - \text{extend of crossroads}) 1.8 \text{ if } W < 1.80 \text{ m} \\ = (\text{Extend of a street (both sides)} - \text{extend of crossroads}) W \text{ if } W \geq 1.80 \text{ m} \end{cases}$$

$$S = C/N$$

1. W=2.40 m or 1.80m

$$C = (299.68-5) \times 2.40, N = (299.68-5) \times 2.40, S = C/N, S_2' = 707.23/707.23 = 1.$$

However, proposing a specific type of footpath pavement material such as tiles with a lighter is an interesting alternative to enhance thermal comfort.

2.2 Lighting (Current score $S = 0$, improved score $S_1'' = 0.64$ with $D = 14$ m, $S_2'' = 1$ with $D = 9$ m).

Where:

D = interval of distance between light poles (m)

$$C \begin{cases} = (\text{Extend of street with pedestrian lighting} - \text{entire extend of crossroads}) \times 9 / D \text{ if } D > 9 \text{ m} \\ = (\text{Extend of street with pedestrian lighting} - \text{entire extend of crossroads}) \text{ if } D \leq 9 \text{ m.} \end{cases}$$

N = (Extend of street (both sides) - crossroads extend) (m)

$$P = C/N$$

$$S \begin{cases} = 1 & \text{if } P \geq 1 \\ = P & \text{if } P < 1 \end{cases}$$

1. $D=14$ m

$$C = (299.68 - 5 \times 9) / 14, N = (299.68 - 5), P = C/N, P = 0.63$$

2. $D=9$

$$C = (299.68 - 5 \times 9) / 9, N = (299.68 - 5), P = C/N, P = 1$$

Appendix D

Appendix D Questionnaire survey

Date

Are you a man	<input type="checkbox"/>	Woman	<input type="checkbox"/>
How old are you	<input type="checkbox"/>		
18-24 years old	<input type="checkbox"/>		
25-34 years old	<input type="checkbox"/>		
35-44 years old	<input type="checkbox"/>		
45-54 years old	<input type="checkbox"/>		
55-64 years old	<input type="checkbox"/>		
65-74 years old	<input type="checkbox"/>		
Older than 75 years old	<input type="checkbox"/>		

PART A General Importance

Please rank the importance of the following walking indicators by selecting one number from 1 to 5 (1 not very important, 5 very important)

Indictors	1	2	3	4	5
Slowertraffic speed					
Buffer and barriers (curb and furnishing zone)					
Fewertraffyclane					
Shorter crossing distance(curb extension)					
Mid-block crossing					
Social space(café)					
Landscape and trees					
Furniture and facilities (trash receptacle)					
Footpath pavement					
Marking (crosswalk)					
Sidewalk on bothsides					
Width of footpath					
Standard driveway					
Lighting					
Slope					
Ramp					
toilet					
grad					
Pedestrian signal					
Bench and seating area					
Park and space for playing					
Shade/ Thermal comfort					

PART B *General estimation of each walkability indicator' status*

Please rank the status of the following walking indicators by selecting one number from 0 to 4 (0 awful, 5 good) in the following neighbourhoods

a. European center, b. Medina, c. El bouni

Indictors	0	1	2	3	4
Slowertraffic speed					
Buffer and barriers (curb and furnishing zone)					
Fewertraffyclane.					
Shorter crossing distance(curbs extension)					
Mid-block crossing					
Social space(café)					
Landscape and trees					
Furniture and facilities (trash receptacle)					
Footpath pavement					
Marking (crosswalk)					
Sidewalk on bothsides					
Width of footpath					
Standard driveway					
Lighting					
Slope					
Ramp					
toilet					
grad					
Pedestrian signal					
Bench and seating area					
Park and space for playing					
Shade/ Thermal comfort					

List of abbreviations

CWI: Comfort Walkability Index

SWTCI: Street Walkability and Thermal Comfort Index

S (i): Scores

C (i): coefficients

5Cs: Connected, Convenient, Comfortable, Convivial and Conspicuous

7 Cs: 5Cs+ Coexistence and Commitment

PLOS: Pedestrian Level of Service

LOS: Level of service

SWEAT-R: the Senior Walking Environmental Assessment Tool – Revised

GIS: Geographic informatic System

PEAT: The Path Environment Audit Tool

WSAF: The Walking Suitability Assessment Form

PIN3: Neighbourhood Audit Instrument

NEWS: The Neighbourhood Environment Walkability Survey

PEDS: The Pedestrian Environment Data Scan

NSAT: The Neighbourhood Sidewalk Assessment Tool

I-M: Irvine Minnesota Inventory

SPACES: Systematic Pedestrian and Cycling Environmental Scan

MAPS: Microscale Audit of Pedestrian Streetscapes

PSI: Pedestrian safety index

Pt: Perceived temperature

SET*: Standard Effective Temperature

OUT-SET*: outdoor variant of SET*

PMV: Predicted Mean Vote

UTCI: Universal Thermal Comfort Index

PET: Physiological Equivalent Temperature

Tmrt : Mean Radiant Temperature

Csa: Mediterranean Climate

TSV: Thermal Sensation Vote

List of tables

Tables	Pages
Table 1 The 5Cs and 7 Cs dimensions definition.....	14
Table 2 Pedestrian comfort facilities on street level.....	18/19
Table 3 Summary of previous walkability assessment tools	25/26
Table 4 Summary of operational indicators assessed by PLOS.....	27/28
Table 5 List of pedestrian comfort indicators appropriate for the neighbourhood micro scale.....	43 44
Table 6 Interpretation of CWI rating.....	44
Table 7 Thermal sensation and PET range for Tel Aviv (Csa) (Cohen et al., 2013; Lin and Matzarakis, 2008; Matzarakis et al., 1999).....	47 47
Table 8. PET scores according to thermal sensation and PET range in a Csa.....	49
Table 9 Pedestrian comfort facilities on street level.....	49
Table 10 SWTCI % interpretation.....	51
Table 11 Overview of PET calculations method in outdoor environments.....	55
Table 12 Thermal sensation and PET range for Tel Aviv (Csa climate) (Cohen et al., 2013; Lin and Matzarakis, 2008; Matzarakis et al., 1999; Potchter et al., 2018).....	59
Table 13 PET scores according to the Thermal sensation and PET range in Csa Climate (Labdaoui et al., 2021).....	59
Table 14 The characteristics of the selected streets.....	63
Table 15. Scores and coefficients of walkability comfort indicators in two selected areas.....	69 73
Table 16 PET scores according to the TSV scale in a Csa.....	73
Table 17 The scores and coefficients of street comfort indicators	80
Table 18 Microclimatic data and PET results using Envi-met and RayMan software...	82
Table 19 PET values and score results in the selected streets.	84
Table 20 SWTCI average and significance in the selected area	87
Table 21 Walkability indicators relevance on PET based on previous studies...	103/104

List of figures

Figures	Pages
Fig. 1. Conceptual framework of the literature review.	9
Fig .2. A simplified diagram for understanding the combination of walkability and thermal comfort	33
Fig. 3. Explicit summary thesis	37
Fig. 4. Explicit outline methods	41
Fig. 5. Conceptual framework of the comfort walkability index (CWI).	42
Fig. 6. Conceptual framework of the STWCI	48
Fig. 7. Main scopes for PLOS models at the street level (Asadi-Shekari et al., 2013)	52
Fig.9. Walk scores in main streets at Annaba city	60
Fig .10. Selected streets at Annaba city centre and El Bouni.	62
Fig.11. Location of selected streets at three distinct neighbourhoods	64
Fig. 12. Comparison of the pedestrian comfort indicators scores in the selected neighbourhoods	68
Fig. 13. Scores for pedestrian facilities and PET values in the Colonial Centre on two representative summer days	70
Fig. 14. Scores for pedestrian facilities and PET values in the Old Town on two representative summer days	70
Fig. 15. Scores for pedestrian facilities and PET values in El Bouni on two representative summer days	71
Fig. 16. Changes in PET values in the two selected areas on the two representative summer days	72
Fig. 17. Changes in CWI in the neighbourhoods on 18 July 2017	75
Fig. 18. Changes in CWI in the neighbourhoods on 8 August 2017	75
Fig. 19. Changes in CWI in the two neighbourhoods on the two representative summer days	76
Fig.20. Comparison between CWI and Walk Score® rates in the selected area	77
Fig. 21. Comparative analyses of PET results on three selected streets	85

Continued list of figures	Pages
Fig. 22. Comparative analysis of comfort indicator scores on street level.	86
Fig. 23. Street walkability Thermal Comfort Index at the selected streets	89
Fig. 24. Comparatives analysis of the Street Walkability Thermal Comfort Index on the selected streets	90
Fig. 25. CWI and SWTCI interactivity	107
