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Analysis of the Stair Elevation of Pedestrian Bridges for Pedestrian Safety and Comfort

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ABSTRACT

In the development of a sustainable city, it is essential to create pedestrian pathways and bridges that are both friendly and comfortable. A city requires pedestrian bridges that offer a safe way for pedestrians to crossroads. However, in practice, many pedestrian bridges are rarely used. This study aims to analyze the stair elevation of pedestrian bridges by examining the physiological workload involved in climbing the stairs and how this workload varies with the age of pedestrians. The research measured the energy expended by pedestrians in relation to their available capacity. The study was conducted on the stairs of a pedestrian bridge with a 27-degree slope. It was found that adult pedestrians aged between 25 and 45 years expend moderate to high levels of energy when climbing these stairs. The presence of stairs in public facilities encourages individuals to increase their physical activity for health purposes, making it important that the design of the stairs' slope considers both safety and comfort for routine use. The linear equation for Cardiovascular Load (%CVL) while climbing stairs is expressed as $y = 0.999x + 8.733$, where x represents age. This equation indicates that pedestrians over the age of 41 will expend more than 50% of their capacity. The 27-degree slope of the pedestrian bridge may be inconvenient for some users. Therefore, lowering the slope of the stairs should be considered in the design to enhance safety, comfort, and encourage increased use of the stairs.

1. INTRODUCTION

The increase in community activities and transportation amplifies the necessity for pedestrian facilities. In developing a sustainable city, it is necessary to develop friendly and comfortable pedestrian ways and bridges. A sustainable city development should equipped with several instruments such as ecosystem services-based carrying capacity, integrated inter-city transportation, ecocorridors in the form of gardens and street trees, and others [1, 2]. A city requires comfortable pedestrian pathways and bridges to serve the community in walking and safely crossing roads. Pedestrian bridges serve as facilities for crossing roads, motorways, and railways. However, in reality, many pedestrian bridges in some cities are rarely used. An observation was conducted on a pedestrian bridge near a mall in a city in Indonesia, revealing that only 10 to 20 pedestrians use the bridge to cross the road per day. Interviews were conducted with individuals who chose to disobey the rule and not use the bridge while crossing the highway; their primary reason for avoiding the pedestrian bridge was fatigue, as the stairs were too high, causing exhaustion during ascent.

Well-designed pedestrian bridges improve connectivity and accessibility between different parts of a city. They facilitate smoother and more direct routes for pedestrians, including those with disabilities or mobility challenges. This can significantly enhance the ease of movement across barriers like highways or rivers. These bridges also help reduce congestion at street level. When people choose to walk across a bridge rather than waiting at crosswalks or traffic lights, it can lead to smoother vehicular flow and decreased delays for both pedestrians and drivers. Encouraging walking as a mode of transportation supports sustainability goals by reducing reliance on motor vehicles. Pedestrian bridges promote healthier, environmentally friendly transportation, and help to align urban development with sustainability principles. Some cities, like Copenhagen, are well-known for being very pedestrian- and cyclist-friendly. Tokyo, another example, has excellent pedestrian infrastructure. Many pedestrian bridges throughout the city are designed with comfort and accessibility in mind, featuring lanes for wheelchairs and clear directional signs. The movement of people relies not only on spatial syntactic variables but also on the quality and comfort of pedestrian infrastructure [3].

Numerous stairs in public facilities are not optimally designed in terms of size, making it difficult for users to climb. A study conducted on the design of stairs at a University in Surabaya, Indonesia, found that 32.5% of the stairs did not offer a comfortable size for users [4]. According to the Directorate General of Highways in Indonesia, the recommended specifications include a thread depth of 24-30 cm, a maximum riser height of 15 cm, a minimum lane width of 51 cm for a single path, and a width of 120 cm for two lanes. The maximum slope for public stairs is 30 degrees.

Several pedestrian bridges lack safety and comfort facilities. Desirable attributes of pedestrian bridges encompass adequate lighting, cleanliness of steps and handrails, roofs for protection against rain and heat, and other amenities. The dimensions of pedestrian bridge stairs must ensure user safety during ascent, necessitating a rough surface on the steps to prevent pedestrians from slipping. Causes of falls on staircases include difficulties in seeing steps, poor lighting, high risers, short treads, and slipping off the steps [4]. Inconsistently high risers lead to accidents due to overestimation or underestimation of the height [5].

The energy expended while climbing stairs is proportional to the heavy physical load. In a study at Tirtayasa University, 43% of adolescent respondents expended energy at a heavy level when climbing 2 floors or 8.8 meters of a building [5]. Individuals aged 20 to 35 years exhibit the highest levels of physical ability and strength. Those in optimal physical condition, with an ideal body mass index, demonstrate maximum ability when climbing stairs. However, individuals over 40 years old experience a heavier physical load while ascending stairs. Physical ability can decrease by up to 10% for individuals around 50 years old. Halsey et al. [6] measured heart rate were used to estimate energy expenditure during climbing stairs at speeds chosen by the participants. The height of climbing up and down was 14.05 m. The average energy expenditure for ascending one step per stride was 8.5 kcal/min and ascending two stair steps per stride was 9.2 kcal/min. Experiments were conducted on individuals to measure energy expenditure while climbing stairs. Research used two methods of ascending stairs conducted by Halsey et al. [6], double-step methods need different amounts of work energy from each step method. The study found that the double-step method needs a greater metabolic energy than each step method, energy expenditure for each step method was 1.0-1.3 kcal/hour. The speed of stair climbing differs among age groups. The age group over 60 years old climbs at a slower pace compared to those under 60 years old. Leg extensor power shows a strong correlation with the walking speeds of elderly people on stairs [7]. Yaguchi et al. [8] observed no differences in kinematic and kinetic characteristics in the lower limb between the beginning and end phases of long stair climbing among adolescent participants. The speed of climbing stairs influences the relative aerobic strain and energy efficiency. Mbachu [9] found in his research that higher climbing speed correlates with increased energy efficiency and relative aerobic strain (RAS). High-speed climbing becomes crucial during emergencies using public stairs. The descending speed on stairs is affected by interactions among individuals, individual characteristics, and flow units [10]. Extensor power represents the walking speed of elderly people, it shows a strong correlation to people climbing stairs. The inclination of the stairs has a linear relationship with climbing speeds on stairs [7]. In a study of stair climbing speeds, university students demonstrated a maximum ability of 122 steps per minute, sustaining this pace for 2-6 minutes [11]. Gender affects the speed of descending stairs, with male groups descending faster than female groups [12].

The design of public facility stairs that disregard energy expenditure in climbing often deters many people from using them. In addition to demanding significant energy, stairs also pose a potential risk of injury, especially for adult and elderly age groups if they are not used carefully. However, despite these drawbacks, the use of stairs also offers health benefits. Regularly ascending and descending stairs can enhance the body's metabolism and guard against metabolic syndrome [13-15]. Metabolic syndrome involves the stabilization of various components related to blood glucose levels, LDL, HDL, total cholesterol, blood pressure, lipid fractions, and abdominal obesity. Individuals who frequently engage in stair climbing as part of their daily activities have shown improvements in cognitive abilities, reporting increased energy, reduced irritability, and decreased fatigue [16]. Physical activity, including walking in a comfortable environment, positively affects both physical health, as measured by heart rate and blood pressure, and mental health, as assessed by the Indonesian versions of the Profile of Mood States (POMS) and State Trait Anxiety Inventory (STAI) by Pratiwi et al. [17]. By providing safe and comfortable pedestrian bridges, the quality of life for city residents can be improved, creating a more welcoming and comfortable environment for everyone. The use of non-motorized transportation, such as walking and using pedestrian bridges, supports the principles of sustainable and environmentally friendly transportation. This aligns with the global goal of reducing emissions and dependence on private vehicles by encouraging walking and the use of mass transit.

The study aims to analyze the pedestrian workload while using pedestrian stairs. It investigates how physiological loads during stair climbing relate to pedestrian age, seeking to determine the age limit at which individuals feel comfortable and safe when ascending the stairs on the current bridge dimensions. The study models the physical load experienced while climbing pedestrian bridge stairs by age and examines how the slope of the stairs can be adjusted to promote health, and safety, and increase user preference.

2. METHODS

This research was conducted as a field study wherein respondents were selected at the study site at the Pedestrian Bridge when they were about to ascend the stairs. The subjects were asked for their willingness to participate in this study. The subject is confirmed to be in good health. They asked for information about their personal physical characteristics including age, weight, height, and occupation. Each subject had their heart rate measured while ascending the pedestrian bridge stairs.

2.1 Research location

Observation and data collection were carried out on the stairs of a pedestrian bridge in Cilegon City. The stairs of the pedestrian bridge had common dimensions and a slope typical for structures in Indonesia: slope angle of 27 degrees, step height of 25 cm, step width of 30 cm, lane width of 120 cm, and a bridge height of 5 meters. The slope of the stairs was determined based on the step's height, width, and the presence of a flat platform to break the ascent.

2.2 Subjects

Observation and measurement of subjects' working pulse were conducted over a month at the study site, where all subjects were users of the pedestrian bridge. These individuals were in optimal physical condition and overall good health. Before the measurements began, each subject confirmed their willingness to participate in the research. Subjects were selected using purposive sampling, a method where the researcher chooses participants based on specific criteria relevant to the study objectives. In this case, subjects were chosen based on their age and normal body mass index, fitting within the study's defined age range. Only those within the age range who were willing to participate were included as research subjects. Data collection spanned one month to adequately represent the typical users of the pedestrian bridge.

The subjects in this study ranged in age from 17 to 45 years and were grouped into three age classes: Late adolescence (17 – 25 years old), Early adulthood (26 – 35 years old), and Late adulthood (36 – 45 years old). There were 30 subjects in each category, aligning with the central limit theorem, stating that with a sample size of 30 or more, the data tends to resemble a normal distribution. The total number of subjects in this research was 90.

2.3 Data collecting

Immediately after the subjects finished ascending the pedestrian bridge stairs, their working pulse was measured using an Oximeter. Subjects required 30 – 60 seconds to climb the 5-meter height of the stairs. Once they completed the ascent, subjects rested, sitting in chairs provided for a 5-minute period. The resting pulse was then recorded after the subjects had rested for 5 minutes. The objective of this recovery phase was to restore the body's functions back to normal after undergoing high-intensity activities. A recovery period lasting 3-5 minutes assists in gradually decreasing heart rate and restoring breathing rhythm to normal levels [18]. Strenuous activities can cause muscle fatigue and shortening. To restore the muscles to their original state and potentially increase flexibility, incorporating activities like a 5-minute walk or stretching exercises can be beneficial.

2.4 Data processing

The energy expended during activities represents a physiological load, which can be quantified by measuring the volume of oxygen inhaled or the heart rate during the activity. It is essential to ensure that the subjects selected for this measurement are in good health, as their heart rate should reflect the energy they expend without being influenced by any underlying health conditions. Heart rate effectively indicates the total energy output of an individual, and this output can vary based on factors like body mass index, exercise habits, age, and more.

In everyday activities, a person is considered to be operating safely if they utilize less than 30% of their maximum energy capacity. This ratio of energy used during work relative to the maximum energy capacity is termed the percentage of cardiovascular load (%CVL). When using %CVL to gauge physical exertion during aerobic activities, it's crucial to adjust the threshold for physical work intensity differently from routine daily tasks.

For measuring aerobic intensity with respect to health, there are three designated levels of aerobic intensity: light intensity (30-39% CVL), moderate intensity (40-49% CVL), and high intensity (50-59% CVL). Although climbing the stairs of a pedestrian bridge is part of daily routine, it aligns with the sustainability principle that promotes healthier lifestyles through walking and stair climbing. This study, therefore, categorizes stair climbing as a health-based activity for assessing physical load. The comfort and safety of pedestrians are gauged by the percentage of energy they expend to climb the stairs.

The %CVL is typically calculated as exercise intensity, which represents the heart rate during physical activity as a percentage of the Maximal Heart Rate Reserve (HRR). %CVL is determined by the ratio of the difference between the heart rate during exercise (HR_{work}) and the resting heart rate (HR_{rest}) to the difference between the maximal heart rate (HR_{max}) and the resting heart rate (HR_{rest}). This calculation is performed using the Karvonen formula, as outlined in Eq. (1).

$$\%CVL = \frac{100(\mathrm{HR_{work}}\text{-}\mathrm{HR_{rest}})}{\mathrm{HR_{max}}\text{-}\mathrm{HR_{rest}}} \tag{1}$$

where,

HR_{work} = heartrate while working or exercising.
HR_{max} = subject maximum heart rate.
HR_{rest} = heartrate after rest for 5 minutes.

3. RESULTS

Physical work capacity refers to a worker's potential for energy output, primarily dependent on the energy available in the form of food and oxygen, which collectively sum up the energy provided by both oxygen-dependent and oxygen-independent processes.

Field observations involve direct measurement of the working and resting pulse of the subject using oximeters. The upper limit is the individual's predicted maximum volume of oxygen uptake in litre per minute, calculated from a calibration procedure utilizing a predicted maximum heart rate given by [19]:

$$HR(max) = 200 - (0.65) * age \tag{2}$$

Participant characteristics and the maximum heart rate are presented in Table 1.

Table 1. Subject characteristics and their heart rate upper limit

Subject	Weight (kg)	Height (cm)	Age (years)	HR Max (beats/minute)
S1	58	165	17	189
S2	60	143	17	189
S3	43	151	17	189
S4	59	170	17	189
S5	52	144	17	189
S6	62	161	19	188
S7	65	165	20	187
S8	68	173	20	187
S9	72	170	20	187
S10	45	155	20	187
S11	59	148	20	187
S12	79	170	20	187
S13	78	169	21	186
S14	63	169	21	186
S15	48	160	21	186
S16	50	162	21	186
S17	52	168	21	186
S18	56	165	22	186
S19	58	168	22	186
S20	67	181	22	186
S21	65	149	22	186

S22	74	177	23	185
S23	45	143	24	184
S24	43	150	24	184
S25	56	153	24	184
S26	67	170	25	184
S27	63	148	25	184
S28	50	149	25	184
S29	70	173	25	184
S30	56	155	25	184
S31	43	145	26	183
S32	44	150	26	183
S33	72	170	26	183
S34	77	163	27	182
S35	49	146	27	182
S36	52	144	28	182
S37	68	149	28	182
S38	65	158	28	182
S39	70	170	28	182
S40	68	168	28	182
S41	65	168	28	182
S42	48	142	28	182
S43	44	144	29	181
S44	58	160	29	181
S45	72	162	29	181
S46	77	175	29	181
S47	47	150	30	181
S48	62	166	30	181
S49	73	170	30	181
S50	86	172	31	180
S51	53	145	31	180
S52	72	164	32	179
S53	66	150	32	179
S54	56	143	33	179
S55	66	167	34	178
S56	70	154	34	178
S57	45	144	34	178
S58	70	165	34	178
S59	52	145	35	177
S60	73	170	35	177
S61	72	170	36	177
S62	50	145	37	176
S63	80	172	37	176
S64	53	142	37	176
S65	70	177	37	176
S66	74	168	38	175
S67	60	145	38	175
S68	62	145	38	175
S69	62	148	38	175
S70	72	168	38	175
S71	56	165	38	175
S72	75	166	40	174
S73	75	170	41	173
S74	55	144	41	173
S75	79	165	41	173
S76	81	165	42	173
S77	56	150	42	173
S78	55	144	42	173
S79	84	180	42	173
S80	61	148	42	173
S81	78	170	42	173
S82	74	170	43	172
S83	77	170	43	172
S84	72	175	44	171
S85	56	155	44	171
S86	74	180	44	171
S87	70	167	45	171
S88	83	168	45	171
S89	57	151	45	171
S90	51	148	45	171

The late adolescence group is the 1st to 30th subject, the early adulthood group is the 31st to 60th subject, and the late adulthood group is the 61st to 90th subject.

3.1 Working energy

The working energy is classified based on the ratio of energy consumption (working pulse) to the maximum capacity of subjects, expressed as a percentage of Cardiovascular Load (%CVL). Table 2 presents subject's Cardiovascular Load during climbing stairs and rest periods. Orange cells in the table represent subjects expending energy at high levels when climbing stairs, while yellow cells indicate subjects expending energy at a moderate level.

Table 2. Subject pulse (beats/minute) during climbing stairs and recovery times

Subject	Resting Pulse	Working Pulse	CVL (%)
S1	77	97	17.87
S2	82	102	18.70
S3	72	92	17.10
S4	71	96	21.20
S5	74	100	22.62
S6	73	112	34.02
S7	86	109	22.77
S8	81	104	21.70
S9	78	112	31.19
S10	78	110	29.36
S11	72	113	35.65
S12	71	119	41.38
S13	71	112	35.54
S14	80	117	34.79
S15	77	107	27.43
S16	85	117	31.57
S17	91	112	22.02
S18	72	99	23.75
S19	86	105	19.06
S20	84	122	37.36
S21	81	123	40.11
S22	90	111	22.09
S23	91	127	38.54
S24	92	122	32.47
S25	84	111	26.89
S26	82	116	33.42
S27	75	122	43.22
S28	98	121	26.82
S29	100	125	29.85
S30	78	116	35.93
S31	74	117	39.41
S32	71	102	27.65
S33	85	118	33.64
S34	71	114	38.58
S35	87	113	27.24
S36	83	127	44.53
S37	74	124	46.38
S38	86	134	50.10
S39	79	120	39.88
S40	87	120	34.81
S41	77	123	43.89
S42	96	119	26.81
S43	96	127	36.41
S44	80	114	33.61
S45	88	117	31.13
S46	81	116	34.95
S47	78	120	40.98
S48	89	127	41.53
S49	78	126	46.83
S50	92	129	42.12
S51	94	130	41.93

S52	94	126	37.56
S53	70	129	54.03
S54	86	132	49.70
S55	77	125	47.57
S56	95	131	43.43
S57	92	130	44.24
S58	89	120	34.87
S59	80	125	46.27
S60	87	125	42.11
S61	75	120	44.29
S62	91	131	47.09
S63	82	126	46.83
S64	94	128	41.49
S65	79	125	47.45
S66	74	123	48.37
S67	90	129	45.72
S68	90	126	42.20
S69	92	135	51.62
S70	83	134	55.25
S71	70	120	47.48
S72	70	135	62.50
S73	74	120	46.30
S74	71	127	54.71
S75	88	127	45.69
S76	95	121	33.46
S77	77	120	44.93
S78	76	131	56.88
S79	70	126	54.53
S80	89	134	53.76
S81	95	124	37.32
S82	87	131	51.73
S83	91	125	41.95
S84	76	129	55.56
S85	78	133	58.89
S86	89	135	55.83
S87	84	129	51.87
S88	74	121	48.58
S89	89	132	52.60
S90	92	125	41.90

According to Table 2, the subjects' pulse rates before climbing stairs ranged from 70 to 100 beats per minute, while the working pulse measured shortly after climbing the stairs ranged between 92 and 135 beats per minute. Within the early adulthood group, 3 subjects, or 10% of the group, expended energy at heavy aerobic levels with a %CVL of more than 50%, while 14 subjects making up 46.67%, expended energy at a moderate aerobic level. In the late adulthood group, a total of 13 people, or 43.33% of subjects, expended energy at heavy aerobic levels, and 15 individuals, or 50%, expended moderate energy while climbing the pedestrian bridge stairs.

Bridgers [19] proposed a method for determining excessive work intensity. The heart rate is measured between 30 seconds and 1 minute after the cessation of work and again between 2.5 and 3 minutes. The first reading should not exceed 110 beats per minute, and the second reading should be at least 20 beats per minute lower. An initial reading surpassing 110 beats per minute suggests excessively arduous work for the individual. If the first reading is below 110 beats per minute and the second reading is not at least 20 beats per minute lower, it implies that the work–rest cycle contains insufficient rest. Climbing bridge stairs led to an increase in pulse exceeding 110 beats per minute for some subjects, indicating excessive work intensity. The high work intensity deters some pedestrians from using pedestrian bridges.

The physical ability of subjects is influenced by various factors such as age, exercise habits, food intake, and gender, among others. With differing physical capacities, the physical load during stair climbing is estimated based on Percentage of Cardiovascular Load (%CVL). Percentage of CVL is a helpful measure in assessing effort and intensity [20].

The percentage of cardiovascular load is an objective means of assessing estimated energy consumption (HR_{work}) against the maximum capacity of subjects. It indicates the percentage of the energy used by an individual in relation to their available capacity. This energy estimate is particularly suitable for work involving a significant physical contribution and having a lower influence on mental factors. Percentage of CVL serves as an objective assessment because it considers everyone's maximum ability and reflects relative intensity more accurately. The slope of the stairs in this research is well-suited for the adolescent age group (17-25 years old) and some within the early adulthood group (25-35 years old). However, the slope of these stairs is unsuitable for individuals in the late adulthood age group, especially those above 35 years, as 43.33% of subjects in this age range expend energy at a heavy level when climbing stairs.

3.2 Data processing

In planning a pedestrian bridge designed to serve community members ranging from children to the elderly, it is crucial to understand the physical load experienced by individuals of various ages while climbing stairs. To this end, a linear regression formula was developed to quantify the energy expended during stair ascent.

Data on the subjects' age and their corresponding %CVL were collected and plotted on a scatter diagram. This plot revealed a strong linear correlation between %CVL and subject age, indicating that as age increases, so does the cardiovascular load during stair climbing. Figure 1 illustrates the plotted data, visually representing the relationship between %CVL and subject age.

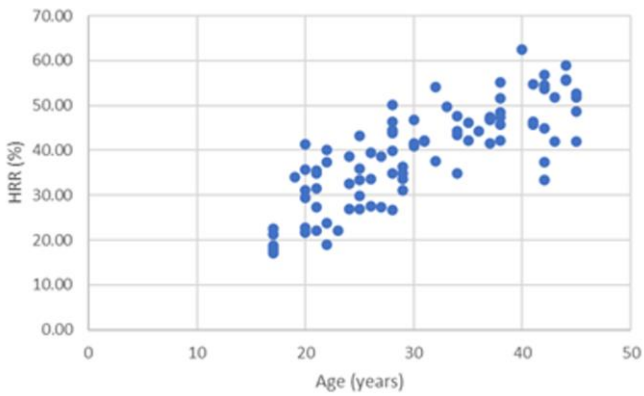

Figure 1. Scatter diagram of relative cardiovascular load (%CVL) and subject age

Based on the scatter diagram, there appears to be a positive relationship (or positive correlation) between the subjects' age and the subjects' %CVL. As subjects' age increases, their %CVL also tends to increase.

Formulating the linear equation for %CVL during stair climbing with a 27-degree slope:

$$y = 0.999x + 8.733 \quad (3)$$

where, y = subject's CVL(%), x = age (years).

A linear regression model was generated using Excel from Office 2019. The multiple R, which is the correlation coefficient, resulted in a strong correlation within the model with a value of 0.795.

Based on the energy formula related to age, the slope of the pedestrian bridge stairs commonly found in the research is only suitable for individuals up to 41 years old. Beyond this age, a person is likely to experience a cardiovascular load above 50% or the high load category.

4. DISCUSSION

So that pedestrians feel comfortable when climbing bridge stairs, the energy required for climbing should not exceed a moderate level. High energy demand would discourage pedestrians from using the bridge stairs due to their experience in fatigue. Approximately 10% of subjects in early adulthood and 43.33% of subjects in late adulthood expended high levels of energy when climbing the pedestrian bridge stairs, which have a 27-degree inclination. %CVL serves as an estimation of physical workload by considering the subject's capacity. If climbing stairs becomes a daily activity to encourage physical exercise among residents, then the design of the stairs' slope should not demand excessive energy and lead to a high %CVL. The %CVL for climbing stairs in public facilities should ideally not surpass 50% of an individual's capacity. As a comparison, the limit of physical fatigue based on the relative Cardiac Vascular Load (%CVL) for daily activity on industrial workers is set at 30%. An individual experienced a significant increase in their maximal heart rate (%HR max), surpassing the recommended 30% CVL threshold during 8-hour shifts, indicating physiological fatigue [20, 21].

Pedestrians using pedestrian bridge stairs will feel comfortable when expending energy at a light or moderate level, with a percentage of CVL below 50%. In a literature review by Jennings et al. [22] on the frequency of stair usage in public facilities across several global cities, there was a decrease in public interest in using stairs due to the amount of energy required to climb stairs. Heavy physical activity leads people to avoid climbing the stairs as part of their daily routines. There is a noticeable tendency for people in some countries to avoid using stairs, a habit that needs to be altered for public health. Stair designs should encourage physical activity and promote their use. According to the American Heart Association [23], for health reasons, adults aged 25 to 64 should engage in some form of physical activity every day. Exercising once or twice a week can reduce the risk of metabolic and heart diseases. The adult age group should do at least 150 minutes of moderate-intensity activity each week. Climbing stairs includes moderate-intensity activities if they cause an increase in breathing rate and body warmth. A city that has a sustainable transportation system including mass transportation and a comfortable pedestrian way will make the community work effectively within it [24].

The design of stairs in public facilities should consider the energy expenditure of climbing them and limiting the CVL to a maximum of 50%. This consideration stems from the understanding that using stairs positively impacts human health. Engaging in physical activity by climbing stairs can enhance the body's metabolism and cognitive function [13-16]. Ascending and descending stairs is an effective method to keep the body physically active, particularly beneficial for adults to prevent metabolic syndrome. The focus should be on reducing the physical strain involved in climbing stairs, especially for the adult age group, thereby encouraging frequent use of stairs.

4.1 Energy modeling while climbing stairs

A high correlation coefficient (0.795) indicates a robust linear relationship between the dependent variable (%CVL) and the independent variable (age). The coefficient of determination (R squared) for the model is 0.632 or 63.2%. This value indicates that 63.2% of the variation in y-values around the mean is explained by the x-values. In simpler terms, 63.2% of the values align with the model. The linear regression exhibited a p-value of 0.000, signifying a 0% probability of the model being entirely random. In essence, the model is 100% capable of estimating the subject’s %CVL.

According to the linear model for energy expenditure in stair climbing derived from this research, pedestrians under the age of 42 will use up to 50% of their energy capacity. However, individuals over 41 years old may find using the stairs uncomfortable, as they would exceed the 50% energy capacity limit. This research aligns with Stacoff research that age was found to be a factor which should be considered because the young age group walked faster and produced larger vertical Ground Reaction Forces on stair ascent than the middle and old age group, it makes middle and old age spend more energy when stair ascent [25]. Due to the heavy cardiovascular load required for some people to climb the stairs of the pedestrian bridge, it is rarely used by the community. The 27-degree slope of the staircase on the pedestrian bridge presents a barrier to healthy usage due to the high cardiovascular load it imposes, resulting in infrequent use. This observation aligns with Meeder's findings, which demonstrate that a steeper slope significantly reduces the attractiveness of walking; specifically, a 1% increase in slope correlates with a 10% decrease in walking attractiveness [26]. Similarly, Shah et al. [27] found that people moved faster on stairs with lower heights when analyzing the speed of pedestrian flow at four different stair dimensions in a station. Further research on various stair configurations has also shown that the gradient of stairs significantly affects the density-specific flow of pedestrians on stairs [28].

The commonly found 27-degree slope on pedestrian bridges should be redesigned to a gentler incline, enhancing convenience for users and optimizing the facility's utility. Zedi's research emphasizes the importance of designing stairs that are comfortable and align with the physical activities of building users [29]. Such design principles promote a building environment that supports user health and encourages optimal use of stairs. It is crucial to educate and guide architects and urban planners in creating stair designs that are beneficial for community health.

This research has some limitations as it was conducted only in one city with a tropical climate in Indonesia. The outside air temperature during the day at the research site was around 30 degrees Celsius, with a high humidity level of about 60%. Environmental conditions will naturally affect the energy expended during activities. This study used physical measurements of heart rate. While heart rates are generally similar among healthy individuals with a normal body mass index, the sample size of 30 in each age group is considered sufficient. However, heart rate variations while climbing stairs may occur between subjects due to differences in exercise habits, age, nutrition, and other factors. By using a larger sample size, the variation in the physical abilities of the community can be better accounted for. Including more participants in higher age ranges will also enhance the study's results.

Further research should focus on determining a slope for stairs that is comfortable and healthy for people up to 60 years old or middle-aged. Designing pedestrian bridge stairs with a lower inclination will make them healthier and more comfortable for users. With a more user-friendly and comfortable design, the community is likely to use the pedestrian bridge more frequently, thereby achieving the goal of promoting community health through improved pedestrian infrastructure.

5. CONCLUSION

In some cities, the stairs on pedestrian bridges do not comfortably serve the community in safely crossing roads. Comfort is primarily determined by the energy expended by individuals when climbing these stairs. An individual's physical capacity to handle this task is influenced by various factors such as age, exercise habits, diet, gender, and more, which in turn affect the physical load experienced during the climb. The most objective way to measure an individual's physical load is by using their percentage cardiovascular load (%CVL).

Our findings indicate that approximately 10% of subjects in early adulthood and 43.33% of those in late adulthood expend a high level of energy when ascending stairs on a pedestrian bridge with a 27-degree incline. This high workload intensity discourages the use of these bridges for pedestrian crossing.

The relationship between a subject's CVL during stair climbing and their age is expressed by the linear equation $y = 0.999x + 8.733$, where y represents the subject's CVL (%) and x represents their age (in years). It is generally expected that individuals should expend energy within 50% of their capacity when climbing stairs until the age of 41. However, individuals in the late adult age group (35 to 45 years) need to be cautious when climbing stairs on the pedestrian bridge as many in this group expend high levels of energy.

There is a critical need to provide education and guidance to architects and urban designers to create stair designs that are both comfortable and healthy for community use. This will ensure pedestrian bridges are more accessible and appealing, thereby encouraging their use for safe road crossings.

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