Construction Characteristics and Design Strategy of the “Constant-holistic Shadow” in Mountainous Urban Area in Hot Summer Zone

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Abstract: The sunlight in summer is generally strong in hot summer zone, so the long-lasting shadow is conducive to people’s outdoor activities for a long time. Creating a space with “Constant-holistic Shadow” has become an important way to improve the outdoor thermal comfort. However, with special shadowing condition featuring in a varied topography with big vertical height, the sunshine shadowing formation in mountainous urban area is significantly different from that of plain area. Therefore, it is necessary to take the special shadowing conditions into consideration in exploring the influence and relevance on the “Constant-holistic Shadow” construction. This paper analyzed the characteristics of outdoor spatial morphology and shadow forming elements in mountainous urban areas, revealed the correlation between the characteristics and “Constant-holistic Shadow” space, and expounded the main design strategies of “Constant-holistic Shadow” space in mountainous urban areas so as to provide ideas and strategic guidance for more effective construction of “Constant-holistic Shadow” space in mountainous urban areas.

1. Introduction
The sunlight in summer is generally strong in hot summer zone, greatly affecting the thermal comfort of people in outdoor activities, making people tend to actively seek comfortable space with shadow. The “Constant-holistic Shadow” space is formed by buildings, structures, plants and other shadow-making buildings in a certain range. During a certain period of time, it keeps a complete full shadowed area, serving as an ideal outdoor activity space for people without changing the field. The mountainous urban area is in a varied topography with different vertical height. Comparing to it, some cities in plain area have similar terrain characteristics. In this kind of urban areas featuring mountainous terrain characteristics, we should fully consider the particularity that is significantly different from the plain urban areas of the terrain carrying the shadow when building the “Constant-holistic Shadow” space. This is what we have to take an active and in-depth exploration.

With regard to the construction, utilization, comfort and shadow space of outdoor public space in mountainous urban areas, some scholars believe that in those areas, flat land is a limited precious resource, which promotes the publicity and externalization of some living spaces to some extent, so that we can see people’s daily life in the urban public space [1]; Considering the outdoor activity space in mountainous urban area, proper environmental design to the shadow area can fully use the existing outdoor space and provide a more natural and humanized place [2] Because the altitude is higher than...
that of the surrounding plain areas, the mountain areas in hot summer zone is generally hot with more solar radiation. In the design of outdoor activity site, the thermal environment comfort of the site should be considered, and the design of shadow space with good thermal comfort is particularly important. [3] In the environmental design of shadowed area, all kinds of movable or temporary building structures and plants are supposed to be utilized with permanent main structure of building to jointly shape public shadow space environment, so as to minimize the negative impact of shadows and create the most effective and sustainable shade with suitable sunshine environment space. The available research proves that there has been some study on the flat land use and terrain change in mountainous urban areas, but there is no active use of shadow space for the terrain characteristics of mountainous urban areas, especially the specific exploration in constructing “Constant-holistic Shadow”. Therefore, in view of the particularity of the terrain and the corresponding outdoor space in the mountainous urban area, this paper analyzes the characteristics of the outdoor spatial morphology and the forming elements of the “Constant-holistic Shadow” in the area, expounds the correlation between these characteristics and the construction of the constant total shadow, and expounds the design strategy of the construction of “Constant-holistic Shadow” in mountainous urban area, so as to provide significant ideas and strategic guidance for improving the light and heat comfort of “Constant-holistic Shadow” in mountainous urban areas, improving the utilization rate of outdoor shadow space, and enriching the theory and method of “Constant-holistic Shadow” space construction.

2. Characteristics of Outdoor Spatial Morphology and “Constant-holistic Shadow” Space Element in Mountainous Urban Area

There is a big difference between the outdoor space form between mountain areas and plain areas, making the “Constant-holistic Shadow” space elements in outdoor different from normal plain area. This paper explores the particularity of terrain of mountainous urban area, and the shadow-making characteristics of “Constant-holistic Shadow”, and expounds the spatial characteristics of “Constant-holistic Shadow” in mountainous urban area.

2.1. Characteristic of Outdoor Spatial Morphology in Mountainous Urban Area

The mountainous urban area shares a varied topography with big vertical height, which is reflected in the overall appearance of outdoor space. Based on the special nature of the terrain, the buildings in mountainous urban comply with the topography and are built closing to the mountains rather than in the horizontal layout in the plain area.

In the artificial exploitation of the mountain, people adopt different measures such as digging, leveling and earthwork balance according to the special shape of the mountain to improve the utilization rate of the mountain land. Therefore, the construction of outdoor “Constant-holistic Shadow” space in mountainous urban area is different from that in plain area in view of the mountain itself, the cliff, platform and other topographic elements caused by people. Complying with the fluctuation of the hillside, the buildings are distributed in step like, standing on two different elevations. The two buildings on the same side of the mountain are on different levels, so that the falling surface of the structure is placed in two different elevation differences (Fig. 1). At the same time, mountain city is different from plain city in road and landscape layout, so it is necessary to consider the complex terrain characteristics of mountain city. During the development of mountains, the natural mountains are artificially transformed according to the actual use to form slope land, platform land, winding mountains and other construction forms (Fig. 2).
2.2. Characteristics of Shadow-making Elements of Outdoor “Constant-holistic Shadow” Space in Mountainous Urban Area

Owing to a varied topography with big vertical height, the outdoor spatial morphology in mountainous urban area is different from the general plain area. Under special outdoor spatial morphology, the elements of outdoor “Constant-holistic Shadow” change. Even if the height of the two shadow-making building is the same, the height difference is presented as the height difference distance (h) from the top height of the building. The shadowed area made by shadow-making building with higher horizontal plane is projected to the low elevation difference, making the shadow of the structure is divided into two parts and placed on two different horizontal planes (Fig. 3). When the elevation position coincides with the boundary of the building, the overall height of the building is higher (H1 + H3), which makes the overall shadow-making building higher in height (Fig. 4). In addition, different slope and aspect make the outdoor space change with the change of slope and aspect.

Therefore, the difference of elevation in the outdoor space in mountainous area is more complicated than that of the general plain area, which makes the surface carrying the shadow in outdoor “Constant-holistic Shadow” change from one plane to two or more planes. In the meanwhile, plus the height of terrain, the overall height of the shadow-making building becomes even higher.

![Fig. 3 Schematic diagram of shadowed area made by the same structure in different horizontal planes](image1)

![Fig. 4 Schematic diagram of the shadowed area made by the structure in different height](image2)

2.3. Characteristics of Outdoor “Constant-holistic Shadow” Space in Mountainous Urban Area

The particularity of outdoor “Constant-holistic Shadow” in mountainous urban area is reflected in the characteristics of “Constant-holistic Shadow”. The characteristics of terrain change outdoor in mountainous urban area create the spatial characteristics of “Constant-holistic Shadow” in form, shape, orientation and so on. For example, when the shadow-making build is located in different elevation surfaces, the “Constant-holistic Shadow” space is placed in different surfaces, and the shadow is placed in several corresponding spaces with different elevation differences according to the changes of the surface (Fig. 5). In addition, it can be seen from the plan that when the building is located in the plane, it represents as a complete “Constant-holistic Shadow” area; when the building is located in the mountainous urban area, due to the earthwork of the mountainous area in the early design stage, the horizontal plane of the surface carrying the shadow will be divided into two, and the “Constant-holistic Shadow” space and the mountain coincide. (Fig. 6, Fig. 7)

In building the target of outdoor “Constant-holistic Shadow” in mountainous urban area, in combination with the actual elevation difference change, we should consider the change of site elevation difference in mountainous area, and the location and angle of retaining wall, the correlation characteristics of different shadow forming elements and “Constant-holistic Shadow”. We should create a special “Constant-holistic Shadow” for outdoor activity to meet the needs of the crowd to use the activity site in the corresponding period of time.
3. Correlation Analysis on the Shadow Forming Elements and “Constant-holistic Shadow” Space in Mountainous Urban Areas

The outdoor spatial morphology and shadow forming elements in mountainous areas are related to the spatial size, shape, spatial distribution and time distribution of “Constant-holistic Shadow”. As the “Constant-holistic Shadow” space is mainly affected by the side interface and the top interface, we should consider the influence of terrain change on the “Constant-holistic Shadow” space formed by the side interface and the top interface in discussing the correlation of “Constant-holistic Shadow” in mountainous urban areas.

3.1. Correlation with the Distribution of the “Constant-holistic Shadow” Space

Mountain terrain is vertical and multi-dimensional in direction, which provides non planar and non-orthogonal shadowing forms for mountain urban. Therefore, in the early stage of mountain development, people conduct earthwork according to the terrain, thus the original slope is leveled into several flat ground with different elevations, and the distribution of “Constant-holistic Shadow” space in mountain city will change as the position of retaining wall changes. Assuming that the solar altitude, the size of the shadow-making building and the height are fixed, the location of the retaining wall will affect the distribution of “Constant-holistic Shadow” space. When the position between the building and the retaining wall is infinitely close, we can deem the height of the building and the height of the retaining wall as the total height of the shadow-making building. Then the “Constant-holistic Shadow” space is taken as a whole, and only the shadow is at the low elevation; when there is a fixed distance between the shadow-making building and the retaining wall, the “Constant-holistic Shadow” space in the mountainous urban area, cut apart into two different horizontal elevations, is different from that in the plain area; When the distance between the shadow-making building and the retaining wall reaches a certain value, the sunlight intersects with the retaining wall, and the “Constant-holistic Shadow” space in this area is divided into two independent shadow spaces, and the “Constant-holistic Shadow” space at low elevation increases with the elevation (Fig. 8).

3.2. Correlation with the Shape of “Constant-holistic Shadow” Space

The shape of “Constant-holistic Shadow” space both in the general plain area or the mountainous urban area is closely related to the size and shape of shadow-making building like the square, the circle, the
Different shapes of shadow-making buildings affect the boundary shape of “Constant-holistic Shadow” space. Because of the elevation in mountainous city, the different arrangement and distance of retaining wall has different influence on the shape of “Constant-holistic Shadow” space.

At the same time, the shadowed area created by the building in the surface carrying the shadow with elevation change is bigger than that in the flat area (Fig. 9). In addition, the “Constant-holistic Shadow” space in mountainous urban area is related to the position of retaining wall. In a specific period of time, when there is a certain distance between retaining wall and the building, the shadow shape does not change; when the retaining wall reaches the boundary of shadowed area made by the building, the “Constant-holistic Shadow” space formed by the top of the building will appear dislocation, breaking the continuity and integrity of the original “Constant-holistic Shadow” space (Fig. 9).

When there is an angle between the retaining wall and the bottom of the structure, the spatial morphology of “Constant-holistic Shadow” changes. When the angle range of the retaining wall exists in the shadow formed by the boundary of the side interface, there is no significant difference between the “Constant-holistic Shadow” space shape and the horizontal shape of the retaining wall (Fig.10). When the angle of the retaining wall is large and it is located on the shadow boundary formed by the top section boundary, the “Constant-holistic Shadow” space appears dislocation, and the spatial form changes (Fig. 10.).

Meanwhile, the amount of elevation affects the size of “Constant-holistic Shadow” space. To a certain extent, the more the amount of elevation, the larger the area of “Constant-holistic Shadow” space (Fig. 11).

3.3. Correlation with the Coverage of the “Constant-holistic Shadow”

The coverage of outdoor “Constant-holistic Shadow” in mountainous urban area is closely related to projection direction, slope gradient and aspect. According to the features of slope aspect elements of
outdoor “Constant-holistic Shadow” in mountainous urban area, we could conclude that when the solar elevation and the height of the shadow-making building are fixed, the shadow horizontal distance on level ground is D1. When the shadow horizontal distance made by the shadow-making building on the south slope, the shadow width D1 > D2; when the shadow horizontal distance made by the shadow-making building on the north slope, the shadow horizontal distance D3, D1 < D3 (Fig. 12). It can be seen that the area of shadow-making building has closed relation to the aspect of the surface carrying the shadow.

In planning and constructing mountainous urban, the applicability standard of slope is evaluated. Gentle hill with the slope in 3-8 degrees is the most ideal construction site; hillock with the slope in 8-810 degrees is the middle hill, which requires backfill of the earthwork and the site only needs less excavation and filling earthwork; when the slope is 10-25 degrees, it needs more excavation and filling earthwork; when the slope is greater than or equal to 25 degrees, it is not suitable for construction land [5]. Therefore, when considering the outdoor spatial slope elements of “Constant-holistic Shadow” in mountainous urban areas, only the slope variable of 0-25 degrees is considered. The horizontal distance of outdoor “Constant-holistic Shadow” decreases with the decrease of the angle between the slope and the building (Fig. 13). The shadow coverage of the “Constant-holistic Shadow” outside the north slope increases with the increase of the angle between the slope and the building (Fig. 14).

Therefore, when considering the correlation between slope and outdoor space with “Constant-holistic Shadow”, we should change the angle between the structure and the hillside, retain the optimized slope elements as far as possible and properly reduce the earthwork balance. In combination with landscape facilities and road system, we can provide people with good thermal comfort and entertainment places.

Fig. 12 schematic diagram of shadowed area in different positions of the mountain at the same time

Fig. 13 schematic diagram of shadow forming variation law of different slopes on the South Slope

Fig. 14 schematic diagram of shadow forming variation law of different slopes on the North Slope

3.4. Correlation with Time Period of “Constant-holistic Shadow” Space

As a three-dimensional space, “Constant-holistic Shadow” space form with time changes when the shadow body is located in different directions of the mountain. The shadowed area outdoor in mountainous area changes with time. Here we choose a shadowing-making building located in the east slope of a certain period. From 9:00-17:00, the area with “Constant-holistic Shadow” drops sharply from large to small during 9:00 to 12:00, and surges from 12:00-17:00. The shadowed area of 9:00-12:00 is less than that of 12:00-17:00. However, the shadowed area of the west slope is opposite to that of the south slope (Fig. 15, Fig. 16). It can be seen that the slope and time are highly relevant to the shadowed area. At the same time, the shadowed area is different in different slope.
4. Design Strategy of “Constant-holistic Shadow” in Mountainous Urban Area

4.1. Planning and Design Stage
In the early planning and design stage, there are differences in outdoor “Constant-holistic Shadow” space with different orientation of the mountain. Due to the different slope of the construction land in different positions of the mountain, the spatial time rule of “Constant-holistic Shadow” is different. Under the consideration of land use properties and building functional attributes, we should consider the building goal of outdoor “Constant-holistic Shadow” space, as well as the outdoor activity time demand of different functional attribute land projects. In the planning and development of mountainous urban area, we should consider the space “Constant-holistic Shadow” of outdoor activity site as far as possible, and choose the suitable slope aspect and the suitable mountainous urban area for outdoor activity.

4.2. Site Design Stage
According to the background of the project, a detailed survey of the project site is carried out to fully investigate the site landform and landscape, and to consider the space demand and objectives of “Constant-holistic Shadow” of the outdoor activity site. Considering the actual demand and influences of slope of the site and the road, the plane position and other factors on the “Constant-holistic Shadow” space, we should think about whether it can reduce the leveling area and reduce the earthwork, and keep the favorable slope on the “Constant-holistic Shadow” space, and increase the horizontal shadow area of the “Constant-holistic Shadow”, or whether it is necessary to increase the horizontal area of “Constant-holistic Shadow” space by increasing the number of elevations and the horizontal angle of retaining wall after earthwork and the horizontal with the structure.

4.3. Multi Stage Coordination in the Design Process
The multi-stage coordination in the design process follows the principle of macro first and micro second. It first determines the coverage and time period demand and horizontal area demand of the “Constant-holistic Shadow”, and ensure the coverage and boundary range of the target shadow area by controlling the lope and aspect, and the size of the shadow-making building. Finally, it builds the target “Constant-holistic Shadow” through landscape design, and the supplement the missing shadowed area.
5. Conclusion
The mountainous urban area is obviously distinguished from the flat urban area in terms of terrain gradient, aspect and shadow forming law, so it shares apparently different conditions in building the “Constant-holistic Shadow” space reflecting in its special shadow forming elements such as coverage and shadow horizontal distance. Thus, it shows its uniqueness in the formation conditions, utilization needs and methods, and build goals of “Constant-holistic Shadow” space. The construction of “Constant-holistic Shadow” space in mountainous urban areas should be based on the correlation between the “Constant-holistic Shadow” space in size, shape, distribution, time and other aspects with the shadow forming elements, and take corresponding special construction strategies, such as preliminary planning, site design refinement, the size of the shadowed area, plants and other complementary means in shadow making, so as to provide basis and overall strategy for the construction of mountain and related structures in mountain cities, and lay the foundation for the next exploration of “Constant-holistic Shadow” space in mountain cities.

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