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Associations among perceived built environment, attitudes, walking behavior, and physical and mental state of college students during COVID-19

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ABSTRACT
Owing to strict access control implemented on university campuses during COVID-19, college students experienced increased isolation, resulting in several physical and mental health issues. This study investigates the relationships among perceived built environment, walking attitudes, walking behavior, physical and mental state, and the impact of COVID-19. A cross-sectional survey was conducted among undergraduate students (N = 429) at Dalian University of Technology, China, on September 20 (Sunday) and 21 (Monday), 2020. The survey questionnaire included questions related to socio-demographic factors, perceived environment (accessibility, road condition and safety, and aesthetics), walking attitudes, walking behavior (number of walking trips), physical and mental state, and the impact of pandemic. Subsequently, two structural equation models (SEMs) were developed to analyze the proposed conceptual framework. The empirical results indicated that the SEMs fit the data well, thereby validating the conceptual framework. Perceived environment (especially accessibility), attitudes, and walking behavior significantly influenced physical and mental state. Perceived environment mediated the effects between attitudes and walking behavior and physical and mental state. The pandemic negatively impacted attitudes and physical and mental state. The effect of perceived accessibility on walking behavior and that of walking behavior on physical and mental state were stronger on weekends, whereas the effects of attitudes and the pandemic on physical and mental state were stronger on weekdays. The findings indicate that universities should implement appropriate strategies to improve the objective and subjective built environment, especially accessibility, and cultivate positive attitudes among students to promote walking and improve physical and mental health during COVID-19.

1. Introduction
In recent years, the pursuit of a healthy lifestyle and the shift toward sustainable development has led to an increase in walking as a mode of transportation. As the most fundamental and traditional mode of transportation, walking accounts for approximately 40% of the total trips in metropolitans in China, with an even higher proportion in smaller cities (Yang et al., 2006). During the coronavirus disease 2019 (COVID-19) lockdowns, walking was the main mode of travel and physical activity for students on university campuses, with significant impacts on their physical and mental health. Owing to strict access control on campuses during the pandemic, college students experienced increased isolation on a daily basis. Although this measure helped control the spread of COVID-19, it led to several physical and mental health issues. Studies have reported that COVID-19 lockdowns negatively impacted the health behavior (e.g., eating/sleeping patterns, physical activity) and psychological and physical health (Al Miskry et al., 2021; Ingram et al., 2020; Pakenham et al., 2020). University students are a particularly vulnerable group and experienced increased anxiety and moderate to severe stress during the mandatory lockdowns (Husky et al., 2020). Therefore, walking behavior and physical and mental state of college students during the pandemic is an important area of study.

The elements of the built environment, including density, diversity, design, destination accessibility, and distance to transit, also known as the “five Ds”, have a significant influence on travel behavior (Ewing and Cervero, 2010). Travel attitudes are also important determinants of travel behavior (De Vos et al., 2012; Frank et al., 2007; Kizony et al.,...
travel behavior, and walking behavior have been comprehensively examined in a previous study (Chan et al., 2019). Active transportation also has positive correlations with public health (Tao et al., 2020). A recent review observed that there is growing evidence that walking improves mental health (Kelly et al., 2018).

In general, the relationships among the built environment, travel attitudes, and travel behavior have been well established (Ma and Cao, 2019), and the associations between the built environment and health have been examined extensively in previous studies (Saarloos et al., 2009). However, to the best of our knowledge, physical and mental state and the impact of COVID-19 have not yet been systematically integrated into the framework of the built environment, walking attitudes, and walking behavior among college students. Besides, as the variation in lifestyle and travel patterns on weekdays and weekends can affect the associations among variables, it is necessary to distinguish between weekdays and weekends while conducting such research.

To address the gaps in the existing research, this study aims to assess the associations among the perceived environment, walking attitudes, walking behavior, and physical and mental state of college students during a COVID-19 lockdown. Understanding these relationships is not only important for additional theoretical research, but also provides a quantitative basis for developing policies to encourage walking and improve physical and mental health. Specifically, this study attempts to answer the following questions.

Q1: What are the impacts of the perceived built environment and walking attitudes on walking behavior and physical and mental state, and which element of the built environment has the strongest influence?
Q2: What are the effects of the COVID-19 pandemic?
Q3: Are there any significant differences between the behavioral patterns on weekends and weekdays?

The rest of this paper is organized as follows: Section 2 reviews the related literature and establishes the hypotheses and conceptual framework of the study; the research design, measured variables, and statistical analyses used in the study are discussed in Section 3; the empirical results are presented in Section 4, and the results and limitations of the study are analyzed in Section 5; finally, the major findings and conclusions are summarized in Section 6.

2. Theoretical background

To provide a theoretical foundation for the study, we reviewed the existing literature and obtained an understanding of the built environment, travel attitudes, walking behavior, and physical and mental state. Subsequently, we developed the hypotheses and conceptual framework of this study.

2.1. Built environment and travel attitudes

The built environment refers to both the objective and subjective/perceived dimensions of the built environment. The objective dimensions of the built environment are measured through systematic observations and audits, or calculated using existing spatial data (e.g. street network and land use data) from geographic information systems (GIS) (Ma et al., 2014). The perceived built environment is primarily assessed through self-reported data (e.g. interviews or questionnaire surveys) that reflect subjective perceptions of the environment (Brownson et al., 2009). The most commonly used questionnaire scales for this purpose are the Neighborhood Environment Walkability Scale (NEWS) and its abbreviated form (NEWS-A) (Cerin et al., 2009). The perceived built environment has strong effects on walking behavior (Herrmann-Lunecke et al., 2021). The perceived dimensions of the built environment can have a stronger association with travel behavior than the objective dimensions (Ma and Dill, 2015). This is because, theoretically, human behavior is directly impacted by perceptions rather than the actual environment (Boulding, 1956). Moreover, different people might have different perceptions of the same built environment and behave differently (Ewing and Handy, 2009). Therefore, if the objective built environment is the same, it is prudent to focus only on the perceived built environment. Therefore, our first hypothesis is:

H1: The perceived environment has a positive effect on walking behavior.

The commonly considered travel attitudes include the general travel attitude (e.g. preference for travel), attitudes toward certain travel modes (e.g. preference for walking), and attitudes toward travel-related policies (Guan et al., 2020). Travel attitudes, which are generally measured using factor analyses or psychometric scales to capture meaningful constructs, are primarily used to reveal the preferences of travelers and their perceptions toward different transportation modes, as well as their travel intentions (Chan et al., 2019). For example, a seven-item scale was developed to measure the walking attitudes of respondents (Chan et al., 2019). Attitudes also have significant associations with travel behavior, regardless of the environmental characteristics (Arroyo et al., 2020; Ralph et al., 2020; Yang and Diez-Roux, 2017). Therefore, our second hypothesis is:

H2: Positive walking attitudes encourage walking behavior.

Considering the relationship between travel attitudes and the built environment, three typical influential mechanisms exist. 1) Attitudes affect the objective built environment through self-selection of residential locations. Residential self-selection refers to the tendency of people to choose where they live based on their travel attitudes (Wolday et al., 2018). People who lack freedom in choosing their residence (Lin et al., 2017) or live in the same neighborhood are excluded from the residential self-selection mechanism. As this study investigates students living in the same objective built environment, this type of causality was not relevant to this study. 2) Attitudes affect the perceived built environment through the perception of the residential environment. Personal attitudes may influence the perception of the built environment (Möckel, 2016). 3) The built environment affects attitudes through residential determination based on cognitive dissonance theory. The main idea behind this theory is that a person may take psychological action (commonly change their attitudes) to reduce cognitive dissonance, accompanied by some level of psychological discomfort/tension/distress (Festinger, 1957). Residential determination is caused by the inconsistency between predetermined travel attitudes and the actual built environment. Cognitive dissonance theory has been examined and applied in numerous studies (Chatman, 2009; Harmon-Jones et al., 1996; Lin et al., 2017). Therefore, our third hypothesis is:

H3: Attitudes affect the perceived environment through the perception of the built environment.
2.2. Walking behavior and physical and mental state

In previous studies, walking behavior has been typically described in terms of the walking frequency, daily step counts, or time spent walking. For example, one study investigated the effects of the objective neighborhood characteristics, perceived neighborhood environment, and walking attitudes on the frequency of walking (Chan et al., 2019). Some studies tracked the daily step counts of the study participants over 7 days using an accelerometer (Leung et al., 2018) or estimated the total time spent walking by asking respondents to specify the number of days during the previous week on which they walked for at least 10 min and to clarify the amount of time they usually spend walking every day (Yang and Diez-Roux, 2017). Compared to other variables, it is difficult to define and measure health, especially mental health. According to the World Health Organization (WHO), mental health is "a state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community" (World Health Organization, 2004). Mental health considers several aspects such as depression, anxiety, psychological stress, psychological well-being, subjective well-being, and social isolation and loneliness. For example, a recent study used the five-item Mental Health Inventory (MHI-5) (Berwick et al., 1991) to evaluate subjective well-being and depression (Kroesen and De Vos, 2020).

Regular walking can provide several physical health benefits including improved physical fitness, a reduction in the risk of disease, and a reduced risk of disease-specific and all-cause mortality (Kelly et al., 2011). Walking also serves as an effective intervention for clinical depression (Robertson et al., 2012). Although there is little evidence on the effects of the perceived environment and attitudes on the physical and mental state, it is reasonable to propose that the perceived environment and attitudes have positive effects on physical and mental state. Therefore, we present the following hypotheses:

H4: Walking behavior has a positive effect on physical and mental state.
H5: The perceived environment has a positive effect on physical and mental state.
H6: Attitudes have a positive effect on physical and mental state.

Table 1: Descriptive statistics of socio-demographic variables.

| Variable                           | Categories             | Number | Percentage (%) |
|------------------------------------|------------------------|--------|----------------|
| Gender                             | Male                   | 270    | 67.3           |
|                                    | Female                 | 131    | 32.7           |
| Grade                              | Sophomore              | 180    | 44.9           |
|                                    | Junior                 | 158    | 39.4           |
|                                    | Senior                 | 63     | 15.7           |
| Body Mass Index (BMI)              | <18.5                  | 64     | 16.0           |
|                                    | 18.5–24.9              | 267    | 66.6           |
|                                    | 25.0–29.9              | 54     | 13.5           |
|                                    | 30.0 or above          | 16     | 4.0            |
| Academic performance (hundred-mark system) | 90 or above             | 24     | 6.0            |
|                                    | 89–80                  | 213    | 53.1           |
|                                    | 79–70                  | 137    | 34.2           |
|                                    | 69 or below            | 27     | 6.7            |
| Monthly expenditure (RMB)          | More than 500          | 14     | 3.5            |
|                                    | 3000                   |        |                 |
|                                    | 2000–3000              | 71     | 17.7           |
|                                    | 1000–2000              | 256    | 63.8           |
|                                    | <1000                  | 60     | 15.0           |
| Exercise frequency (times per week) | 0–1                    | 156    | 38.9           |
|                                    | 1–2                    | 154    | 38.4           |
|                                    | 3–5                    | 64     | 16.0           |
|                                    | 6 or above             | 27     | 6.7            |

2.3. Impact of COVID-19

To control the spread of COVID-19 and ensure the safety of students, strict access control was imposed on university campuses during the COVID-19 pandemic. This measure significantly restricted the travel behavior of college students. The COVID-19 pandemic has caused several physical and mental health problems. For example, sub-syndromal mental health problems were found to be a common response to the pandemic (Rajkumar, 2020). The wide scope and spread of the pandemic could lead to a mental health crisis (Dong and Bouey, 2020).

Accordingly, we propose the following hypotheses:

H7: The pandemic negatively impacts physical and mental state.
H8: The pandemic negatively impacts walking behavior.
H9: The pandemic negatively impacts walking attitudes.

Based on these nine hypotheses, the conceptual framework of the study was established as follows (Fig. 1).

3. Methodology

3.1. Study design, setting, and participants

A cross-sectional study was conducted in Dalian University of Technology, China, using a self-reported questionnaire survey. The data was collected on September 20 (Sunday) and 21 (Monday), 2020 during the COVID-19 pandemic. During the data collection period, the pandemic was rather severe. As of September 21, a total of 265 confirmed cases were reported in Liaoning Province. To contain the spread of COVID-19, Dalian University of Technology implemented strict access control to the campus, and the travel of all the students was limited to the campus. The university students were invited to participate in the study. To ensure that the collected data were representative and useful, students from different majors (almost all departments) and different grades (sophomore to senior) were invited randomly to fill out
As freshmen were not entirely familiar with the campus, only sophomores (44.9%), juniors (39.4%), and seniors (15.7%) were invited to answer the questionnaire. The Body Mass Index (BMI) of most of the participants was normal, but some (20.0%) had a BMI of more than 30.0 or less than 18.5. Most of the participants (77.3%) exercised only twice per week or less, indicating that walking was the main physical activity.

### Table 2

| Variable name                          | Description                                      |
|----------------------------------------|--------------------------------------------------|
| **Socio-demographics**                  |                                                  |
| Gender                                  | Male, Female                                     |
| Grade                                   | Sophomore, Junior, Senior                        |
| Body Mass Index (BMI)                   | BMI = Weight (kg) / Height (m)^2                 |
| Academic performance (hundred mark system) | 90 or above, 89-80, 79-70, 69 or below         |
| Monthly expenditure (RMB)               | More than 3000, 2000-3000, 1000-2000, <1000     |
| Exercise frequency (times per week)     | 0, 1-2, 3-5, 6 or above                           |
| **Perceived built environment**         |                                                  |
| Accessibility                           | Shopping and dining areas are within easy distance on campus. |
|                                        | Classrooms and self-study rooms are within easy distance on campus. |
|                                        | There are many places to go within easy walking distance on campus. |
| Road condition and safety               | The surface of footpaths on campus is well maintained in general. |
|                                        | (Traffic safety) Walking on campus is safe.       |
|                                        | (Personal safety) The campus streets are well lit at night and we feel safe to walk on campus. |
| Aesthetics                              | There is shade along the streets on campus.       |
| **Attitudes**                           |                                                  |
| Walking attitudes                       | I enjoy walking on campus.                       |
|                                        | I walk because it is good for health.            |
| **Walking behavior**                    |                                                  |
| Number of walking trips on weekend      | The number of walking trips on Sunday.           |
| Number of walking trips on weekday      | The number of walking trips on Monday.           |
| **Physical and mental state**           |                                                  |
| Physical and mental state on weekend    | Physical and mental state score on Sunday.       |
| Physical and mental state on weekday    | Physical and mental state score on Monday.       |
| **Impact of COVID-19 pandemic**         |                                                  |
| COVID-19 impact                         | The COVID-19 pandemic has a negative impact on me.# |
| **Note:**                               | #Reversed item.                                  |

The variables considered in this study included six sections: 1) socio-demographics, 2) perceived built environment, 3) walking attitudes, 4) walking behavior, 5) physical and mental state, and 6) the impact of the COVID-19 pandemic. In total, this included four latent factors and eleven items. Detailed information relating to each variable is presented in Table 2.

As stated in Section 2.1, only the perceived dimensions of the built environment were considered in the study as the objective dimensions of the built environment (the university campus) were the same for all the participants. The perceived built environment scale was based on the NEWS-A questionnaire (Cerin et al., 2009) and the items were selected based on the current status of the university campus. Three variables of the perceived built environment—accessibility, road condition and safety, and aesthetics—were derived from a factor analysis based on eight survey questions. The survey questions were answered using a five-point scale ranging from strongly disagree (1) to strongly agree (5). The values of Cronbach’s alpha of the items ranged from 0.688 to 0.727, indicating that they had good reliability. In addition, confirmatory factor analysis (CFA) was performed to verify the validity of the perceived built environment. The walking attitudes were measured using two items, with a five-point scale ranging from strongly disagree (1) to strongly agree (5). The reliability and validity of the walking attitudes were acceptable as well (Cronbach’s alpha = 0.662).

Walking behavior was assessed by the number of walking trips. The number of walking trips within the university campus on weekends and weekdays were obtained from the data recorded on Sunday and Monday, respectively. As the possibility and proportion of college students suffering from specific physical or psychological issues were relatively low, and specific diseases like hypertension and depression reflected the long-term health of the respondents rather than their flexible physical and mental state during the survey, the general daily physical and mental state of the respondents were based on their perceptions of their physical and mental health. To better capture the physical and mental state of the respondents, the related items were subjectively assessed using a ten-point scale ranging from poor (1) to excellent (10).

As the survey was conducted during the COVID-19 lockdown, the impact of the COVID-19 pandemic was also included in the questionnaire and scored using a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). The survey also included a list of socio-demographic variables including gender, grade, Body Mass Index (BMI), academic performance, monthly expenditure, and exercise frequency.

### 3.2. Measured parameters

A total of four statistical analyses were performed during the study. First, a descriptive analysis was performed to understand the basic information of the variables. Second, a Pearson correlation analysis was performed to explore the interrelations among the main variables. Third, t-tests were performed to examine the systematic differences in the key variables between the two groups (Sunday and Monday, i.e., weekend and weekday). Subsequently, a series of structural equation models (SEMs) were established using MPlus 8 to examine the associations among the perceived environment, walking attitudes, walking behavior, and physical and mental state.

Compared with traditional regression analysis, SEMs can process multiple dependent variables simultaneously and allow independent
and dependent variables to contain measurement errors (Maruyama, 1997). Furthermore, SEMs allow the comparison and evaluation of different theoretical models. The maximum likelihood estimation was selected to estimate the SEMs, but the observed variables were assumed to follow a multivariate normal distribution. This ensures that standard errors are not underestimated (Kline, 2005). Furthermore, bootstrapped parameter estimation (Bootstrap = 5000) was used to generate repeated samples from the data (Hayes, 2009) and significant effects were
determined from the bias-corrected bootstrap confidence intervals (Ma and Cao, 2019). A total of six model fit indices were used to evaluate the fit of the models (McDonald and Bollen, 1990): the chi-square ($\chi^2$), relative chi-square (chi-square/df; < 3), comparative fit index (CFI; greater than 0.90), Tucker–Lewis index (TLI; greater than 0.90), root mean square error of approximation (RMSEA; < 0.05), and standard root mean-squared residual (SRMR; < 0.08) (McDonald and Ho, 2002). To clarify the differences between the models for weekends and weekdays, two structural equation models were developed based on the proposed conceptual framework: Model 1 was developed using the data recorded on Sunday (weekend), and Model 2 was developed using the data recorded on Monday (weekday).

4. Results

4.1. Descriptive statistics

A descriptive analysis was performed to obtain an initial understanding of the perceived built environment, walking attitudes, walking behavior, physical and mental state, and the impact of the COVID-19 pandemic.

The perceived environment variables were just above neutral: perceived accessibility, mean (M) = 3.115 and standard deviation (SD) = ±0.762; perceived road condition and safety, M = 3.156 and SD = ±0.873; and perceived aesthetics, M = 3.379 and SD = ±1.116. These results indicate that the perceived built environment of the campus required improvement. The average of the walking attitudes was 4.110, with SD = ±0.896, which indicates a generally positive attitude among the respondents. Surprisingly, the average number of walking trips on Sunday and Monday were both about six, suggesting that, on average, the respondents had relatively similar walking behaviors on weekends and weekdays. The number of walking trips on Sunday ranged between zero and thirteen, whereas that on Monday ranged between zero and fourteen, which indicates that different respondents exhibited different walking behaviors on the same day. The average physical and mental state on both days were above eight, indicating that most of the respondents were in a good physical and mental state. Nevertheless, the physical and mental state cannot be overlooked as some respondents were in a poor state (scored less than five). On average, the COVID-19 pandemic did not have a severe impact on the respondents [M = 2.636, SD = ±1.969], although some respondents were negatively influenced. Therefore, the COVID-19 pandemic was definitely an influencing factor.

4.2. Correlation analysis and t-tests

The correlation analysis identified four significant correlations among the main variables. First, as expected, walking behavior on weekends was positively correlated with the perceived accessibility ($r = 0.249, P < 0.01$), road condition and safety ($r = 0.115, P < 0.05$), and aesthetics ($r = 0.112, P < 0.05$), as well as the walking attitudes ($r = 0.222, P < 0.01$) of the students. In contrast, walking behavior on weekdays was only positively correlated with the perceived accessibility ($r = 0.123, P < 0.05$). Second, physical and mental state was positively correlated with the perceived accessibility, road condition and safety, and aesthetics, and the walking attitudes and behavior (all with $P < 0.01$) on both weekends and weekdays. Third, the walking behavior on weekends was positively correlated with that on weekdays ($r = 0.527, P < 0.01$), as was the physical and mental state. Finally, the impact of the COVID-19 pandemic was negatively correlated with the walking attitudes ($r = -0.170, P < 0.01$) and physical and mental state of the students on both weekends ($r = -0.132, P < 0.01$) and weekdays ($r = -0.159, P < 0.01$). Notably, no correlation was found between the impact of the COVID-19 pandemic and walking behavior. This may be because the strict campus access control did not restrict travel within the campus.

The t-test is widely used to determine the statistical significance of the mean differences between two groups (Guo et al., 2020). In this study, t-tests were employed to examine the mean differences in the key variables on Sunday (weekend) and Monday (weekday). The results indicated that there was a significant difference in the physical and mental states on Sunday and Monday. Therefore, a separate analysis was performed for the data recorded on Sunday and Monday to explore the differences between weekends and weekdays considering the effects of the perceived built environment, walking attitudes, and walking behavior on the physical and mental state of the students during the pandemic.

4.3. Structural equation models

Two SEMs, model 1 and model 2, were established based on the hypothetical conceptual framework using the data recorded on Sunday (weekend) and Monday (weekday), respectively. The results of the SEMs indicated that both models were established successfully. The results of model 1 and model 2 are depicted in Fig. 2 and Fig. 3, respectively. The standardized direct, indirect, and total effects of the two models are presented in Table A.1 and Table A.2 in the Appendix. The fit indices of the models and the explained variance ($R^2$) of the perceived built environment, walking attitudes, walking behavior, and physical and mental state are also shown in Fig. 2 and Fig. 3. The results indicated that both the models fit the data well. Therefore, the conceptual framework was supported by empirical analyses.

The results are discussed in greater detail in Section 5.

5. Discussion

The results (Fig. 2, Fig. 3, Table A.1, and Table A.2) clearly demonstrated that various relationships exist between the perceived environment, walking attitudes, walking behavior, physical and mental state, and the impact of the COVID-19 pandemic. The empirical results confirmed the validity of the proposed conceptual framework (Fig. 1). These findings can provide guidance for encouraging university students to walk and improve their physical and mental health during COVID-19 lockdowns.

5.1. Effects on perceived environment and walking attitudes

The modeling results indicated that walking attitudes had significant effects on the perceived accessibility, road condition and safety, and aesthetics. The direct effects on these three variables were all significant at the 95% confidence level. The socio-demographic variables had a relatively consistent influence in both the models. In accordance with the findings of a previous study (Ewing and Handy, 2009), the socio-demographic variables influenced the perception of the built environment and walking attitudes. Surprisingly, males were more likely to have a poor perception of accessibility and a better perception of aesthetics. Gender had no significant impacts on walking attitudes. Furthermore, university students in higher grades tended to have worse perceptions of the built environment and negative walking attitudes. Although BMI had no significant impact on the perceived built
environment, it significantly influenced walking attitudes, either directly or indirectly. The academic performance of the students had no significant effects on the perceived environment and walking attitudes. The students with a higher monthly expenditure perceived better accessibility, which may be attributed to travel with the intention of shopping.

After verifying the hypothesis that walking attitudes affect the perceived environment, we attempted to develop SEMs that hypothesize that the perceived environment affects walking attitudes and establish non-recursive SEMs to examine the bidirectional interactions between the perceived built environment and walking attitudes. The SEMs hypothesizing the effects of the perceived environment on walking attitudes indicated that the perceived accessibility significantly affected walking attitudes at the 95% confidence level, the effect of the perceived aesthetics on walking attitudes was only significant at the 90% confidence level. Considering the significance of the effects and the magnitude of the coefficients, the effect of walking attitudes on the perceived environment were much stronger than that of the perceived environment on walking attitudes, which is inconsistent with the findings of previous research (Van Acker et al., 2014). The effects of the perception of the residential environment were stronger than those of residential determination. However, the data did not support the non-recursive models. Although the iteration eventually converged, the result of the parameter estimation was impractical, in that the absolute value of an eigenvalue of the regression matrix was greater than 1. The same problem was encountered in a previous study (Kim and Mokhtarian, 2018) and may be attributed to the presence of multi-faceted attitudinal factors in the models, which leads to overparameterization.

5.2. Effects on walking behavior

There were several notable findings relating to the effects of the perceived built environment on walking behavior. In accordance with previous studies (Chan et al., 2019; Ma and Cao, 2019), the perceived built environment, especially the perceived accessibility, was found to be positively associated with walking behavior. The results of the two models indicated that the perceived accessibility had a significant direct effect on walking behavior at the 95% confidence level, with a stronger effect on weekends. In contrast, the effects of the perceived road condition and safety and aesthetics on walking behavior were not significant. This may be attributed to the special characteristics of university students. First, the constitution of the students was relatively good, therefore their walking behavior was less affected by the perceived road condition and safety. Second, as shown in previous studies, perceived aesthetics are primarily associated with leisure/recreational walking (Chan et al., 2019). As most of the trips on campus were for study/work rather than leisure/recreation, the perceived aesthetics did not have a significant effect on walking behavior.

The influence of walking attitudes on walking behavior was different on weekends and weekdays. Walking attitudes had a significant effect on walking behavior on weekends (model 1), which corresponds with the findings of previous studies on travel behavior and attitudes (Kamrussaman et al., 2016; Vale and Pereira, 2016). In contrast, no direct impact was found between walking attitudes and walking behavior on weekdays (model 2). This is possibly because walking behavior on weekdays varies with the study and work schedules of the students rather than their walking attitudes. Furthermore, compared with walking behavior on weekdays, travel arrangements on weekends might be more flexible and casual; consequently, walking attitudes have a stronger influence on walking behavior on weekends. The perceived accessibility was found to have a significant mediating effect between walking attitudes and walking behavior.

The effects of the socio-demographic variables on walking behavior were investigated as well. Students in higher grades tended to walk less (model 1), whereas students with a higher monthly expenditure (models 1 and 2) and exercise frequency (model 1) tended to walk more. Consequently, the two models exhibited variations of approximately 13.5% and 5.7% in walking behavior.

5.3. Effects on physical and mental state

As expected, the perceived built environment had significant positive direct and indirect effects on the physical and mental state of the students. The perceived accessibility had significant direct and indirect (via walking behavior) effects on the physical and mental state on weekdays (model 2), but only an indirect effect on weekends (model 1). The influences of the perceived road condition and safety and aesthetics were negligible. This may be attributed to the special characteristics of the university students discussed in Section 5.2. In general, studies on the relationship between walking attitudes and physical and mental state are limited. The questionnaire used in this study included a health-related question (I walk because it is good for health) in the walking attitudes section to better understand the relationship between walking attitudes and physical and mental state. The results indicated that walking attitudes had significant direct and indirect effects on the physical and mental state of the students, with a stronger effect on weekdays (model 2). Students with positive walking attitudes were more likely to have a good physical and mental state. Therefore, a positive walking attitude, especially on weekdays, is beneficial to the physical and mental health of an individual. The impact of walking behavior on physical and mental health has always been of interest to scholars. In accordance with the findings of previous studies (Li et al., 2021), walking behavior had a significant impact on physical and mental state, improving the physical and mental state of the students. The effect of walking behavior on physical and mental state was stronger on the weekends (model 1).

Considering the effects of the socio-demographic variables on the physical and mental state of the students, those in higher grades reported worse physical and mental states. Students with a higher BMI, monthly expenditure, and exercise frequency tended to have better physical and mental states. Overall, the two models exhibited variations of approximately 22.8% and 36.8% in the physical and mental state of the students.

5.4. Effects of the COVID-19 pandemic

The results of the two models indicated that the COVID-19 pandemic had direct negative impacts on walking attitudes that were significant at the 95% confidence level. Considering the impact of the pandemic on walking behavior, a significant negative effect was found in model 1, and the pandemic indirectly influenced walking behavior mainly through walking attitudes and the perceived accessibility. However, no significant direct or indirect effects were found in model 2. Although the pandemic had no significant direct effects on the physical and mental state of the students, the overall effects of the pandemic were significantly negative in both models, with a stronger effect on weekdays (model 2). Therefore, in addition to the direct effects, the indirect and total effects of the pandemic should be considered as well to avoid
underestimating the actual impacts of the pandemic, which could lead to incorrect conclusions (Ding et al., 2017). More importantly, suitable strategies should be adopted to reduce the negative impacts of the pandemic, and the physical and mental health of university students should be carefully monitored during the pandemic, especially on weekdays.

6. Limitations

Although several valuable findings were obtained from this study, there are numerous limitations that could be addressed in future studies. First, the study was conducted based on data recorded at only two time points; consequently, the dynamic relationships among the perceived environment, walking attitudes, walking behavior, and physical and mental state over time could not be captured. In future, longitudinal studies can be applied to explore these complex relationships. Second, the perceived built environment only considered the perceived accessibility, road condition and safety, and aesthetics, whereas walking attitudes were only measured by two variables. For a more comprehensive investigation, additional variables related to the perceived environment and walking attitudes should be considered. Additional attitudinal factors (e.g., attitudes toward health, environmental protection, lifestyle, and values) can also be incorporated to extend the framework. Third, only the general daily physical and mental state were recorded in this study. More detailed and precise definitions and measurements of physical and mental health could be used in future studies. For example, mental health can be reflected by several variables such as depression, anxiety, psychological stress, psychological well-being, subjective well-being, and social isolation and loneliness. Finally, this study only distinguished between walking behavior and physical and mental state on weekends and weekdays. Future research can also categorize walking behavior based on the purpose of travel (e.g., walking for study/work or leisure/recreation) to examine the effects of travel purpose on weekends and weekdays.

7. Conclusions

In this study, we successfully integrated the physical and mental state and impact of the COVID-19 pandemic into a framework of the perceived built environment, walking attitudes, and walking behavior of college students during a COVID-19 lockdown. In particular, we identified the relationships between the perceived built environment, walking attitudes, walking behavior, and physical and mental state, explored the impact of the COVID-19 pandemic, and discussed the differences between these associations on weekends and weekdays. The findings of the study provide insights for future research and can serve as a reference for administrators and planners to implement appropriate policies to encourage students to walk and improve their physical and mental health during the pandemic.

The main findings of the study can be summarized as follows: 1) The perceived built environment—especially accessibility—and walking attitudes were positively associated with walking behavior and physical and mental state. Walking behavior had a significant direct effect on physical and mental state. Walking attitudes had significant direct effects on the perceived accessibility, road condition and safety, and aesthetics. The perceived built environment serves as a mediating variable, confounding the impact of walking attitudes on walking behavior and physical and mental state. 2) The COVID-19 pandemic had significant negative impacts on the walking attitudes and physical and mental state of the students. In contrast, it had a relatively weak impact on their walking behavior. 3) Walking attitudes had a significant impact on walking behavior on weekends; however, no direct or indirect relationships were found between walking attitudes and walking behavior on weekdays. The effect of the perceived accessibility on walking behavior and that of walking behavior on physical and mental state were stronger on weekends, whereas the effects of walking attitudes and the pandemic on the physical and mental states of the students were stronger on weekdays.

Based on these findings, several interventions can be considered to encourage walking and improve the physical and mental health of university students. First, the built environment, especially accessibility, should be improved. This can be achieved by improving the objective built environment or by implementing ‘soft’ interventions to improve perceptions of the existing built environment. For instance, universities can organize thematic education activities to help students better understand the layout of the university campus and ameliorate the perceptions of the built environment. Second, considering the importance of walking attitudes, universities can implement intervention programs aimed at increasing awareness on the importance of walking and cultivating positive walking attitudes among students. Finally, effective measures should be implemented to reduce the negative impact of the COVID-19 pandemic, with an increased focus on the physical and mental health of university students, especially on weekdays. Overall, universities should implement appropriate strategies to improve both the objective and subjective built environment, especially accessibility, and cultivate positive walking attitudes among students to increase walking and promote physical and mental health during the pandemic.

CRediT authorship contribution statement

Meng Liu: Formal analysis, Investigation, Methodology, Software, Writing – original draft. Shengchuan Zhao: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing. Jingyao Li: Investigation.

Declaration of Competing Interest

No conflict of interest exists in the submission of this manuscript, and that is approved by all authors for publication. I would like to declare on behalf of my co-authors that the work described was original research that has not been published previously, and not under consideration for publication elsewhere, in whole or in part. All the authors listed have approved the manuscript that is enclosed.

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Appendix. Results of structural equation models
Table A1  
Results of model 1.

| Table A1 | Results of model 1. |
|------------------------------------|-------------------|
| | Accessibility | Road condition and safety | Aesthetics | Walking attitudes | Number of walking trips on weekend | Physical and mental state on weekend |
| | Direct effect | Indirect effect | Total effect | Direct effect | Indirect effect | Total effect | Direct effect | Indirect effect | Total effect | Direct effect | Indirect effect | Total effect |
| Socio-demographics | | | | | | | | | | | | | |
| Gender (male) | | | | | | | | | | | | | |
| | -0.116* | 0.036 | -0.080 | 0.055 | 0.036 | 0.090 | 0.134** | 0.031 | 0.166** | 0.078 | 0.023 | -0.018 | 0.004 | 0.048 | 0.009 | 0.057 |
| Grade | | | | | | | | | | | | | |
| | -0.023 | -0.090** | -0.113* | -0.077 | -0.088** | -0.165** | -0.215** | -0.077** | -0.293** | -0.193** | -0.054 | -0.038 | -0.092* | -0.089** | -0.074** | -0.163** |
| BMI | | | | | | | | | | | | | |
| | 0.027 | 0.044 | 0.072 | 0.047 | 0.043 | 0.090 | 0.027 | 0.038 | 0.065 | 0.095* | 0.035 | 0.027 | 0.062 | -0.012 | 0.045* | 0.033 |
| Academic performance | | | | | | | | | | | | | |
| | 0.005 | 0.000 | 0.006 | 0.073 | 0.000 | 0.073 | -0.085 | 0.000 | -0.085 | 0.000 | -0.056 | 0.003 | -0.053 | -0.023 | -0.003 | -0.026 |
| Monthly expenditure | | | | | | | | | | | | | |
| | 0.200** | 0.041 | 0.241** | 0.029 | 0.040 | 0.070 | 0.053 | 0.035 | 0.088 | 0.088 | 0.042 | 0.065** | 0.106** | 0.030 | 0.069** | 0.099* |
| Exercise frequency | | | | | | | | | | | | | |
| | 0.062 | 0.022 | 0.084 | 0.026 | 0.021 | 0.047 | -0.120** | 0.019 | -0.102* | 0.047 | 0.079 | 0.033 | 0.112** | 0.064 | 0.050* | 0.096* |

Perceived built environment
Accessibility
Road condition and safety
Aesthetics

Attitudes
Walking attitudes
Walking behavior
Number of walking trips on weekend
Impact of the COVID-19 pandemic
COVID-19 impact

Note: ** Indicates significant values at the 95% level.
* Indicates significant values at the 90% level.
Table A2
Results of model 2.

|                          | Accessibility | Road condition and safety | Aesthetics | Walking attitudes | Number of walking trips on weekday | Physical and mental state on weekday |
|--------------------------|---------------|----------------------------|------------|-------------------|------------------------------------|--------------------------------------|
|                          | Direct effect | Indirect effect | Total effect | Direct effect | Indirect effect | Total effect | Direct effect | Indirect effect | Total effect | Direct effect | Indirect effect | Total effect |
| Socio-demographics       |               |                |              |               |                |              |               |                |              |               |                |              |
| Gender (male)            | -0.117*       | 0.036          | -0.081       | 0.055         | 0.035          | 0.090        | 0.129**       | 0.031          | 0.161**       | 0.077        | 0.076        | -0.012       | 0.063        | 0.040        | 0.037        | 0.077        |
| Grade                    | -0.024        | -0.090**       | -0.114*      | -0.077        | -0.088**       | -0.165**     | -0.214**      | -0.079**       | -0.293**      | -0.193**     | -0.025       | -0.029       | -0.054        | -0.048       | -0.121**     | -0.169**     |
| BMI                      | 0.028         | 0.044          | 0.072        | 0.047         | 0.043          | 0.090        | 0.027         | 0.039          | 0.067         | 0.095*       | 0.013        | 0.009        | 0.022        | -0.013       | 0.058*       | 0.045        |
| Academic performance     | 0.006         | 0.000          | 0.006        | 0.073         | 0.000          | 0.073        | -0.081        | 0.000          | -0.081        | 0.000        | -0.056       | -0.017       | -0.073        | -0.017       | -0.012       | -0.030        |
| Monthly expenditure      | 0.199**       | 0.041          | 0.240**      | 0.029         | 0.040          | 0.070        | 0.053         | 0.036          | 0.089         | 0.089        | 0.048        | 0.046*       | 0.094**       | 0.012        | 0.094**       | 0.107**       |
| Exercise frequency       | 0.062         | 0.022          | 0.084        | 0.025         | 0.022          | 0.047        | -0.123**      | 0.020          | -0.103*       | 0.048        | 0.026        | 0.002        | 0.029        | 0.058        | 0.032        | 0.091*       |

Perceived built environment

|                          | Accessibility | Road condition and safety | Aesthetics | Walking attitudes | Number of walking trips on weekday | Physical and mental state on weekday |
|--------------------------|---------------|----------------------------|------------|-------------------|------------------------------------|--------------------------------------|
|                          |               |                |              |               |                                    |                                      |
| Road condition and safety|               |                |              |               |                                    |                                      |
| Aesthetics               |               |                |              |               |
| Attitudes                |               |                |              |               |
| Walking attitudes        | 0.464**       | -               | 0.455**      | -               | 0.455**                           | 0.410**                              | 0.046        | 0.051        | 0.097        | 0.382**       | 0.127**       | 0.509**     |

Walking behavior

|                          | Number of walking trips on weekday | COVID-19 impact |
|--------------------------|------------------------------------|-----------------|
|                          |                                     |                 |
| Impact of the COVID-19 pandemic |                                     |                 |

Note: ** Indicates significant values at the 95% level.* Indicates significant values at the 90% level.
