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Study of Flexibility Factors in Determining the Design of Ergonomic Urban Pedestrian Sidewalk Facilities

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ABSTRACT

Sidewalks play a crucial role in enhancing the comfort, safety, and accessibility of pedestrians. However, their design often neglects ergonomic principles, particularly in Makassar City. This study aims to determine ergonomic sidewalk heights using a local anthropometric approach based on knee-to-floor dimensions (LL) and allowance factors. Data were collected from 16 road segments in Makassar through observation, surveys, and statistical analysis. The results revealed that the existing sidewalk heights varied between 16–34 cm, with the highest interval at 28–30 cm (34%). While 96% comply with national standards (10–30 cm), they do not fully address user comfort. By applying allowance factors, the ergonomic sidewalk heights were determined as 11.93 cm (low allowance), 23.85 cm (medium allowance), and 35.78 cm (high allowance). These findings provide essential guidelines for adaptive sidewalk design, improving pedestrian comfort, accessibility, and safety, and are relevant for developing more inclusive urban infrastructure.

1. INTRODUCTION

Sidewalks are an important component of urban infrastructure that greatly affects the comfort, safety, and accessibility of pedestrians. However, in many cities experiencing rapid urbanization, especially in developing countries such as Indonesia, sidewalk designs often do not consider ergonomic principles, causing discomfort and increasing the risk of accidents [1, 2]. For example, in Makassar City, the lack of ergonomic considerations in sidewalk design has resulted in height variations that do not correspond to local anthropometric dimensions. Although national standards specify a sidewalk height range of 10–30 cm, these guidelines often ignore local anthropometric variations, resulting in designs that are not fully inclusive or comfortable for all users. In the context of sidewalk design, the aspect of clearance is often a concern to ensure that the sidewalk can accommodate the various needs of users. Designs that do not consider clearance factors can cause discomfort, increasing the risk of accidents [3], and reduce the ergonomic value of the sidewalk.

The flexibility factor in sidewalk design includes various elements, such as sidewalk width, distance between physical elements, and flexibility in accommodating user activities. In urban studies, this aspect becomes important because rapidly growing cities are faced with the challenges of population density, increased pedestrian activity, and the need for inclusive public spaces [4, 5]. Therefore, sidewalk design needs to consider ergonomic factors, including comfort, safety, and efficient use of space.

Ergonomics is the science that studies design for humans. It includes human understanding of work systems, principles, skills, data, and work methods in determining the design of the system to suit the fulfillment of individual needs, limitations, and skills [6].

Ergonomics in sidewalk design includes both physical and psychological considerations of users [7, 8]. For example, pedestrians need sidewalks that are not only wide enough to walk on, but also provide space to stop, rest, or interact socially [9]. In addition, ergonomic design must take into account the diversity of users, including people with disabilities [10], children, and the elderly.

In Indonesia, urban sidewalk design often faces challenges in terms of planning and implementation [11]. Many sidewalks in big cities are still far from international standards that prioritize comfort and accessibility, including sidewalks in Makassar City. This reflects the need for in-depth studies to understand the factors of relaxation that can improve the ergonomic value of sidewalks.

Based on the research results [12], which analyzing the comfort level of sidewalks as pedestrian facilities in Makassar City, the results of the study showed that the comfort level was high on segment 3 of Jalan Jenderal Sudirman, segment 2 of Jalan Andi Pangerang Pettarani, segment 2 of Jalan Jenderal Sudirman and segment 4 of Jalan Jenderal Sudirman. While the comfort level was low on segment 2 of Jalan Ujung Pandang, segment 1 of Jalan Jenderal Sudirman, Jalan Sungai Tangka, segment 1 of Jalan Andi Pangerang Pettarani, Jalan Somba Opu, and segment 1 of Jalan Ujung Pandang [12]. While the characteristics of users show that the largest pedestrian flow is 1.07 people/meter/minute, the largest pedestrian speed is 85.47 m/minute, the largest pedestrian density is 0.0129 org/m, and the largest pedestrian ratio is 0.0133 org/m^2. The average pedestrian travel time is 125 seconds per segment.

Figure 1. Sidewalk today

The sidewalks in Makassar City currently as seen in Figure 1 do not comply with the provisions set by the Public Works Department, especially with regard to the suitability of users according to the body posture of those who will use them [13]. The sidewalks of each area or road in the city have different heights, and what's worse is that on the same road, the sidewalks have different sizes at the beginning, middle, and end of the road.

Common problems in pedestrian sidewalk design, lack of attention to ergonomic values. Sidewalk designs that do not pay attention to ergonomic factors can cause fatigue, discomfort, and even injury to pedestrians [14]. One of them is the height of the sidewalk that does not match the conditions of users who do not pay attention to the aspect of individual user flexibility in Makassar City.

Previous studies have addressed sidewalk design from an ergonomic and accessibility perspective, but most have relied on generic anthropometric data that does not account for local variations. This study fills this gap by introducing the Ahmad Hanafie (AH) allowance factor, which adjusts sidewalk height based on local knee-to-floor (LL) dimensions. By integrating local anthropometric data, this study provides a more inclusive and adaptive approach to sidewalk design, ensuring that urban infrastructure meets the needs of diverse populations, including children, seniors, and people with disabilities.

The main objective of this study is to determine the ergonomic sidewalk height for Makassar City using a local anthropometric approach. These findings are expected to provide practical guidance for city planners and policy makers to create a more inclusive and pedestrian-friendly urban environment.

2. LITERATURE REVIEW

2.1 Definition of ergonomics and anthropometry

Ergonomics is a multidisciplinary science that aims to understand and optimize the interactions between humans and other system elements to improve comfort, safety, efficiency and performance [15, 16]. Ergonomics focuses on the adaptation of the work environment or public facilities to human needs, based on principles that cover three main domains: physical, cognitive, and organizational [17-19].

In the context of ergonomics, the anthropometric approach is one of the important foundations used to support designs that are appropriate to human needs and capabilities [20]. Anthropometry, which comes from the words "anthropos" (human) and "metron" (measure), is a science that focuses on measuring the dimensions of the human body [16]. This science plays an important role in the design of ergonomic products, facilities, and work systems. Along with the development of technology and urbanization, the need to create user-friendly designs is increasing. Anthropometry provides critical data that allows designers, engineers, and researchers to understand the dimensions of the human body in various conditions. The dimensions of the human body that are measured can include height, limb length, head circumference, hand reach, and joint movement angles. This data is not only important to support user comfort but also prevent the risk of injury and increase productivity.

In the application of anthropometric-based ergonomics, one of the main approaches is the design adjustment with human body percentile data. The 5th, 50th, and 95th percentiles are often used to represent variations in body dimensions in a particular population [21]. For example, the 5th percentile is used to accommodate individuals with the smallest body dimensions, while the 95th percentile is used for individuals with the largest body dimensions, but in the research that will be conducted it will be different because it will use the Ahmad Hanafie (AH) Allowance. This approach ensures that the majority of users can feel comfortable and safe when using a particular product or facility.

In addition, anthropometric variations based on geography, ethnicity, and age are important factors in designing ergonomic designs. The anthropometric data used must reflect the local population so that the design is relevant to the needs of users in a particular area. For example, the height of a sidewalk in a city must be adjusted to the knee-to-floor dimensions of the local population to ensure comfort and accessibility. The differences in human body dimensions in various regions of the world, such as Asia, Europe, and America, show that no single design can be applied universally without local adjustments.

Ergonomics-based design must take into account user anthropometric variations, such as height, stride length, ankle angle, and range of motion [17, 22]. These adjustments aim to reduce the risk of injury, increase movement efficiency, and create an optimal user experience. In the context of sidewalk planning, ergonomic principles emphasize the importance of understanding local needs to ensure the design can accommodate the diverse body dimensions of users [23].

Similar studies also highlight the importance of a comprehensive approach in integrating anthropometric data into infrastructure [24, 25]. The data should reflect local population variations and take into account external factors such as weather conditions, intensity of use, and physical activity levels. For example, adjusting the width of a sidewalk to the average human stride width can increase path efficiency by up to 25% under high traffic conditions.

The principles of physical ergonomics in sidewalk design also include the analysis of body posture when walking, which is directly related to the dimensions of the sidewalk surface [26]. The texture and slope of sidewalks should be designed to minimize muscle fatigue, especially for users who walk long distances. In addition, the presence of supporting elements such as guideways for the visually impaired and spaces for wheelchair users can strengthen the inclusiveness of sidewalk design, as recommended by the World Health Organization [27].

2.2 Application of ergonomics in public infrastructure

Ergonomic public infrastructure design involves a systemic approach that integrates human needs into the physical design of facilities, ensuring that each element supports user comfort, safety, and efficiency. For example, research by Giannoulaki and Christoforou [28] shows that sidewalks designed with local anthropometric dimensions in mind can improve pedestrian movement efficiency by up to 30% compared to sidewalks without ergonomic adjustments. These adjustments can also reduce conflicts between pedestrians and vehicles, creating a more harmonious environment in urban areas.

Ergonomics in sidewalk design also involves a detailed analysis of the physical workload experienced by users. In addition, studies have found that mismatching sidewalk heights with users' body dimensions can cause changes in walking patterns that increase the risk of falling or tripping [29].

Furthermore, the texture of the sidewalk surface is also a critical element in ergonomic design. The results of studies that have been conducted state that sidewalk surfaces designed with the right texture can reduce the risk of slipping by up to 40%, especially in wet conditions. This factor is very important in urban contexts with high rainfall levels.

2.3 Physical ergonomics in sidewalk design

Sidewalks are one of the most frequently used infrastructure elements in everyday life and have an important role in supporting the mobility of urban communities [30]. Physical ergonomic aspects in sidewalk design include height, width, surface texture, and slope angle. These parameters not only affect user comfort, but are also closely related to safety, especially in areas with high pedestrian density. These parameters must be adjusted to the characteristics of the local population to ensure user comfort and safety. For example, sidewalk heights that do not match the average body dimensions of local residents can cause fatigue and increase the risk of injury.

2.4 Implications of ergonomics on urban quality of life

Ergonomically designed sidewalks have a profound impact on individual comfort and the overall quality of life of communities. Studies have found that good sidewalks can increase people’s physical activity levels by up to 20%, which contributes to improved physical and mental health. Increased walking not only helps reduce the risk of chronic diseases such as obesity and heart disease, but also increases social interaction in public spaces, thereby strengthening social cohesion in communities.

In addition, ergonomic sidewalk infrastructure has the potential to improve the aesthetics of a city, sidewalks designed with texture, lighting, and green elements, such as trees and plants, in mind can create a more visually appealing environment. This not only improves the user experience but can also attract more economic activity, such as street vendors and sidewalk cafes, which ultimately increases the value of surrounding properties.

Even farther [1], ergonomic sidewalks also play an important role in supporting inclusive mobility. The World Health Organization (2017) also emphasizes the importance of sidewalk infrastructure that is accessible to all community groups to achieve equality in urban mobility.

2.5 Ergonomics standards and policies in public infrastructure

International organizations such as the World Health Organization (WHO) and the American Society of Civil Engineers (ASCE) have issued guidelines for ergonomic sidewalk design. For example, the WHO recommends that sidewalks should have a flat surface, a minimum width of 1.8 meters, and the height of the sidewalk is in the range of 10–15 cm and is free from physical obstacles to support the mobility of vulnerable groups [31]. However, these standards often do not consider local anthropometric characteristics, which can cause discomfort and reduce accessibility for users in various regions. This study overcomes these limitations by combining Ahmad Hanafie's (AH) allowance factor adjusted to the anthropometric characteristics of sidewalk users in Makassar City. This approach ensures that sidewalk designs not only meet international standards but can also improve comfort and safety for all users, including vulnerable groups such as people with disabilities and the elderly. In Indonesia, national standards related to sidewalk design are regulated by several important policies. According to "Law of the Republic of Indonesia No. 22 of 2009 concerning Traffic and Road Transportation," sidewalks are part of pedestrian facilities that must guarantee the safety and comfort of their users [32]. In addition, "Government Regulation (PP) Number 34 of 2006 concerning Roads" states that sidewalks must be designed to support connectivity between roads and provide adequate space for pedestrian mobility [33]. Furthermore, it was conveyed that the function of sidewalks according to the law includes aspects of safety, comfort, and accessibility for all users, including vulnerable groups such as the elderly and people with disabilities.

3. METHODOLOGY

The research methodology follows a structured process to ensure a systematic and reliable investigation of the study objectives. The summarized flow, as illustrated in Figure 2, outlines the key stages of the research, from problem identification to result interpretation. Below is a step-by-step explanation.

3.1 Research location

The location of the research conducted was 16 road sections, namely on the main road of Gowa - Makassar, Alauddin Street, Samata Street, Sam Ratulangi Street, Ahmad

Yani Street, Sudirman Street, Mappaodang Street, Andi Pettarani Street, Andi Tonro Street, Cenderawasi Street, Arief Rate Street, Urip Sumoharjo Street, Independence Pioneer Street, Batua Raya Street, Deng Sirua Street, Tallassa City Street are roads in the city of Makassar, South Sulawesi Province.

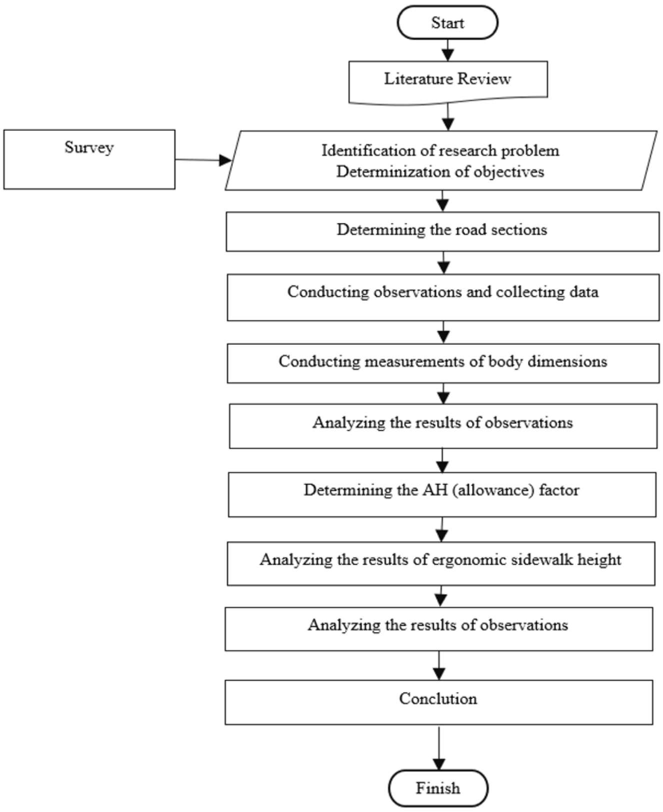

Figure 2. Research methodology flow

3.2 Data collection methods

Primary data is data obtained directly. Primary data collection techniques are carried out directly for this study. Data obtained through the process of observation, measurement surveys and documentation. Primary data obtained in the field are the height of the existing sidewalk, and the dimensions of the body of road users.

Secondary Data Secondary data is data obtained by reading, studying, and understanding from other sources. Secondary data collection techniques are not obtained from sources or research objects directly but can be obtained through research journals, reference books, the internet, previous research and regulatory policies concerning the ideal height of sidewalks as ergonomic pedestrian facilities.

3.3 Data analysis techniques

Steps in data analysis to determine the height of an ergonomic sidewalk:

-Determining the road sections to be studied with 16 road sections in Makassar City, including inter-city roads, major roads within the city, and connecting roads within the city.

-Conducting observations and collecting data on 50 sidewalk height measurements, from 16 road sections in the city of Makassar.

-Conducting measurements of body dimensions that affect the height of the sidewalk, namely the knee-to-floor body dimension (LL), the purpose of using LL is the body dimension in humans that most affects a person's stride height. The number of observations made was 100 respondents who were sidewalk users. To ensure the validity and reliability of the data obtained, the sampling method followed a stratification approach by considering the demographic distribution of sidewalk users in Makassar.

-Analyzing the results of observations of measurements of the user's body dimensions using statistical analysis, namely data uniformity tests. The purpose of conducting data uniformity tests is to identify extreme data, avoid data patterns that are too large and vice versa, resulting in deviations far from the average trend [34]. Data homogeneity tests use standard deviation and analysis of variance to identify extreme data that may disrupt the average trend.

$$\text{Upper Control Limit (ECL)}=\dot{x}+2\delta\times \tag{1}$$

$$\text{Lower Control Limit (LCL)}=\dot{x}-2\delta\times \tag{2}$$

where,

$\dot{x}$= Average observation

$\delta\times$= Standard deviation of the subgroup

Data adequacy test with a 5% level of accuracy and a 95% confidence level to ensure that the number of samples collected reflects the population representatively.

$$N' = \left[\frac{K/S\sqrt{N\sum X_i^2 - \left(\sum X_i\right)^2}}{\sum X_i} \right]^2 \tag{3}$$

where,

K = level of confidence in research 95% = 2

S = level of accuracy in research 5%

N = number of direct observation data

N' = number of theoretical data

X_i = i-th observation data

The condition is that if $N' \leq N$ then the data is considered sufficient.

Determining the AH (allowance) factor for the ergonomic height of the sidewalk aims to provide comfort for sidewalk users, reduce personal burdens, and minimize fatigue and obstacles in activities. This slack factor approach is adopted from ergonomic studies that have been applied in work environments and public transportation [17]. The AH clearance factor was developed to adapt the height of the curb to the biomechanics of the user's stride, thus ensuring optimal comfort without increasing the risk of injury due to too high or too low a stride. The details are as follows:

AH (low) = 25%, the lifting ability of the legs is given to road users in normal conditions without any load when stepping on the sidewalk. Used for areas with light pedestrian flow, such as residential areas.

AH (medium) = 50%, the leg lifting capacity is given to road users in moderate conditions with low loads (usually lifting a little skirt)./pants if women) then walk on the sidewalk. Recommended for protocol roads or areas with medium to high pedestrian density.

AH (high) = 75%, the lifting ability of the legs is given to road users in the city burdened condition, (usually stop first or take a run-up) then step on the sidewalk. Applied in areas where pedestrians are more burdened or often stop before taking a step.

Analyzing the results of ergonomic sidewalk height using the formulation:

$$TDT = \dot{X}DT - (\dot{X}DT\ (1 - \%\ All(AH))) \quad (4)$$

where,

TDT = Height Body Dimension

$\dot{X}DT$ = Average Body Dimensions

All (AH)= Ahmad Hanafie (AH) Allowance.

4. DATA COLLECTION AND CALCULATION

4.1 Characteristics of sidewalk height

Measurement of sidewalk height characteristics with a total of 50 points taken randomly with 16 road sections in Makassar City, the data has been subjected to statistical analysis of frequency distribution tests such as Figure 3.

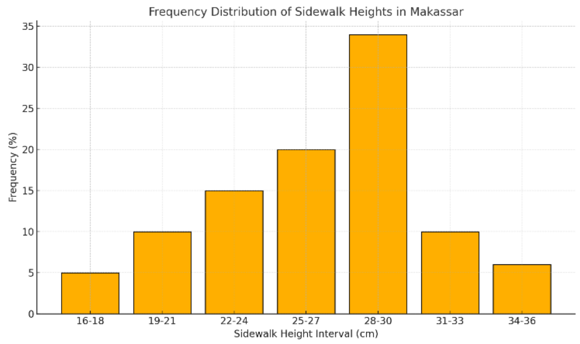

Figure 3. Frequency distribution of sidewalk heights in Makassar

Characteristics of the height of the sidewalk in Figure 3 shows that the results of the current conditions, the highest interval is at a height of 28-30 cm, there are 34% of the height of the sidewalk, while the ideal height based on the Department of Transportation, Directorate General of Taxes. Land is between 10 - 30 cm, showing 96%. Has been appropriate.

4.2 Body dimension characteristics

Measurement of body dimension characteristics that affect the height of the sidewalk is the knee-to-floor body dimension (LL) with a total of 100 respondents taken randomly, the data has been subjected to statistical analysis of frequency distribution tests as in Figure 4.

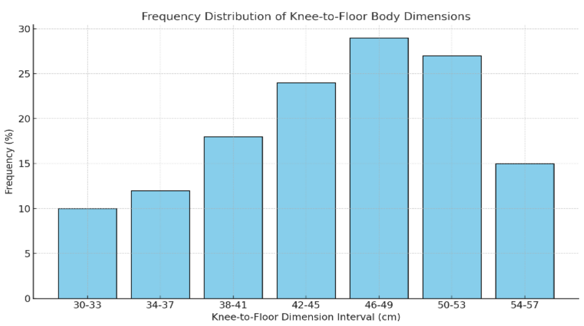

Figure 4. Frequency distribution of knee to floor body dimensions

Characteristics of body dimensions in Figure 4 from knee to floor of 100 respondents have the highest percentage in the 46-49 cm interval of 29% with 29 respondents, the 50-57 cm interval of 27% with 27 respondents, and the third interval, namely 42-45 cm of 24% with 24 respondents.

Based on the results of the uniformity test analysis of Eqs. (1) and (2), the results obtained for the body dimensions from knee to floor (LL) are shown in Table 1.

Table 1. Data uniformity test results

Symbol	Results
$\dot{X}$ = sample mean	47.70 cm
δ = standard deviation	4.79
δ×= subgroup standard deviation	1.24
BKA = upper control limit	50.17
BKB = lower control limit	45.23

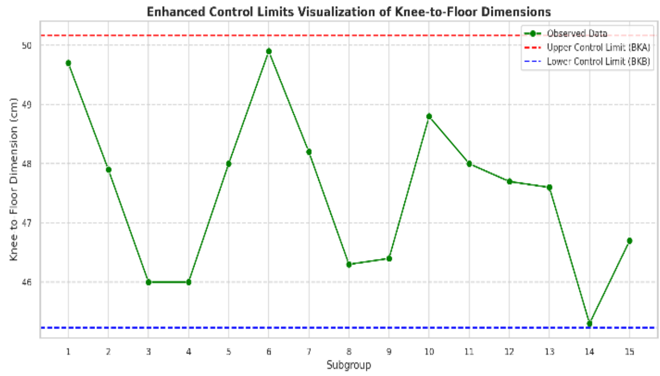

Figure 5. Enhanced control limits visualization of knee to floor dimensions

Figure 5 shows that the results of the data uniformity test analysis are between BKA and BKB, namely 50.17 and 43.23. So the data is considered uniform.

Based on the results of the analysis of the data adequacy test, Eq. (3) obtained the results for the body dimensions from knee to floor (LL).

Table 2. Results of data adequacy test

Symbol	Results
K	95%
S	2
δ	4.79
N	100
N'	16.08

Table 2 shows that the results of the data adequacy test analysis n < n', namely 100 < 16.08, are in accordance with the requirements for the data adequacy test analysis, meaning the data is sufficient.

Based on the analysis results, the body dimensions from knee to floor (LL) were obtained which had ergonomic value by taking into account the user's flexibility factor using Eq. (4), namely:

For All(AH)(low) clearance = 25%

TLL = $\dot{X}$LL – ($\dot{X}$LL (1 - % All(AH))

= 47.70 - (47.70 (1 - 0.25)

= 47.70 - (47.70 (0.75)

= 47.70 - 35.78

= 11.93 cm

For AH (moderate) relief = 50%

$TLL = \dot{X}LL - (\dot{X}LL (1 - \% All(AH))$
= 47.70 - (47.70 (1 - 0.50)
= 47.70 - (47.70 (0.50)
= 47.70 - 23.85
= 23.85 cm
For AH(high) clearance = 75%
$TLL = \dot{X}LL - (\dot{X}LL (1 - \% All(AH))$
= 47.70 - (47.70 (1 - 0.75)
= 47.70 - (47.70 (0.25)
= 47.70 - 11.93
= 35.78 cm

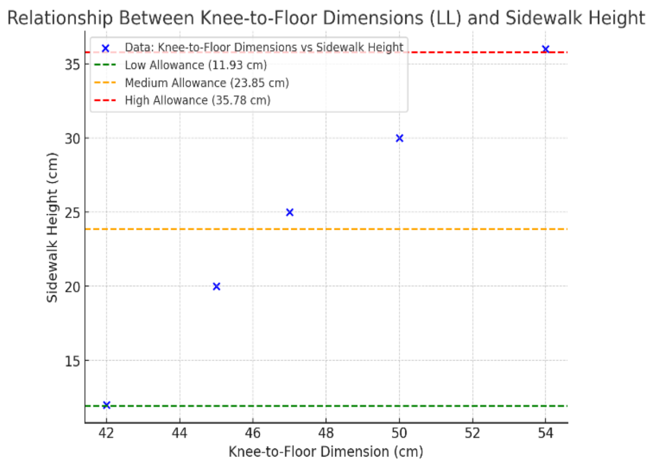

Figure 6. Relationship between knee to floor dimensions (LL) and sidewalks height

The results of the analysis show that there is a linear relationship between the knee-to-floor dimension and the height of the sidewalk (Figure 6). The higher a person's knee-to-floor body dimension, the greater the comfort felt on the sidewalk with a higher height. In addition, the appropriate sidewalk height can help reduce the burden on leg muscles and improve the efficiency of pedestrian movement.

Therefore, this study recommends that the sidewalk height be adjusted to the AH clearance factor, namely:

AH (Low): 11.93 cm
AH (Medium): 23.85 cm
AH (High): 35.78 cm

Simulation results show that sidewalks with low AH provide the highest pedestrian speed, while medium AH provides the optimal balance between comfort and sidewalk capacity in handling pedestrian density. Meanwhile, sidewalks with high AH are more suitable for areas with heavier pedestrian flows or for users with certain physical conditions, such as the elderly and people with disabilities.

The implications of these findings underscore the importance of an ergonomic approach in sidewalk planning, not only to improve user comfort but also to ensure that the resulting design can improve mobility, reduce the risk of fatigue, and create a more inclusive environment for various community groups.

Simulation results show that curb height based on clearance (AH) has a significant impact on pedestrian speed, especially under different density conditions (Figure 7). The curb with low AH (11.93 cm) resulted in the highest pedestrian speed at almost all density levels, indicating that this design is most suitable for areas with low pedestrian flow, such as residential streets. In contrast, the curb with medium AH (23.85 cm) offers an optimal balance between pedestrian speed and capacity to handle higher density. This makes it ideal for protocol roads or areas with moderate to high pedestrian activity.

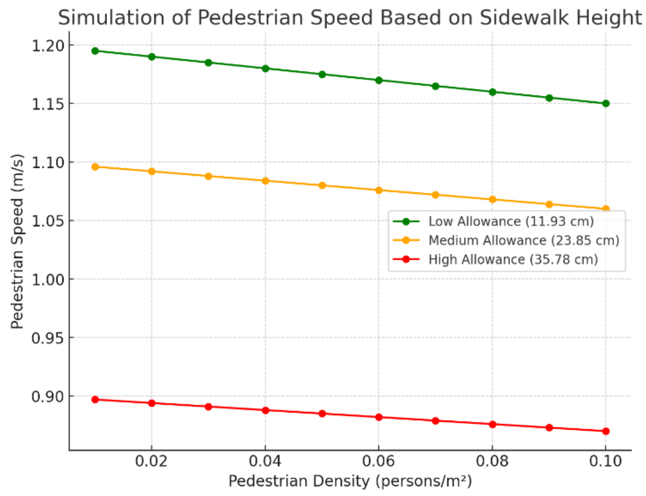

Figure 7. Simulation of Pedestrian speed based on sidewalk height

However, the sidewalk with high AH (35.78 cm) showed lower pedestrian speeds, especially at high density levels, indicating that this design is less suitable for busy urban environments. These simulation results emphasize the importance of adjusting sidewalk height to site-specific needs and pedestrian movement patterns to create an ergonomic and efficient design.

5. RESULT AND DISCUSSION

Based on the characteristics of the height of the sidewalk, it shows that the results of the current conditions, namely the interval of 16 - 34 cm, vary greatly, while those set by the Department of Transportation, Directorate General of Taxes. Land, namely between 10 - 30 cm, show 96%. While the results of previous studies of the Anthropometry of the Indonesian community obtained from the interpolation of the British and Hong Kong communities (Pheasant, 1986) against the Indonesian community (Suma'mur, 1989) and the dimensional terms from (Nurminanto, 1991). The knee height obtained is 54.4 cm if the results are taken as 50%, then the height is 27.4 cm. However, it cannot be used as a benchmark in determining the height of the sidewalk, it needs to be adjusted to the dimensions of the user's body in each region. So the results of the study using the allowance (AH) are used as a reference in determining the height of the sidewalk, especially the protocol road, namely AH (medium) of 23.85 cm. While AH (low) is in accordance with the residential/housing area, the height of the sidewalk is 11.93 cm.

Figure 8 shows a comparison of average sidewalk heights across regions, which can help highlight how the sidewalk height standard in Makassar compares to other regions regionally and internationally. In the context of regional and international comparisons, the sidewalk height standard in Makassar (10–30 cm) is in line with that set by the Department of Transportation, Directorate General of Taxes. However, when compared to international standards or in developed countries such as Europe, Singapore and Japan (10–15 cm) to ensure comfort for all users, this study shows that sidewalks in Makassar still have greater height variations and are less consistent in considering local anthropometry. This study suggests that with a local anthropometry-based approach, sidewalk design can be more tailored to the characteristics of local users without sacrificing safety and comfort aspects. Therefore, a more consistent approach that takes into account the body dimensions of local users is needed.

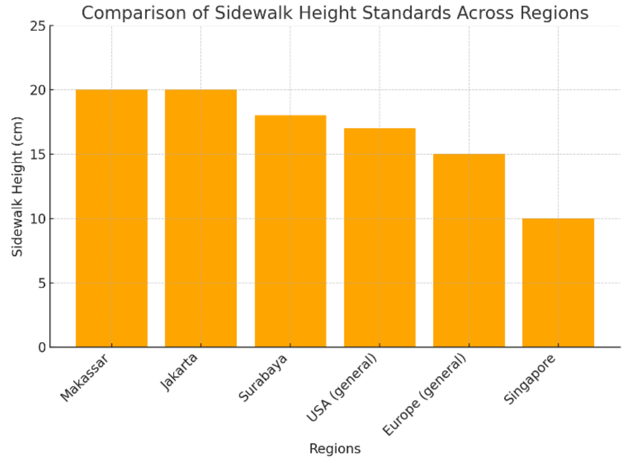

Figure 8. Comparison of sidewalk height standards across regions

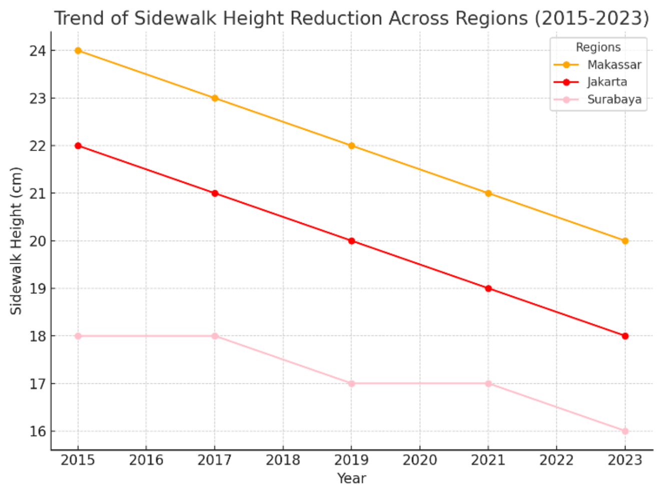

Figure 9. Trend of sidewalk height reduction across regions (2015-2023)

The analysis results from Figure 9 show a consistent decline in sidewalk height in all regions during the period. In Makassar, sidewalk height experienced a significant decline from 25 cm in 2015 to 21 cm in 2023. Similar trends were also seen in Jakarta and Surabaya, although the decline was more moderate.

This decline may reflect efforts to improve accessibility and pedestrian comfort, especially for vulnerable groups such as people with disabilities and the elderly. However, this trend also highlights the importance of ensuring that such changes maintain ergonomic and safety aspects for users.

The resulting heatmap depicts the distribution of pedestrian density across various road segments in Makassar, with variations reflecting the characteristics of the flow in each segment (Figure 10). Roads such as Andi Pangerang Pettarani and Ujung Pandang show higher levels of density, especially in certain segments, highlighting the urgent need for improvements in sidewalk design in these locations to better handle pedestrian flows efficiently. In contrast, road segments such as Somba Opu and Sungai Tangka have lower and more uniform levels of density, indicating that the interventions needed may be less complex. These data provide important insights for sidewalk design planning, where the implementation of medium or high curb heights can be adjusted for high-density areas to improve pedestrian comfort and safety. This narrative reinforces the urgency of implementing ergonomic principles in urban infrastructure, especially on roads with intense pedestrian activity.

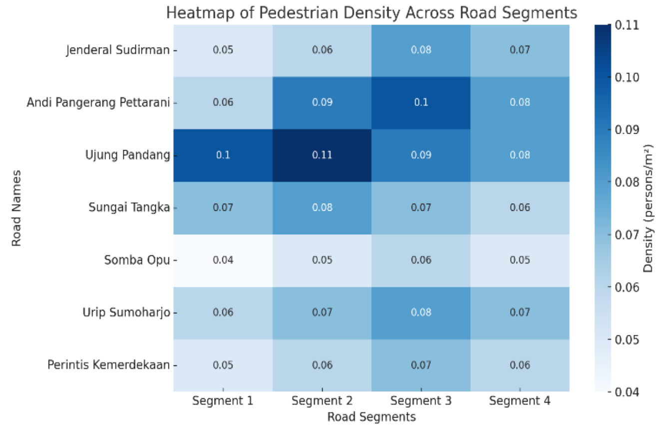

Figure 10. Heatmap of pedestrian density across road segments

Unergonomic sidewalk design can have negative impacts in the long term, such as: Increasing the risk of injury due to the mismatch of sidewalk height with the physical condition of the user, Reducing the efficiency of pedestrian movement, which can lead to increased use of motorized vehicles, impeding accessibility for vulnerable groups, such as people with disabilities and the elderly, thereby reducing inclusivity in public spaces. By considering the AH relaxation factor, this study provides solutions that can improve the quality of sidewalk infrastructure in Makassar City, creating a more comfortable, safe, and inclusive urban environment.

Another impact that needs to be considered is the decline in the quality of life in urban areas due to the suboptimal function of sidewalks as facilities that support comfort and safety. In the long term, non-ergonomic sidewalks can reduce the level of pedestrian connectivity with public facilities, reduce public trust in city infrastructure, and have a negative impact on urban aesthetics and appeal. Therefore, the implementation of sidewalk design based on AH allowance factor not only improves pedestrian comfort and safety, but also has broader economic and social implications. With increased comfort and accessibility, economic activities around pedestrian areas can increase, especially for small businesses such as street vendors and sidewalk cafes. In addition, improving more inclusive sidewalk infrastructure also contributes to the achievement of Sustainable Development Goal (SDG) No. 11 on sustainable cities and communities.

6. CONCLUSION

This study demonstrates the significant impact of ergonomic design on pedestrian comfort, safety, and accessibility. By integrating local anthropometric data and AH clearance factors, this study provides a more inclusive approach to sidewalk design, especially for cities such as Makassar. The proposed sidewalk heights of 11.93 cm (low), 23.85 cm (medium), and 35.78 cm (high) provide practical guidance for city planners, ensuring that sidewalks can accommodate the needs of diverse local users.

These findings underscore the importance of adopting ergonomic principles in urban infrastructure planning. By prioritizing user comfort and safety, cities can create more inclusive and sustainable environments, ultimately improving the quality of life for all residents. Future research could explore the integration of additional ergonomic factors, such as surface texture and slope, to further improve pedestrian infrastructure.

Policymakers and urban planners are advised to adopt the AH allowance factor in sidewalk design, especially in areas with high pedestrian traffic. This approach is not only in line with international standards but also meets the unique needs of local populations, contributing to the achievement of Sustainable Development Goal (SDG) 11: Sustainable Cities and Communities.

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