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Constructing "Constant-holistical Shadow" Space for Universities in Guangzhou under the Various Roads Orientation

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ABSTRACT

The university campus in Guangzhou city, China, are heavily exposed to the sun in the summer, and it is essential to construct a Constant-holistical Shadow (CHS) space that allows university teachers and students to remain in the shadow during their outdoor activities within a certain range of time and during the entire activity period. In this paper, based on the date period in need of shadow for the outdoor activities of university teachers and students in Guangzhou, the CHS spaces under 4 typical orientations, east-west, south-north, southeast-northwest, and northeast-southwest, were simulated by Autodesk Ecotect Analysis. The correlation between the objects blocking the sunlight (sunlight-blockers) and the simulation results is analyzed, to explore the construction and design method of CHS space under the difference of the orientations, and to form a process of designing CHS space that can be applied to different orientations of the building environment. Finally, the feasibility and scientific validity of these methods are simulated and verified step by step using a campus environment in a university in Guangzhou as an example, hoping to provide reference ideas and directions for the planning and design of universities in Guangzhou and its similar latitudes, as well as for the design of buildings and their renovation.

Keywords: Constant-holistical shadow space; roads orientation; architectural design for universities; activity space; Guangzhou City

INTRODUCTION

The thermal comfort provided by outdoor public spaces to people is one of the decisive factors in urban life quality and social and cultural lifestyle (Bajsanski et al. 2016). In hot summers, solar radiation significantly affects the thermal comfort of people outdoors (Nikolopoulou et al. 2001; Nikolopoulou & Steemers 2003). Especially in venues that lack protection from solar radiation, outdoor people often suffer from continuous exposure to the scorching sun, which not only restricts normal outdoor activities (Yang et al. 2018) but also poses severe health risks, including skin cancer and potentially fatal heat-related conditions (Macfarlane 1978).

The shadows of buildings, structures, or plants can alleviate the adverse effects of continuous sunlight in summer to a certain extent (Li et al. 2018; Gong et al. 2018; Omar, 2019) and reduce direct solar radiation (Wong & Yu 2005; Saneinejad et al. 2014; Peng et al. 2021). Outdoor activity spaces designed and created by combining shadows can effectively improve the thermal comfort of active people , making them favored outdoor activity areas (Lin 2009; Watanabe & Ishii 2016). In urban environments, especially on university campuses, the enthusiasm of teachers and students for outdoor activities is limited by the thermal comfort of the main activity areas. A good outdoor thermal comfort environment is conducive to the outdoor activities of teachers and students (Ghaffarianhoseini et al. 2019; Abdallah et al. 2020; Mahmoud & Ragab, 2020). However, the planning and design of many universities have not yet fully utilized the shadows created by buildings, structures, or plants to reduce the negative effects of continuous sun exposure, resulting in 40% of the shade on campus being ineffective (Ghaffarianhoseini et al. 2019). How to effectively use shadows to build comfortable outdoor activity spaces remains an important issue to be explored by university planners, designers, and related researchers (Taleghani, 2018; Huang et al. 2019).

CHS is a natural phenomenon in which sunlight-blockers such as buildings, structures, and plants block sunlight individually or in combination, forming a time-limited dynamic shadow area on the ground and other shadow-bearing surfaces (Gong Zhaoxian et al. 2021). Under natural conditions or normal circumstances without effective treatment, CHS is limited by factors such as the open orientations of the semi-open space, the height-to-width ratio of the sunlight-blockers, the mutual spacing between sunlight-blockers, and the degree of light transmission of the sunlight-blocker. These limitations affect the size, location, and periods of the shadow, making it difficult to meet the date periods, time periods, and areas in need of shadow of outdoor activists (Guohui et al. 2021).

Consequently, based on the space-time in need of shadow of teachers and students in universities in Guangzhou, this article analyzes the correlation between the duration and area of shadowing and the open orientations of sunlight-blockers in CHS spaces at universities in Guangzhou. This analysis assumes constant conditions for other attributes of the sunlight-blockers. Through simulation and comparison using Ecotect Analysis, the study explores construction and design methods for CHS spaces in four typical open orientations: east-west (E-W), south-north (S-N), southeast-northwest (SE-NW), and northeast-southwest (NE-SW). The article integrates simulation, analysis, construction, and comparison with architectural examples to verify the feasibility and scientific validity of these methods.

PROBLEM STATEMENT

Guangzhou is located in the subtropical region with abundant sunlight, making it a typical low-latitude city in China. As of October 2021, Guangzhou boasts a total of 82 colleges and universities, with the current number of college students reaching 1.3 million, ranking third in China (China Government Network, 2022). Despite this, university campuses in Guangzhou have yet to provide a thermally comfortable environment that satisfies teachers and students. More than 60% of respondents from colleges and universities report feeling "very hot" outdoors, often to an unbearable extent (Guohui et al. 2021). The shading facilities on campus fail to adequately address the dynamic changes in time and area when teachers and students engage in outdoor activities. Poorly planned layouts result in issues such as discontinuous shadows or insufficient shading areas, significantly impacting teachers' and students' outdoor activities (Figure 1).

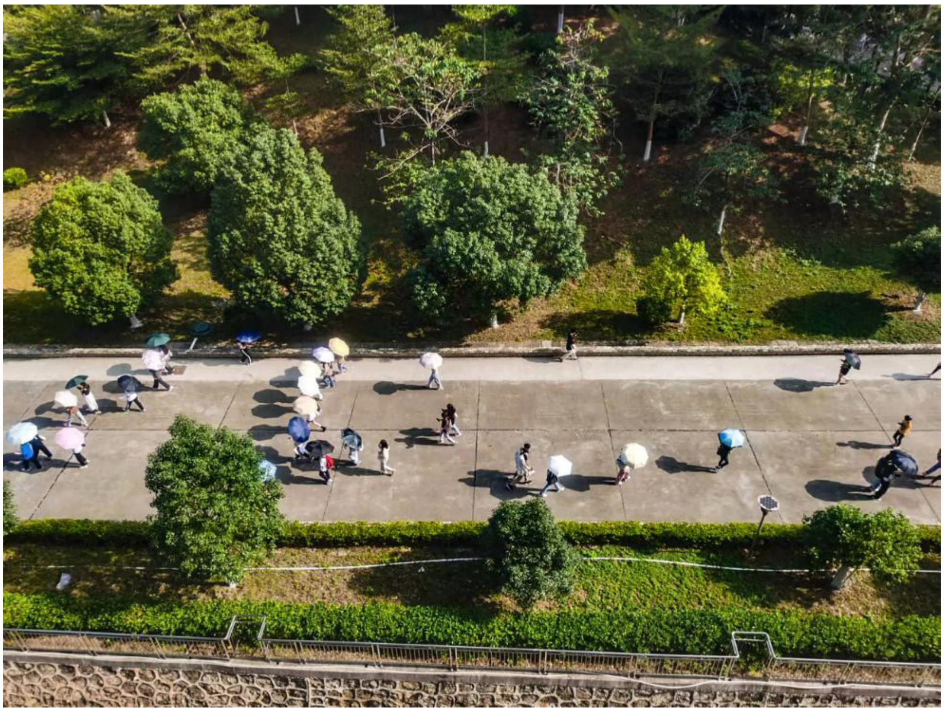


FIGURE 1. Shadow situation of the NE-SW school road in a certain university in Guangzhou

METHOLOGY

CHS SPACE UNDER DIFFERENT OPEN ORIENTATIONS

Due to the dynamic movement of the Earth and the changing angles of the sun's direct rays and altitude, CHS spaces exhibit varying shadow patterns across different dates and time periods.

When the orientation is E-W, the semi-open space between sunlight-blockers experiences significant shadow loss between 10:00 and 14:00. Only from September 1 to October 4, intermittent small-area shadows are produced by buildings on the south side (Figure 2).

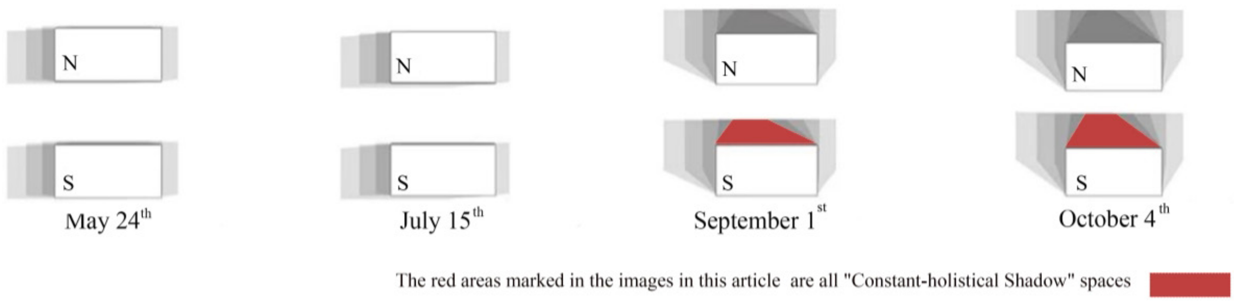


FIGURE 2. The imaging results of the CHS space with an open orientation of E-W from 10:00 to 14:00

Conversely, with an orientation of S-N, the semi-open space enclosed between sunlight-blockers shows noticeable shadow loss across all four simulated days, with considerable differences observed between the CHS spaces on these days. The shaded areas on September 1 and October 4 are notably larger than those on May 24 and July 15 (Figure 3).

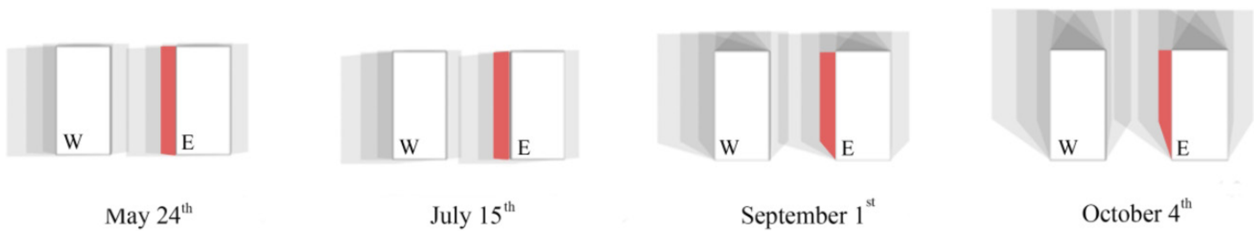


Figure 3. The imaging results of the CHS space with an open orientation of N-S from 10:00 to 14:00

Based on the simulation results above, variations in open orientation significantly influence the shading outcomes of CHS spaces. Therefore, this article employs the method of controlling variables, with "open orientation" as the independent variable, while keeping factors such as height, width, and mutual spacing of sunlight-blockers constant. It compares numerical differences in shading areas of CHS spaces constructed and designed under different open orientations based on the specific dates and time periods required by teachers and students in universities in Guangzhou. This approach validates efficient design methods for constructing CHS spaces and provides guidance for enhancing light and thermal comfort environments in architectural examples.

SIMULATION OF CHS SPACE UNDER DIFFERENT OPENING DIRECTIONS

Based on the gradual values of outdoor air humidity and solar radiation over the years, Zhang Xiangrong and others used the "virtual year" method to determine the start and end outdoor dates in need of shadow in 10 typical cities in China by constructing shading calculation periods (Zhang et al. 2019). This article selects the start and end dates in need of shadow of Guangzhou citizens (May 24 and October 4), and the general start and end dates of summer vacation in Chinese universities (July 15 and September 1) as the four dates of the experiment. Due to the shading demand of teachers and students for attendance and dining during the after-school period of noon, the time period in need of shadow for this simulation will be determined as 12:00 and two hours before and after midday (10:00-14:00).

In the experiment, two rectangular blocks with a length of 30 meters, a width of 20 meters, and a height of 21 meters were set up as building sunlight-blockers. The construction and simulation of a CHS space were carried out for four typical open orientations of the site.

CHS SPACE SIMULATION IN THE EAST-WEST OPEN ORIENTATION

According to the results of multiple combination simulations, when the open orientation is E-W, southern sunlight-blockers significantly shade the area, forming a larger shadowed region. Therefore, when constructing a CHS space in such orientations, priority should be given to adding sunlight-blockers on the southern side to increase effective shading within the site. For example, planting double rows of 12-meter-high trees spaced 8 meters apart, along with 5-meter-high shrubs or small trees, the ratio of the CHS area to the activity space area (C/A) can be increased to 80% (Figure 4). Alternatively, using 12-meter-high trees in double rows (Figure 5) or a combination of 8-meter-high trees with 4-meter-high shrubs in double rows, along with a 6-meter-wide corridor, the C/A of 60% can be created (Figure 6). Even planting double rows of 8-meter-high trees alone can achieve the C/A of 40% (Figure 7).

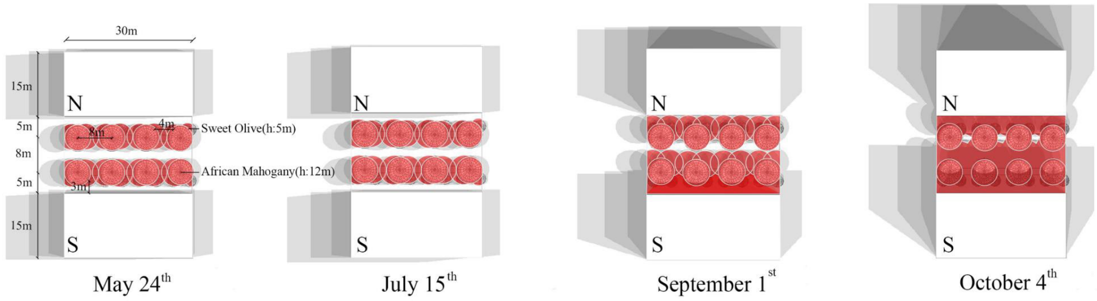


FIGURE 4. The scheme for constructing CHS space of C/A of 80%
(Planting 12-meter-high trees with a spacing of 8 meters, combining 5-meter-high shrubs or small trees)

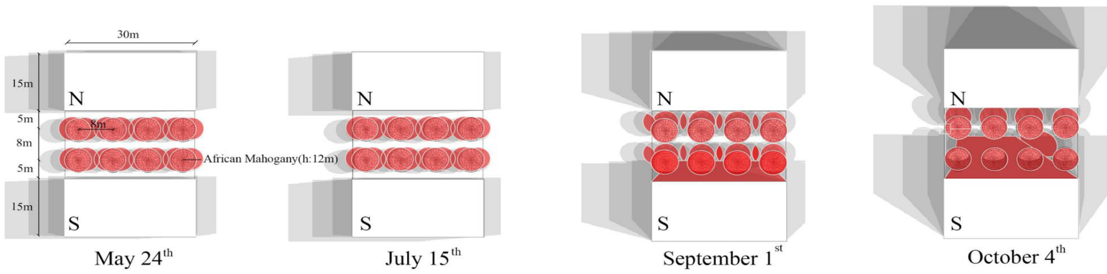


FIGURE 5. The scheme 1 for constructing a CHS space of C/A of 60%
(Double row planting of 12-meter-high trees)

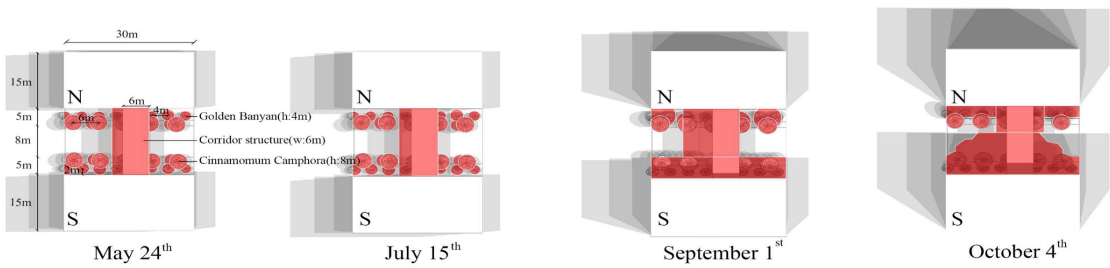


FIGURE 6. The scheme 2 for constructing a CHS space of C/A of 60%
(8-meter-high trees and 4-meter-high shrubs are planted in double rows and combined with a 6-meter-wide corridor)

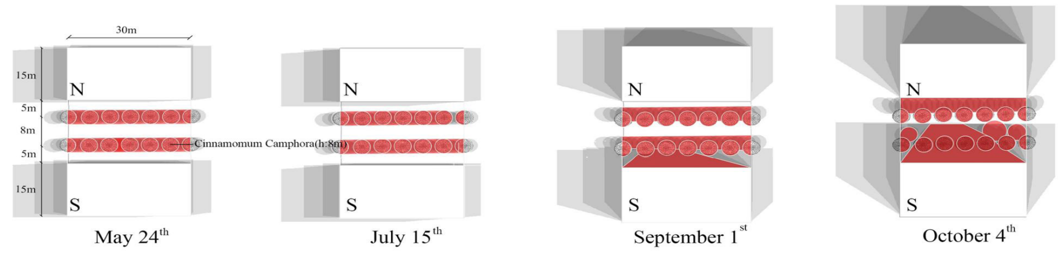


FIGURE 7. The scheme for constructing a CHS space of C/A of 40%
(Double row planting of 8-meter-high trees)

CHS SPACE SIMULATION OF SOUTH-NORTH OPEN ORIENTATION

According to the results of multiple combination simulations, when the open orientation is S-N, the east and west side shadows can significantly block the sun. When constructing a CHS space in such an open orientation site, priority should be given to adding sunlight-blockers on the west side to increase the effective shading area in the site. For example, 12-meter-high trees are planted at 8-meter intervals on the west side of the activity area, and 5-meter-high shrubs and 5-meter cantilevered buildings are planted in separate rows, the CHS space will achieve the C/A of 80% (Figure 8). 8-meter-high middle trees are planted in single rows on the west side of the site and the buildings on the east side are staggered by 5 meters to build a CHS space with the C/A of 60% (Figure 9). Just using a cantilever 5 meters in building on the east side can make the C/A reach 40% (Figure 10).

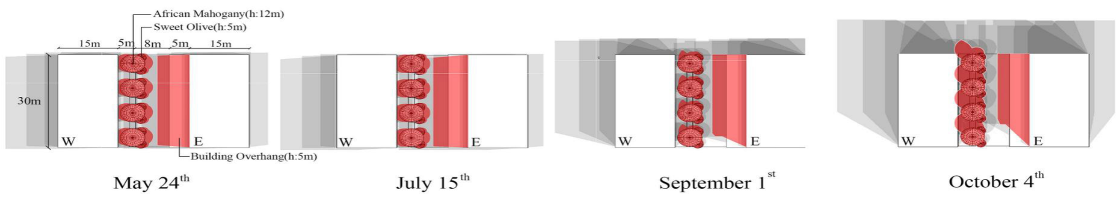


FIGURE 8. The scheme for constructing a CHS space of C/A of 80%
(Combination of 12-meter-high trees,5-meter-high shrubs planted in double rows,and suspending the buildings outwards for 5 meters)

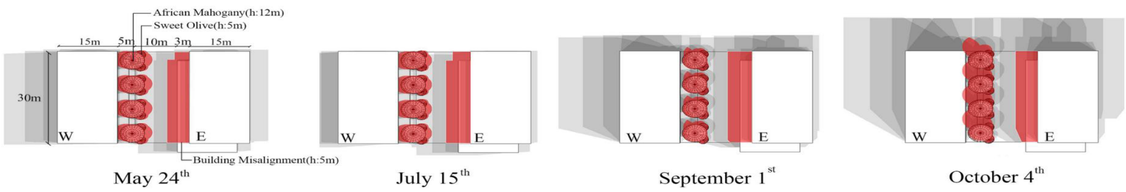


FIGURE 9. The scheme for constructing a CHS space of C/A of 60%
(Combination of 8-meter-high trees and suspending the staggering the buildings by 5 meters)

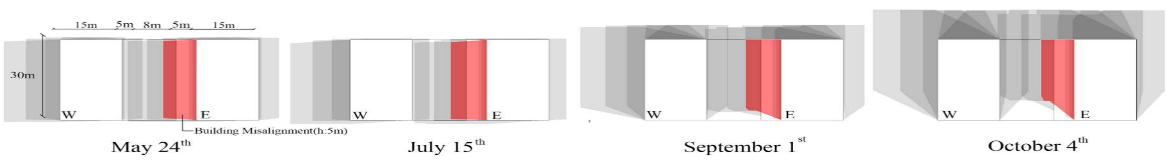


FIGURE 10. The scheme for constructing a CHS space of C/A of 40%
(Suspending the buildings outwards for 5 meters)

CHS SPACE SIMULATION IN THE SOUTHEAST-NORTHWEST OPEN ORIENTATION

According to the results of multiple combined simulations,when the open orientation is SE-NW, the southeast blockers can significantly block the sunlight and create a larger area of shadow. When constructing a CHS space for such an orientation, priority can be given to set the southeast side sunlight-blockers. For example, 8-meter-high trees are planted at 6-meter intervals and 4-meter-high shrubs are planted at 4-meter intervals in double rows ,and 3/5 of the long side of the top of the buildings are overhanged by 3 meters will be achieved the C/A of 80% (Figure 11). Planting 8-meter-high trees at 8-meter intervals and a 3-meter cantilevered building (Figure 12), or just planting 12-meter-high trees at 8-meter intervals can build a CHS space with the C/A of 60% (Figure 13). Just constructing a 4-meter-wide corridor parallel to the open orientation can make the C/A reach 40% (Figure 14).

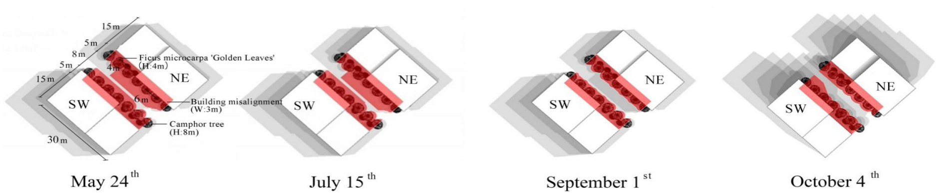


FIGURE 11. The scheme for constructing a CHS space of C/A of 80%
(8-meter-high trees, 4-meter-high shrubs, and overhanging 3/5 of the long side of the top of the buildings outward for 3 meters)

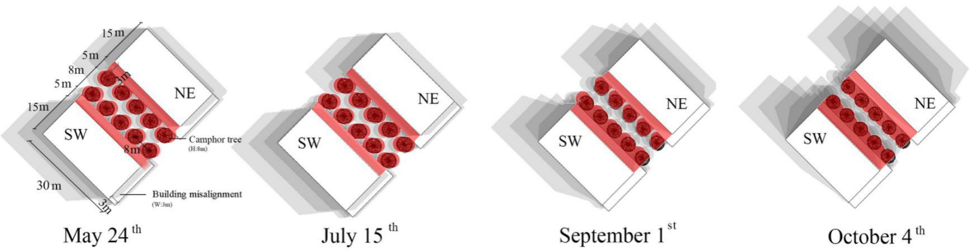


FIGURE 12. The scheme for constructing a CHS space of C/A of 60%
(Combination of 8-meter-high trees at 8-meter intervals and overhanging the buildings outwards for 3 meters)

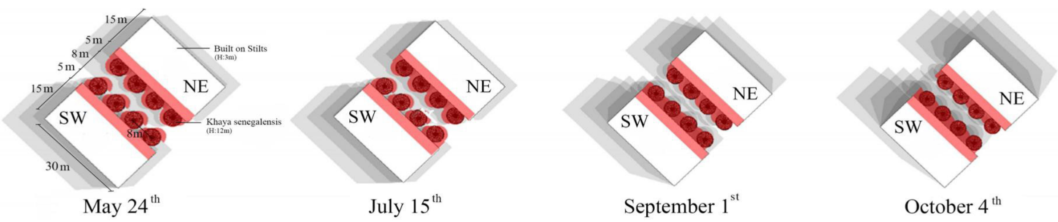


FIGURE 13. The scheme for constructing a CHS space of C/A of 60%
(Planting 12-meter-high trees at 8-meter intervals)

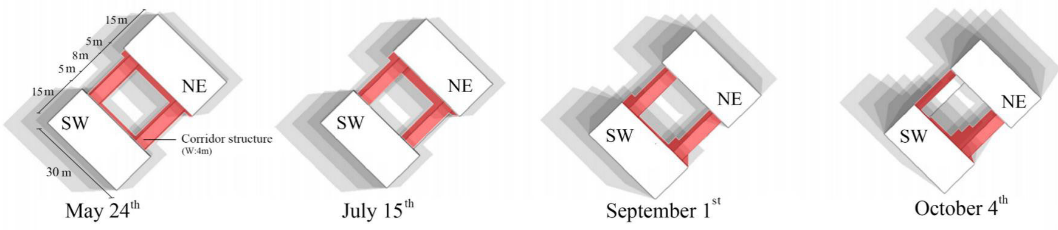


FIGURE 14. The scheme for constructing a CHS space of C/A of 40%
(Setting up two 4-meter-wide corridors parallel to the open orientation)

CHS SPACE SIMULATION IN THE NORTHEAST-SOUTHWEST OPEN ORIENTATION

According to the results of multiple combination simulations, when the open orientation is NE-SW, the blockers on the southwest side can significantly block the sunlight and form a larger shading area of CHS space.For example, four 12-meter-high trees are planted in a square pattern at 8-meter intervals, a 4-meter-wide three-sided corridor is combined, and the top of the building in the northwest corner is “rotated” 15 degrees clockwise, will be achieved the C/A of 80% (Figure 15); and only four square clumps of trees with a height of 12 meters and a distance of 8 meters between trees are planted with a distance of 4 meters. By combining wide three-sided corridors, a CHS space with the C/A of 60% can be constructed (Figure 16), and by simply setting up a 4-meter-wide three-sided corridor, the CHS space with C/A to 40% can also be constructed (Figure 17).

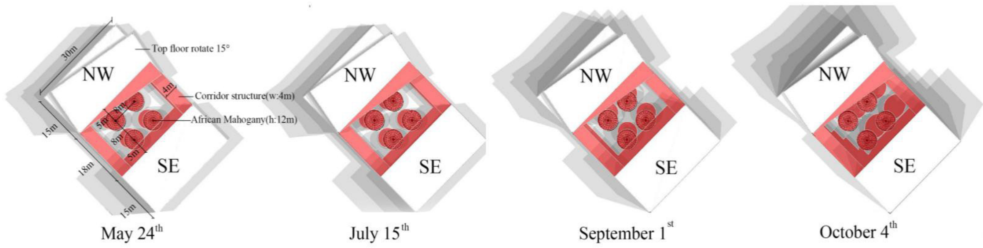


FIGURE 15. The scheme for constructing a CHS space of C/A of 80%
(Combination of 12-meter-high trees clustered at the four corners of a square, a 4-meter-wide three sided corridor, and a clockwise rotation of 15 degrees on the top floor of the northwest building)

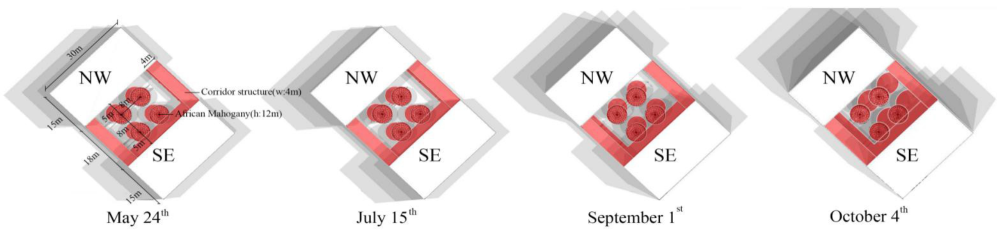


FIGURE 16. The scheme for constructing a CHS space of C/A of 60%
(Combination of 12-meter-high trees clustered at the four corners of a square and a 4-meter-wide three sided corridor)

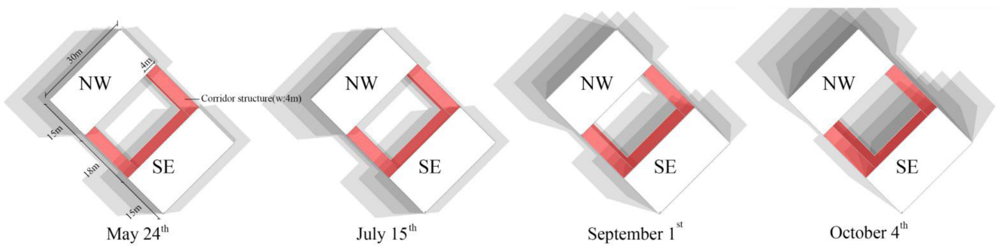


FIGURE 17. The scheme for constructing a CHS space of C/A of 40%
(Setting a 4-meter-wide three sided corridor)

CONSTRUCTION OF CHS SPACE UNDER DIFFERENT OPEN ORIENTATIONS

In the simulation experiment, four typical open orientations were selected: E-W, S-N, SE-NW, and NE-SW. The study discusses and summarizes general architectural and landscape design methods to assist and guide the construction and design of other CHS space with similar orientations. This includes direct access sites like roads and semi-open sites like squares.

In the construction simulation experiment of CHS space for these four typical open orientations, the design method combining "plants, buildings, and structures" or a combination of any two is more effective than using a single element. For example, when the orientation is NE-SW, a CHS space with C/A of 40% can be created by adding structural corridors alone. Using a combination of 12-meter-high trees and corridors can increase this ratio to 60%. When the orientation is S-N, extending the east side of the building by 3 meters can build a CHS space with a shadow area accounting for 40% of the activity area. Introducing a combination of 8-meter-high trees and 4-meter-high shrubs can further increase the C/A to 80%. Selecting appropriate plant species and planting them at specific intervals can enhance the construction of the CHS space. For the E-W orientation, double-row planting of 12-meter-high trees can create a CHS space with the C/A of 60%. Adding 5-meter shrubs to the double-row planting of 12-meter-high trees can increase the C/A to 80% (Table 1).

The above simulation experiment selects four typical open orientations: E-W, S-N, SE-NW and NE-SW, discussers and condenses general architectural design methods and landscape design methods to assist and guide the construction and design methods of other CHS space with similar open orientations, in direct access sites similar to roads and semi-open sites similar to squares.

TABLE 1. CHS space to the activity venue area ratio under different construction design schemes

The C/A of CHS space	The east-west open direction	The south-north open direction	The southeast-northwest open direction	The northeast-southwest open direction
≥80%	Double row planting of 12-meter-high trees, etc.	Combination of 12-meter-high trees,5-meter-high shrubs planted in a double row,and suspending the buildings outwards for 5 meters, etc.	8-meter-high trees, 4-meter-high shrubs, and overhanging 3/5 of the long side of the top of the buildings outward for 3 meters, etc.	Combination of 12-meter-high trees clustered at the four corners of a square, a 4-meter-wide three sided corridor, and a clockwise rotation of 15 degrees on the top floor of the northwest building, etc.
≥60%	8-meter-high trees and 4-meter-high shrubs are planted in double rows and combined with a 6-meter-wide corridor, etc.	Combination of 8-meter-high trees and suspending the staggering the buildings by 5 meters, etc.	Combination of 8-meter-high trees and overhanging the buildings outwards for 3 meters, etc.	Combination of 12-meter-high trees clustered at the four corners of a square and a 4-meter-wide three sided corridor, etc.
≥40%	Double row planting of 8-meter-high trees only, etc.	Suspending the buildings outwards for 5 meters only, etc.	Plantting 12-meter-high trees, etc.	Setting a 4-meter-wide three sided corridor, etc.

The effective construction of CHS space requires an initial analysis of the geographical location, size, and other characteristics of the sunlight-blockers in the existing building environment. This analysis should be based on the date and time periods when shadow is needed by teachers and students in universities. It must also consider the structural and functional constraints of architectural design and renovation tasks. After this analysis, design methods of CHS space can be applied to set and adjust the sunlight-blockers. The shading results should be simulated and tested repeatedly in Ecotect Analysis until the final CHS space meets the shading demands of teachers and students. This process will yield a new plan that can serve as a reference for the architectural design and renovation of colleges and universities (Figure 18)

DESIGN AND VERIFICATION

This article takes a real university environment in a certain Guangzhou as an example to simulate and construct, and gradually verifies the scientificity and feasibility of the construction and design method of CHS space in universities under different open orientations.

This project is located in the teaching area of a university in Guangzhou. Building A is 35 meters high and is mainly used for teaching, with the main entrance located at its southwest corner. Building B is mainly used for offices, supplemented by an external restaurant, with the main entrance located at its south side. The school roads between each other are open from south to north (Figure 19).

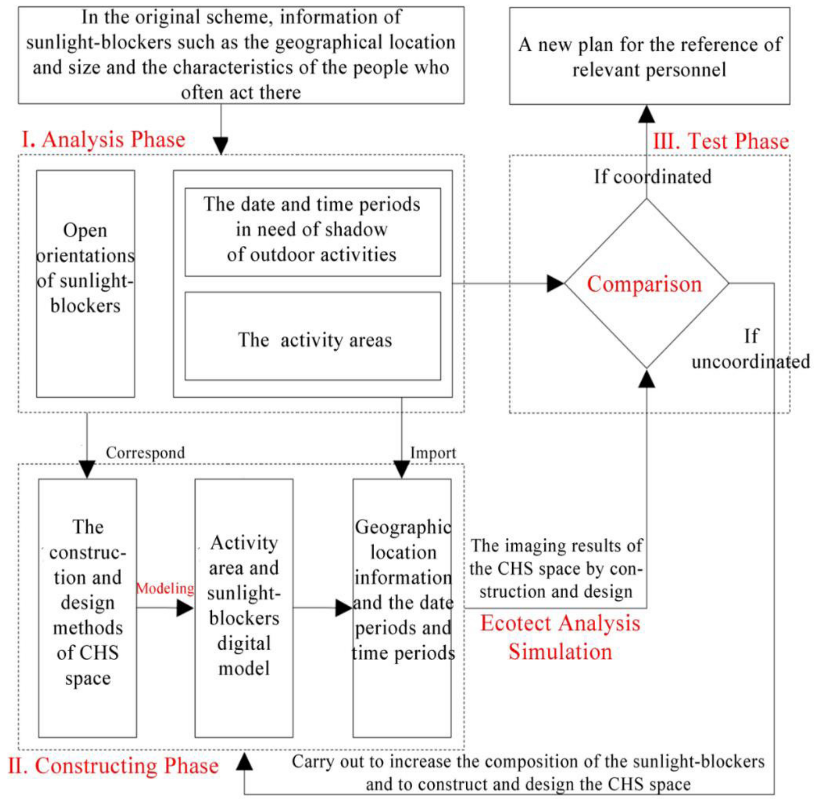


FIGURE 18. The construction and design process of the CHS space in universities under the difference of open directions

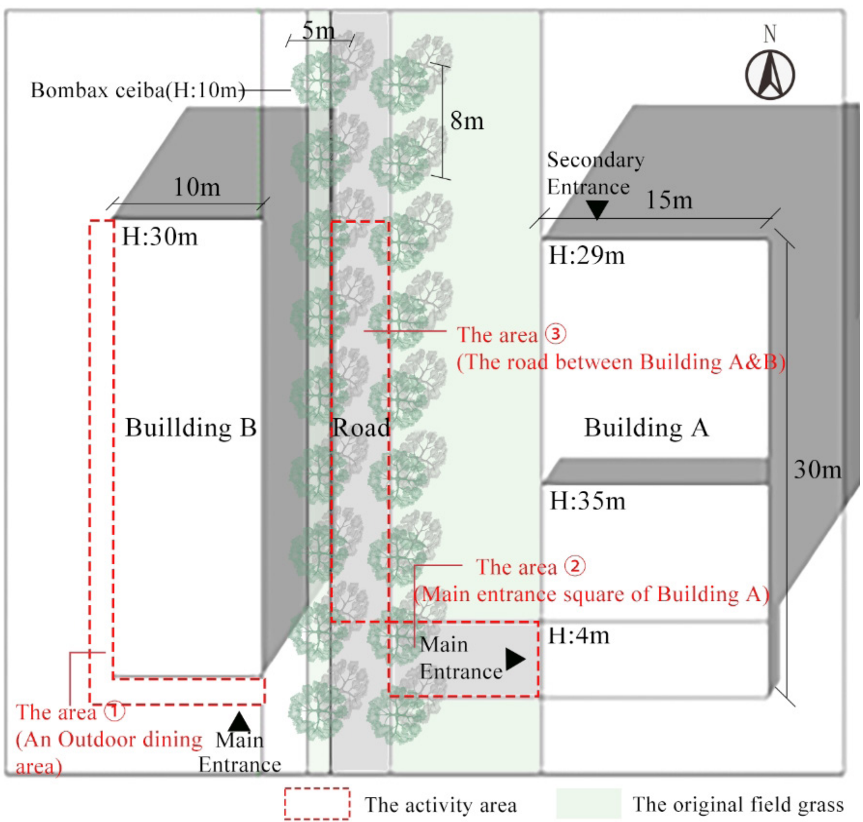
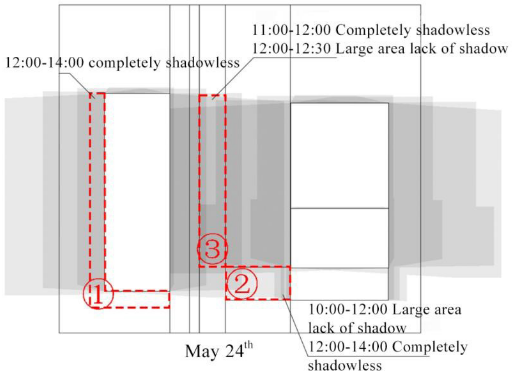
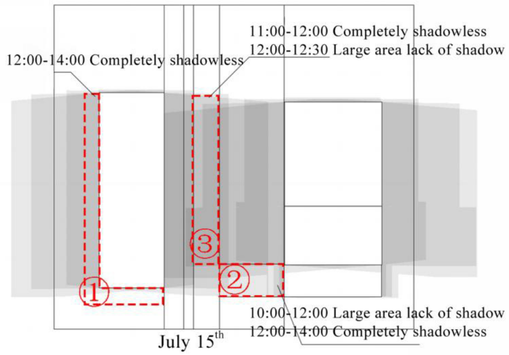
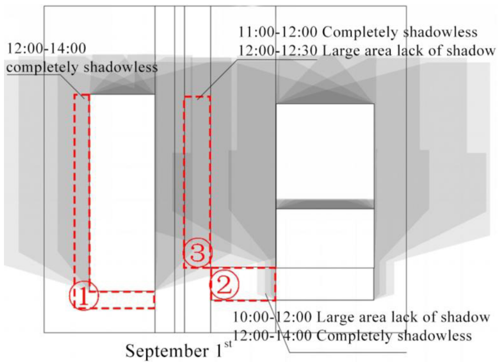
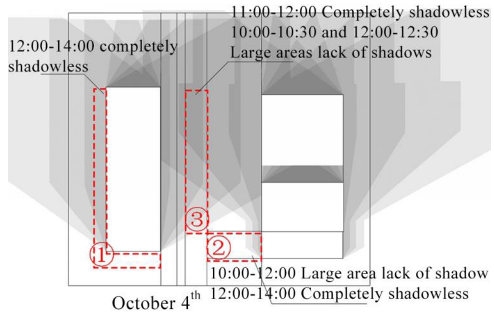


FIGURE 19. The site plan of building A and B in the teaching area of a certain university in Guangzhou

TABLE 2. The shading situation and reasons for the lack of shadow in the CHS space of building A and B during the space-time in need of shadow

	May 24	July 15	The reason for the lack of shadow in CHS space: activity area ①: The east side of the S-N open space lacks sunlight-blockers, and the south side of the E-W open space lacks sunlight-blockers. activity area ②: There is a lack of shadow on the south and west sides of the E-W open space. activity area ③: The east and west sides of the S-N open space lack efficient sunlight-blockers
The CHS space shadow situation in the activity area ①, ② and ③			
The C/A of unconstructed CHS space	There is no CHS in area ①, ② and ③.	There is no CHS in area ①, ② and ③.	
	September 1	October 4	
The CHS spatial shadowing situation in the activity areas ①, ② and ③			
The C/A of unconstructed CHS space	There is no CHS in area ①. In area ②, CHS space with the C/A of about 6.25%. In area ③, CHS space with the C/A of about 21.30%.	There is no CHS in area ①. In area ②, CHS space with the C/A of about 5.59%. In area ③, CHS space with the C/A of about 42.86%.	

ANALYZE THE OPEN ORIENTATION OF ACTIVITY AREAS, DATES AND TIME PERIODS OF TEACHERS AND STUDENTS

According to the survey, this university has a small number of students staying on campus during the summer vacation. The dates in need of shadow for teachers and students can be set from May 21 (the outdoor start date in Guangzhou) to July 15 (the general start date for needing shadow) and from September 1 (the general end date of the summer vacation for Chinese universities) to October 4 (the outdoor end date for needing shadow). There are three activity areas at this site, and outdoor activists in each area are expected to occupy more than 70% of the activity areas in the shadow from 10:00 to 14:00 during these periods.

Based on these dates and time periods, the computer simulation results indicate the following missing shadow problems in the three activity areas:

1. Area ①: The outdoor dining area of Building B has an open orientation of both S-N and E-W. During the dining period from 12:00 to 14:00, the area is almost without guests due to continuous sunshine, lacking any CHS space coverage and being most exposed to the sun during the dates and times in need of shadow.
2. Area ②: The main entrance square of Building A lacks sunlight-blockers on the south side, resulting in a particularly prominent lack of shadow from May 24 to July 15.
3. Area ③: The shared school road between Buildings A and B is insufficiently shaded due to the use of Bombax ceiba trees, which have low branch and leaf density, large height under branches, and wide planting spacing. Additionally, the distance between Buildings A and B from the school road contributes to the lack of effective sunlight-blockers. Only a portion of the CHS space is available from September 1 to October 4 (Table 2).

After calculation, the CHS space in the three activity areas is largest in Area ③ on October 4, accounting for 42.86% of the area. However, there is still a significant gap between the proportion of continuous shadow area and the expected 70%. It is necessary to construct a CHS space in the corresponding open orientation to solve the problem of exposure to sunlight.

GRADUALLY BUILD A CHS SPACE IN NEED OF TEACHERS AND STUDENTS

CONSTRUCTING CHS SPACE IN THE ACTIVITY AREA ①

Activity area ① has the problem of missing shadows in both the E-W and S-N orientations. Adjustments to the south and west sides of the structure can be considered separately. To maintain the existing open view of the dining area at the bottom of Building B, the use of frame overhangs was explored.

At a height of 3.5 meters from the ground, the building was cantilevered 1 meter to the west and 1 meter to the east, and an impervious frame was set up for simulation and testing. It was found that the CHS space constructed by overhanging 1 meter provided some shadow during the shading demand period. Although it did not cover 70% of the activity area, the CHS space constructed showed some effectiveness compared to the situation before construction. This indicates the feasibility of this construction method and provides a reference for subsequent design.

Next, the distance of the overhang was increased by 1 meter to the west and east, and simulations and comparisons were carried out. When the overhangs were extended 4 meters to the south and 3 meters to the west, the CHS space covered 77.8% (Table 3).

CONSTRUCTING CHS SPACE IN THE ACTIVITY AREA ②

For the east-west activity area ② at the main entrance of Building A, consider adjusting the composition on the south side. To enhance the short main entrance canopy of the pre-construction Building A, extend the main foyer along the canopy. This will complement the building's existing functions of shade and rain protection and reinforce the main entrance's prominence.

Along the main entrance foyer of Building A, which protrudes southward, a parallel extension of 10 meters is made along the activity area ②. A main entrance porch is added, aligned with the top of the 4-meter-high foyer. After constructing the initial CHS space, the target CHS space for teachers and students was compared and tested. It was found that the C/A of CHS space is over than 76.4% (Table 4).

TABLE 3. Comparison of the situation and results between the CHS space and the activity area ①

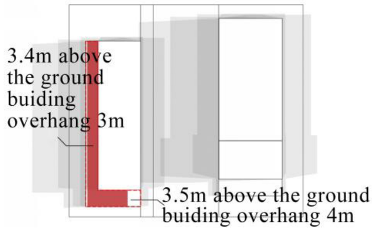
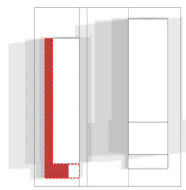
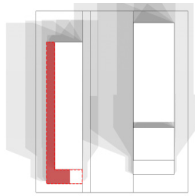
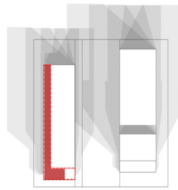
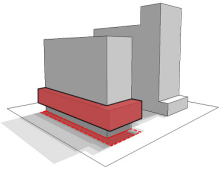
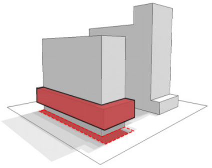
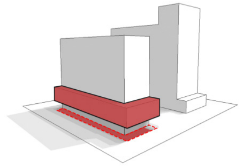
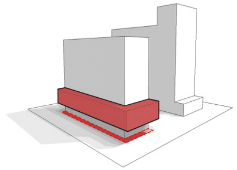
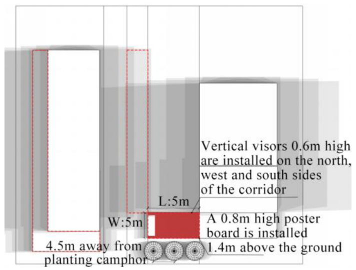
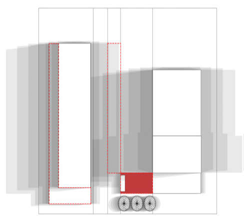
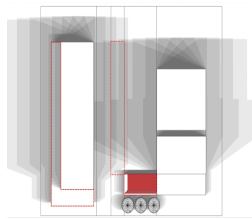
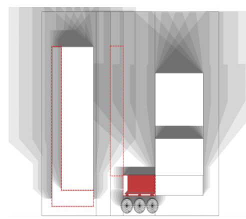
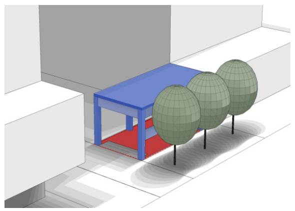
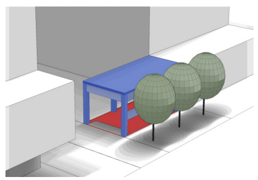
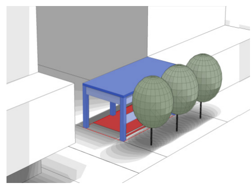
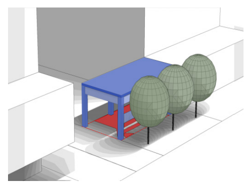
	May 24	July 15	September 1	October 4
Activity area ①Shading situation of CHS space after construction				
Activity area ① perspective view of CHS space after construction				
The C/A of constructed CHS space	80.5%	88.1%	78.8%	77.8%

TABLE 4. Comparison of the situation and results between the CHS space and the activity area ②

	May 24	July 15	September 1	October 4
Activity area ② Shading situation of CHS space after construction				
Activity area ② perspective view of CHS space after construction				
The C/A of constructed CHS space	76.4%	76.5%	83.8%	82.4%

CONSTRUCTING CHS SPACE IN THE ACTIVITY AREA ③

The area ③ with a south-north orientation is located on the school road between buildings A and B. Due to the large distance between the buildings and the small canopy width of the cottonwood trees on both sides, the density of branches and leaves is sparse, and the height under the branches is too high. This results in a continuous lack of shadows in the activity area at midday. Therefore, adjusting the sunlight-blockers on the east and west sides of the school road and its top composition is essential.

The first adjustment involved changing the roadside trees to 12-meter-high African Neems with a spacing of 8 meters. However, simulations revealed that the large height of Neem's under-branching caused significant shadow gaps in the CHS space at 10:00-11:00 and 13:00-14:00, failing to meet the required proportion of the shadow area. In the second construction, 8-meter-high Camphor trees were inserted between the African Neems to fill the space under the branches and enhance the shadow composition. Repeated simulations and adjustments showed that combining African Neems (8 meters apart and 12 meters high) with Camphor trees (6 meters apart and 8 meters high) still left a large shadow gap in the central area of the school road.

In the third construction of area ③, a low flower rack (4.5 meters high, 4 meters long, and 1.2 meters wide) and a high flower rack (5.5 meters high, 4 meters long, and 1.2 meters wide) were alternately set up on the ground at 4-meter intervals. The south side of each was folded down by 45° at 0.4 meters and 0.8 meters, respectively. This arrangement ensured that the shading area of the CHS space accounted for more than 71.66% of the activity area during the dates and time periods in need of shadow for teachers and students, meeting various shading demands (Figure 20 and Table 5).

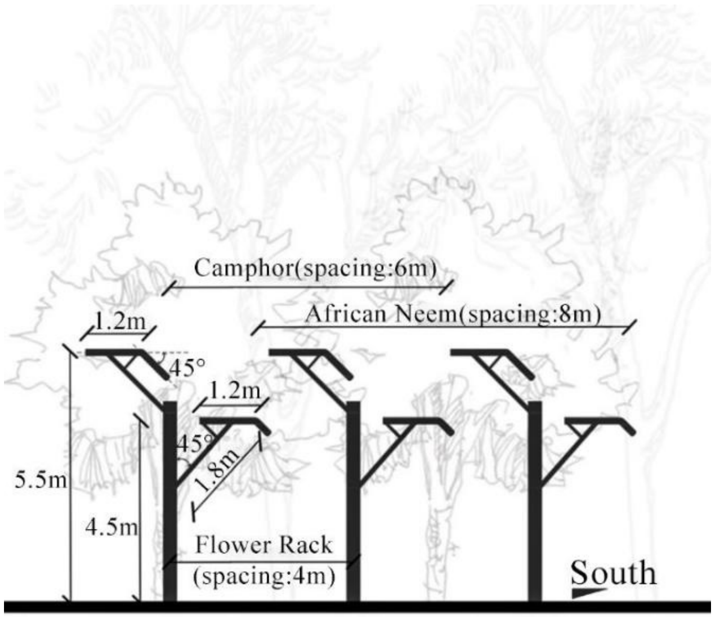


FIGURE 20. Construction and design of CHS space in shaded area ③

TEST AND VERIFY THE CONSISTENT RELATIONSHIP BETWEEN THE SHADING DEMAND OF TEACHERS AND STUDENTS AND THE CHS SPACE AFTER CONSTRUCTED

In terms of shading demand, after simulation and testing, the final CHS space accounts for 91.2% of the total activity areas ①, ②, and ③ during the dates and time periods in need of shadow. Regarding the rationality of the construction, the three activity areas did not adopt a significant renovation plan, resulting in a relatively small negative impact on the original buildings (Table 6). The construction and design of the CHS space in this teaching area are feasible, reasonable, and scientific.

TABLE 5. The activity area ③ is constructed to obtain the CHS space

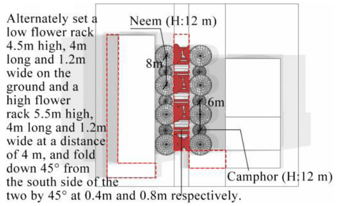
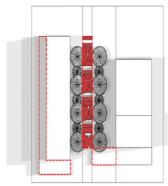
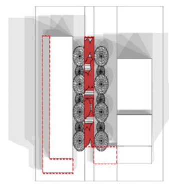
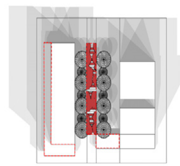
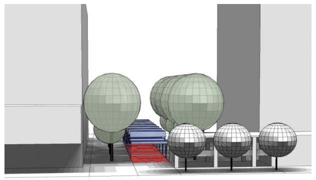
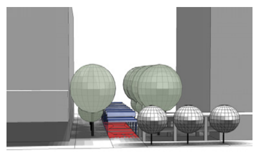
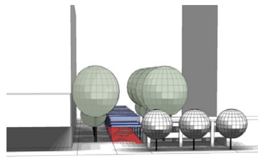
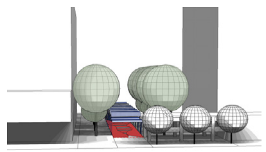
	May 24	July 15	September 1	October 4
The area ③ shading situation of CHS space after construction				
The area ③ perspective view of CHS space after construction				
The CHS space of constructed plan to the activity area ratio	73.10%	71.66%	73.35%	76.69%

TABLE 6. Overall process of constructing the CHS space in the areas of shading demand

	Before effective constructed	the CHS space after the first construction	the CHS space after the second construction	the CHS space after the third construction
The C/As of CHS space in the three areas	The total area of the activity area is 276m^2, and the area of the CHS space is 0, which accounts for 0%	After the first construction, the average area of CHS space is approximately 32.8m^2, accounts for 11.9%	After the second construction, the average area of CHS space is approximately 67.6m^2, accounts for 11.9%	After the thirdconstruction, the average area of CHS space is approximately221.0m^2, accounts for 80.08%
Characteristics of sunlight-blocker	Buildings: Building A is 30 meters high, Building B is 35 meters high Structures: None Plants: No trees or shrubs except Bombax ceibas	Buildings: Extended 3 meters to the west at a height of 6-18 meters in the building Structures: None Plants: No trees or shrubs except Bombax ceibas.	Buildings: Extended 3 meters to the west at a height of 6-18 meters in the building; Structure: Added a 10 meters corridor; Plants: No trees or shrubs except Bombax ceibas	Buildings: Buildings with a height of 6-18 meters should be staggered 3 meters to the west; Structure: Added 10 meters of corridor and flower racks with spacing 4 meters; Plants: Planted African Neems and Camphors.

CONCLUSION

This article addresses the serious problem of outdoor solarization in colleges and universities caused by insufficient shadow area of CHS space under different open orientations. It discusses and researches the idea of constructing CHS space from three aspects: buildings, structures, and plants. Through the simulation and testing of Ecotect Analysis, it provides an effective design method for CHS space under different open orientations, serving as a reference for the construction of CHS space in outdoor areas of colleges and universities.

The construction of CHS space with different open orientations has corresponding priorities: for E-W semi-open space, priority should be given to adjusting the composition on its south side; for S-N semi-open space, priority should be given to adjusting the composition on its east and west sides; for SE-NE semi-open space, priority should be given to adjusting the composition on its southeast side; and for NE-SW semi-open space, priority should be given to adjusting the composition on its southwest side.

Additionally, the construction of CHS space needs to highly respect its own attributes, such as human expectations, cost, structural stability, and the rationality of the transition between the old and new buildings, as well as environmental constraints like human requirements of the site, its historical lineage, and its climatic characteristics.

Meanwhile, this paper has three shortcomings. Firstly, the listed methods are insufficient for further in-depth research. The shadow measurement in the CHS space is affected by spatial and other objective factors, requiring deeper expansion to consider a wider range of shadow types and shape combinations with support from more specific practical situations. Secondly, there is a lack of cost research and estimation for the design of shadow formation in CHS spaces. The project cost is influenced by factors such as design, personnel, and materials. Currently, the architectural design in the transformation stage of the construction site reality is not well grasped, which can lead to increased project costs, inefficient resource use, and potential economic losses. Thirdly, while this paper addresses the construction method of CHS space under different open orientations, there are various combinations of programs that cannot be detailed due to time and space constraints. Further research and large-scale practice are needed to expand and deepen the analytical method, and it is hoped that future research will improve the methodology.

In summary, although research has been conducted on the CHS space of some universities in Guangzhou, verifying the feasibility and scientific validity of their construction and design methods, there is still a shortage of research universities. In the future, it is necessary to consider more diverse combinations of structures and more comprehensive types and forms of structures to better adapt to actual situations and practical demands. Future research should include more relevant university cases to provide better reference directions for the planning, architectural design, and environmental design of universities in Guangzhou and similar latitudes.

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DECLARATION OF COMPETING INTEREST

None

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