Study on the Spatial Form of Urban Green Space for Both of Social Needs and Climate Mitigation

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Abstract: This study stems from the research problem originated from the fact that in the practice of urban renewal design, the emphasis on urban green space planning is relatively low, and also from a limited and single perspective in developing urban green space, where previous studies either focused on the environmental function of climate mitigation, or focused on the social context as urban public spaces. It would cause waste of urban space resources, if it failed to combine these two functions in studying urban space units. Therefore, this study assumes that the green space that can regulate the climate is also capable of influencing people's activities through social aspect, meanwhile the space that affect people's activities can also mitigate the climate. Hence, a concept of adaptable green space is proposed to highlight the comprehensive function the space served, which can satisfy both the social function for pedestrian activity and the ecological mitigation effect. The main objectives of this paper are as follows: Providing an overview of the current state of research on urban green space morphology and its relationship with climate mitigation. Reviewing the current research on urban green space configuration and its relationship with human satisfaction based on environmental psychology. Comparing the spatial features benefit for urban climate mitigation or satisfying for human way finding. Group and find the similarities and differences between them.

Keywords: spatial form; urban green space; social need; climate mitigation

1. Introduction

Urban morphology and greening has been proved to contribute to ameliorate outdoor bioclimatic thermal conditions, the way of usage in public environment and also degree of pedestrian satisfaction toward these spaces [1]. Moreover, through an overview of recent studies on urban green spaces, what is known is that the benefits of greening space in urban areas have been widely accepted; nevertheless, to implement this knowledge globally stays hard, stated by Breuste et al. in 2013 [2]. According to research background estimated by Elmqvist et al, even though U.S. and European cities (e.g., New York City, Seattle, and Vancouver in North America and Berlin, Stockholm, Rotterdam, Vienna, and Helsinki in Europe) have devoted to green infrastructure construction and generating a prevailing trend of outdoor activities, there still left tremendous challenges for developing countries due to their high-speed land transformation to residential use and their overlook to natural green space, especially in megacities [3]. The turning point then comes after the problematic era when rapidly growing Asian cities (e.g., Mumbai, Karachi and Hong Kong) soon were faced with increasing ecological pressures and dramatic loss of green land and more recovery project were invested into developing urban area, such as Shanghai, Guangzhou, Hangzhou and Beijing in China [4].

The research problem originated not only from the fact mentioned above that in the practice of urban renewal design, the emphasis on urban green space planning is relatively low, but also from a single perspective in developing urban green space, where studies either merely focused on the ecological function of climate mitigating, or focused on the social usability as urban public spaces. It would cause some waste of space resources, if it failed to combine these two functions in limited urban space units. Addressing on this problem, with the publication of the Millennium Ecosystem Assessment and the later generalization of the application of the ecosystem services framework to the urban context [5], natural science and ecological research have started to realize the necessity to include sociology research and methods. The resulting interdisciplinary research addresses the benefits that ecosystems can provide for urban citizens through urban green spaces. Owing to the increasing pressure on the urban ecosystems in many cities along with ongoing population growth and related densification, future urban green space research needs to conduct multi-disciplinary research using expertise from both natural and social science.

Kabisch (2015) has uncovered that the two main functions of urban green space: social cohesion and environmental mitigation, and tried to maximize the benefits. Among the ingredients that influence both items, spatial satisfaction from citizens has played a significant role. Specifically, morphology and space configuration of urban green space would not only affect human behavior and preference in green space from the domain of environmental psychology, but also is of great importance in bioclimatic mitigation of such space in the field of urban meteorology. With respect to urban green space management, spatial characteristics should be better satisfying both social and ecological demand, thus this paper attempts to exploit evidence on whether existing studies either on spatial design of urban green space influencing human interaction or on spatial factor helping climate mitigation would present some underlying correlations in between.

Therefore, this study assumes that the green space that can regulate the climate is also a space for attracting people's activities, and the space that attracts people's activities can better regulate the climate. Hence, a concept of adaptable green space is proposed to regulate the function of the climate, which can satisfy both the social function of the pedestrian and the ecological green corridor.

Apart from the number of published studies and reviews in urban green space research, no structured overview of research findings on the comprehensive two functions of green space exists. Most of the reviews being published focus more on the mono-discipline (e.g. ecological function of climate mitigation or psychological function of human satisfaction) but they neither explain the correlation between these two influences of urban green space on people as a whole nor do they use any graphic approach to outline the magnitude of space factor as a shared indicator bridging the two functions in one green space to achieve both the ecological and social functions.

An explicit understanding of the contemporary issues in human– environment interactions in urban green space is still incomplete and lacks insight for urban planners and decision makers. Thus, a synthesis of the main research findings could help city planners understand the benefits related to green space in their part of the world. Urbanization may then proceed, but with a more balanced view on sustainable development of the urban environment, which takes into account the city residents and their quality of life.

The main objectives of this paper are as follows:

Providing an overview of the current state of research on urban green space morphology and its relationship with climate mitigation.

Reviewing the current research on urban green space configuration and its relationship with human satisfaction based on environmental psychology.

Comparing the spatial features benefit for urban climate mitigation or satisfying for human way finding. Group and find the similarities and differences between them.

2. Urban Green Space

Urban green space has been defined as a range of street trees, roof gardens, residential lawns, parks, and urban agriculture. As being significant to mitigate environmental effects induced by urbanization and improve the living quality of citizens, an increasing volume of studies outline the environmental and social benefits related to urban green space, which focus mainly on social benefit or ecological efficiency, are stated as followed:

Social benefits are assumed as supporting social interaction and integration [6]; those that deal with social cohesion, particularly with participatory approaches of using urban green space.

Environmental benefits are included as climate mitigation potential in the form of cooling through shading provision and moisturizing [7], air filtration of pollutants [8] through vegetation or the promotion of biodiversity [9] and reduction of noise [10].

Interdisciplinary studies on urban green space gradually takeover the single perspective ones. Those studies that focused on the comprehensive function of urban green space, including the human perception (including soundscape and feeling of safety), and preference of spatial characteristics by visitors and general satisfaction of local citizens have been an increasing trend [11]. Numerous disciplines involved contained environmental psychology, environmental health, environmental economics, human geography, and urban planning, all of which belongs to social sciences. As Kabisch (2016) stated, however, as we seeing more research interest still stems from urban ecology and ecological themes of social challenges in cities, e.g., population development, urban land use changes, and the climate change effects on urban dwellers. Therefore, how to intergrade the original urban ecological issue with the social questions rose in urban green space is the main focus of this paper.

Human feeling is the linkage between social and natural factors within urban green space [12]. Since citizens' satisfaction within urban green space from both social and nature perspectives mainly comes from space morphology and physical comfort, and physical comfort itself (e.g. noise level, light condition, heat comfort, etc.) is related to spatial forms, thus this study proposed that the common indicator that depicting human-environment interaction and linking both social and ecological functions in urban green space is spatial factor.

For ecological function, spatial factor is capable of explaining thermal mitigation. Climate mitigation is specifically mitigating pedestrian thermal comfort in the urban green space. According to Jamei (2016) [13]. The relationship between urban design parameters and pedestrian thermal comfort has been the subject of many studies [14]. Several studies have examined the influence of urban morphology on wind flow because ventilation is effective in mitigating the high urban air temperatures [15]. Other studies have conducted on the effect of urban configuration accommodating received solar radiation and its outcome on pedestrian thermal comfort [16]. As concluded, urban spatial geometry appears to be very convincing in promoting pedestrian thermal comfort in solar radiation and wind velocity. Therefore, this following paper reviews the studies on that the effect of pedestrian-level urban green space geometry (through altering parameters including aspect ratio (H/W), sky view factor (SVF), street orientation, and neighborhood configuration) on outdoor pedestrian thermal comfort.

For sociological function, spatial factor is key to human perception and satisfaction of the outdoor environment, and the following paper will also look for how spatial characteristics affect human explorative behavior and way finding.

The scale of spatial factors is also worthy to be addressed. Large-scale studies (e.g., several green spaces in the city) cannot be generalized to individual site scale (e.g., a green space in a district or neighborhood) and vice versa [17]. This study therefore uses multi-scalar approaches, where the results could be generalized to another study by translating from one scale (level) to another. The scales used in this study are divided into three levels neighborhood urban fabric, city blocks, and buildings [18]. (Figure 1)

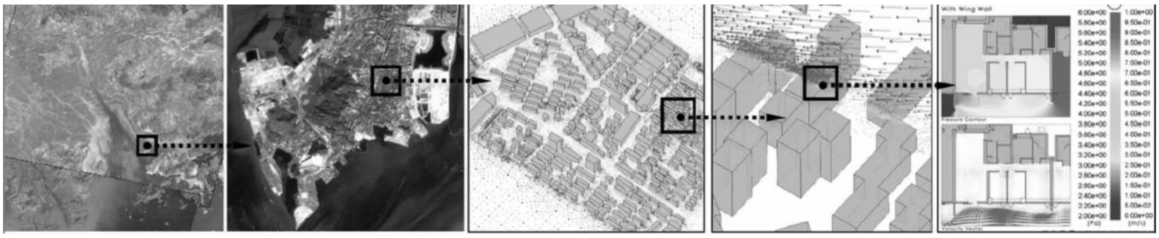

Figure 1. Urban morphology at different scales: from left to right, urban region, city, neighborhood urban fabric, city blocks, buildings. Source: JinyeuTsou, the Chinese University of Hong Kong

3. Spatial Configuration for Climate Mitigation

3.1. Urban Geometry

Although urban microclimate and urban form problems are interdisciplinary studies, the research on the background of different disciplines has its own focus. The research in meteorology and environmental disciplines focuses on the modeling of meteorological dynamics and the calculation of meteorological data in urban environments, while the study of architecture focuses on how urban forms affect microclimates and how to regulate urban forms to optimize microclimate environments. The understanding and operation of formal problems is the main task of architecture. To this end, in the study of urban microclimate, the object of architecture is still urban form, and the corresponding problem is transformed into a meteorological indicator.

Urban climate management depends upon fine-grained spatial mapping. Hebbert (2012) highlight the evidence supporting spatial effect that diurnal patterns of urban wind circulation have a complicated distribution linked to urban topography, spatial form and landscape, meanwhile, solar radiation and shade patterns relate closely to street canyon and arrangement of buildings [19]. As for local grained scale, where gradients arise in a tiny space (few hundreds of meters), proving that urban geometry can be decisive in influencing the characterization of local microclimate [20]. Simulation of the climatic mitigation process usually starts from the effect of various parameters on the urban grains' microclimate, inputted as paving materials, vegetation, water bodies, and urban geometry [21]. Then the next step is studying the effect of urban morphology on the local microclimate and the human thermal comfort of various urban spaces [22].

In the field of climate mitigation, urban spatial scales were specified at three levels: Urban Boundary Layer (UBL), Urban Canopy Layer (UCL) and Urban Street Canyon (USC). Since street canyon is the place for pedestrian activity, research scope in this paper will focus on street canyon level. It indicates the urban space enclosure pattern, which is the main public activity space of the city for architecture: such as the geometry of streets and squares. Specific studies have shown that urban block design and street space design have an impact on the pedestrian thermal comfort, involving local temperature, radiation, wind velocity and humidity in the space.

3.2. Parameters Describing Urban Geometry

3.2.1. *Aspect ratio*

The parameters describing the street canyon morphology are stated as followed.

The main index of street canyon is the aspect ratio, which is the basic boundary condition to simulate the turbulence. The canyon is considered uniform if it has an aspect ratio of approximately equal to 1 (without major openings on the walls), shallow if the canyon has an aspect ratio below 0.5, and deep if the aspect ratio equals 2 [23]. (Figure 2)

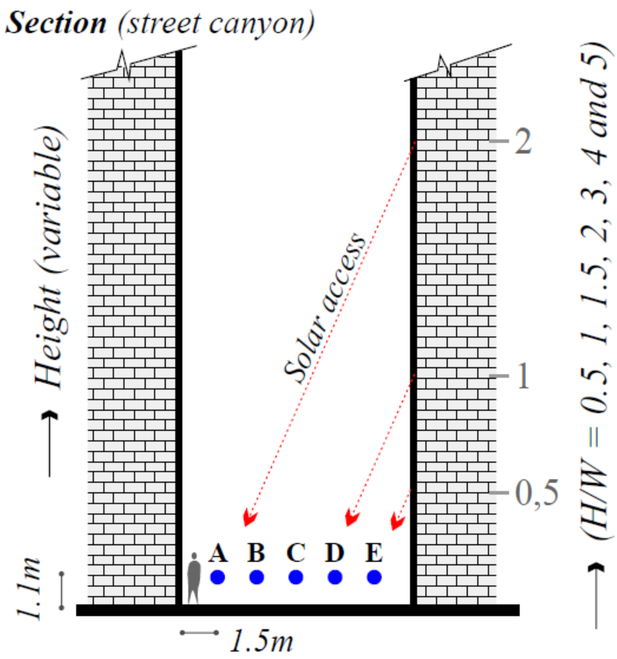

Figure 2. Street aspect ratio, source: Jose Abel Rodríguez Algeciras

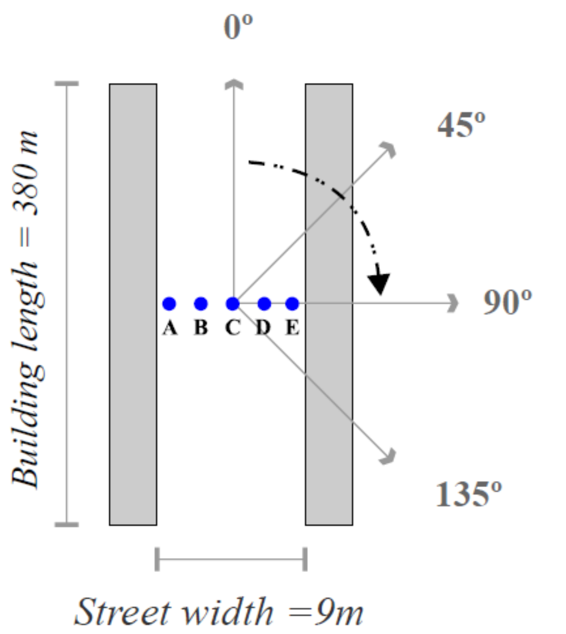

Figure 3. Street orientation, source: Jose Abel Rodríguez Algeciras

3.2.2. *Street orientation*

Solar radiation and air movement are significant constituents of climate, which affect the thermal performance of an urban area. Street orientation is one of the important parameters that determine the solar access and wind speed in urban canyons and are therefore significant in thermal comfort level in sidewalks. A study in Vancouver, Canada revealed that street orientation significantly affects the thermal balance of the urban area. (Figure 3)

3.2.3. *Sky view factor*

Sky view factor (SVF) is defined as "the ratio of the amount of the sky which can be seen from a given point on a surface to that potentially available (i.e., the sky hemisphere subtended by a horizontal surface)". Buildings and vegetation are the urban obstacles, which define the level of the vision toward the sky. SVF is an important parameter in characterizing the geometry, density, and thermal balance of urban areas. This parameter is a dimensionless number between 0 and 1, and it is also an important element in generating and controlling the heat island effect. In urban areas, SVF at any point is less than 1 because of obstacles in the urban sky vault. (Figure 4)

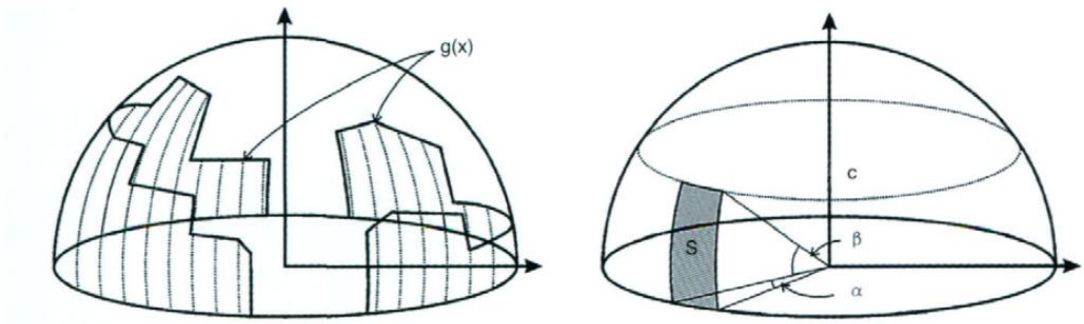

Figure 4. Sky view factor, source: Ding Wowo

3.2.4. *Local and neighbourhood scale*

By contrast, the microscope urban form pertains to the features of the city at the neighborhood or district scale, such as building density and height, permeability, land use, street pattern, distribution and urban design characteristics. A great number of different micro urban forms may be identified in one city. Given that the aim of this paper is to review the studies undertaken at pedestrian level, the effect of geometry was reviewed at local or neighborhood scale.

3.3. Result of Simulation

3.3.1. *Aspect ratio*

Several studies directly measured bioclimatic condition and outdoor thermal comfort, reported a clear correlation between pedestrian thermal comfort and aspect ratio, and suggested the need to consider possible consequences of aspect ratio on the thermal radiation in cities [24]. Compactness of urban space is important (low SFV). The compact urban form results in better thermal condition during summer but is disadvantageous during winter.

3.3.2. *Street orientation*

The majority of the studies concluded that E–W oriented streets experience the worst thermal condition during the day and thus assumed that deeper canyons allow for mutual shading of buildings to improve the thermal condition along the sidewalks. A desirable orientation should depend on the climatic type, the selection for sun or shade, and wind shelter or not.

3.3.3. *Sky view factor*

Cool island and higher night time air temperature (heat island effect) [25] are usually correlated with lower SFVs, which are conclude as beneficial since low value combine with high green coverage. Shanghai examined the micro scale effect of urban form on the potential ventilation in outdoor environments [26] and highlighted the significant role of "enclosure" or SVF in developing the pedestrian-level wind velocity. The authors concluded that a 10% increase in SVF would result in an 8% increase in wind speed at the pedestrian level.

3.3.4. *Local and neighbourhood scale*

Different urban tissues influence wind velocity and mean radiant temperature [27]. The courtyard type has been identified as the most preferable urban configuration

[28]. Compared to squared morphology, studies have proven that organic structure performed better in summer due to the higher level of shading [29]. Also, the rectangular urban square along the N-S direction (gaining solar) had best radiant performance [30]. Shading or exposure is of greatest importance to determine the comfort level in summer. Thus compact urban form was recommended, due to less exposure to the direct solar radiation.

3.4. Trend of Spatial Research on Climatic Mitigation

3.4.1. *Graphical theoretical model of urban texture morphology*

As early as the 1970s, the Martin Research Center of the University of Cambridge summarized the geometric features of modern cities and buildings using European cities as a model [31], and based on this, gave the basic prototype of urban fabric morphology (Figure 5). Martin's model summarizes the texture of traditional cities represented by the European continent. It is characterized by complete neighborhoods, small differences in building unit scales, and basic heights. Based on this model, mathematical parameters are completed. The basic model of the microclimate environment in Western research cities has continued to use the prototype of the urban form of the Martin Research Center, such as the calculation of the average sky openness and the calculation method of urban roughness.

The existing calculation methods are not suitable for the texture patterns of different cities, especially the urban fabrics with poor integrity, large unit differences and excessive differences in construction height. Therefore, for heterogeneous urban textures (American and Asian cities) where the height and volume of buildings are relatively large, many theoretical models of urban form need to be re-established. In view of the particularity of urban form, summarizing the appropriate physical morphological features is a key task to be solved.

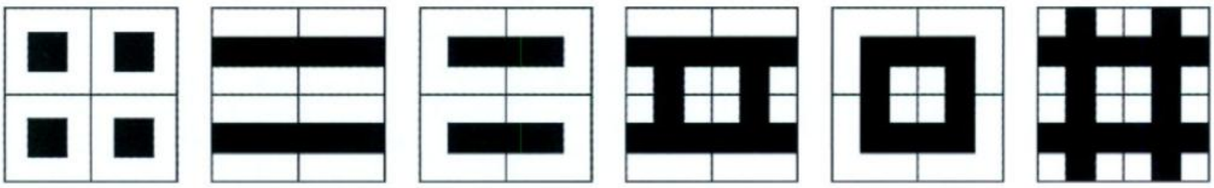

Figure 5. Generic urban forms, based on Martin and March. From left to right: pavilions, slabs, terraces, terrace-courts, pavilion-courts and courts

3.4.2. *Parameterization of urban texture morphology*

There are three aspects: the parametric representation of the geometric relationship of the shape, the mathematical representation of the morphological structure, and the data representation of the spatial structure. The parametric representation of the geometric relationship of the body is the Martin Research Center of the University of Cambridge, England. In the 1960s, it began to try to establish a mathematical model of the study of urban spatial morphology through the study of urban texture types; the main discussion of the mathematical expression of morphological structure Is the Form Grammar, which focuses on the law of the combination or division of object geometry; the spatial representation of spatial structure is Space Syntax. The former two complete the parametric representation of the law of the form itself, but can not express the spatial form between the objects; while the space syntax expresses the structural relationship of the urban space, but its expression method is limited to the interface that hides the space. To study the relationship between urban microclimate environment and urban fabric morphology, it is necessary to complete the parametric representation of urban spatial form. It must express the structure of urban space and at the same time express the specific spatial interface.

4. Human Built-in Definition for Public Space

According to environmental psychology, human-environmental interaction is from three dimensions: perception, cognition and feedback (interaction), so do they generate emotions in the physical space and react to it. Human perceiving physical world and forming cognition and attitude has been defined as a process named "built-in", proposed by Sora Key, thus a "built-in definition" form when people finish turning physical object into cognition. Built-in definition defining a term takes multiple steps from elements to a definition. The sequence of basic function composition can be described in a linear fashion. Current built-in definitions follow four sequential steps: from physical elements to geometric attributes, to perceptual relationships and finally to definition, which is the name associated with a spatial function set. Sora Key (2012) has described eight built-in definitions on human perception of spatial characters, in order to exploit inherent law of human behaviour toward certain spatial morphology, which is enclosure, view field, continuity, directionality, spaciousness, reachability, accessibility, transitionally. Two of them are explicated as followed.

4.1. Enclosure

Enclosure is the extent to which the location is surrounded by architectural elements. The outer shell greatly influences a person's sense of housing. Jay Appleton's prospect refuge theory solves this problem to explain aesthetic preferences in landscape. The opportunity to see and hide is linked to the survival instinct, he says. "The aesthetic satisfaction experienced in thinking about the landscape comes from the perception of the characteristics of the surrounding environment - in terms of shape, color, spatial arrangement and other visible attributes. These properties indicate conditions conducive to survival. Supported by the experience of environmental psychology research, fence is an important environmental quality, which can induce feelings of safety, privacy and preference in physical building environment.

The closure of a position depends on the distance between the position and the wall. Figure 6 shows that if a person sits in the corner (left) rather than in the middle of the room (right), the room will be more soundproof. The diagram in the center shows that the seat shell is horizontally positioned between the first two. To quantify this, the degree of closure is proportional to the inverse distance of the element from its position, expressed as a scalar.

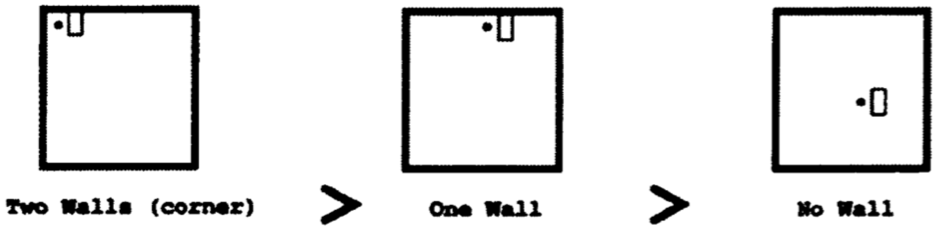

Figure 6. Level of enclosure is relative to the distance from the elements, source: Sora Key

4.2. View Field

Following Benedikt, view field is defined as the visible area from a viewer's position within a field, represented as a set of points. The size of the view field tells how much visual information one perceives from a vantage point. Locations of the points in the set tell what part of the field is visually connected to or concealed from the vantage point. View affects feelings in many different ways: open, secure, or private. The sense of territorial control is also related to view.

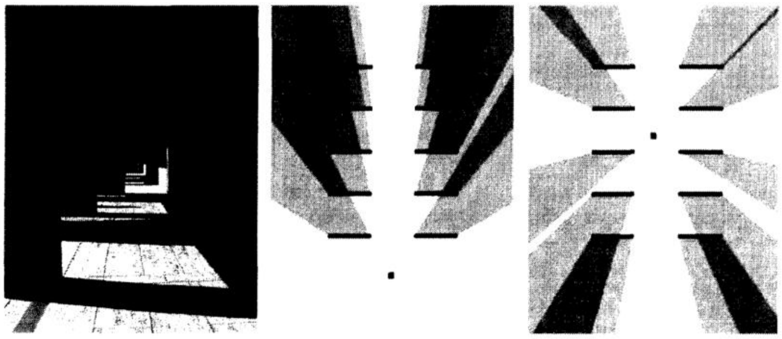

Figure 7. A passage at Salic Institute, La Jolla, CA by Louis Kahn (left). Visual representation of Viewfield of the passage (center, right). Line implies wall. Red dot is the viewer's location. Shaded region is invisible from the viewer's position, source: Sora Key

A path may be designed with a varying View field in mind. Figure 7 shows a space with layers of walls with openings. The experience of walking through the openings, as a sequence, can be described using View field. The arrangement of elements produces a varying shaped View field, producing a repetitive rhythm of changing the size and the location of the visible region. Figure 7 (centre, right) shows visual notation of View field as the viewer moves through the configuration.

5. Result: Connection between Spatial Functions and Climate Mitigation

5.1. Change the Result of Satisfaction: To Amplify or Offset Effect

Based on a comprehensive view, and a prerequisite that urban green space satisfaction is upon social and natural aspects, the result of climatic simulation may alter. The compact urban form results in better thermal condition during summer but is disadvantageous during winter. The most compact morphology is also presented as courtyard. In social aspect courtyard means “highly enclosed by four walls”, which may cause extremely secured or stressed atmosphere depend on different people. In this circumstance, the best thermal condition in summer may be not so pleasant for every user when considering social impact of spatial configuration. (Figure 8, Figure 9)

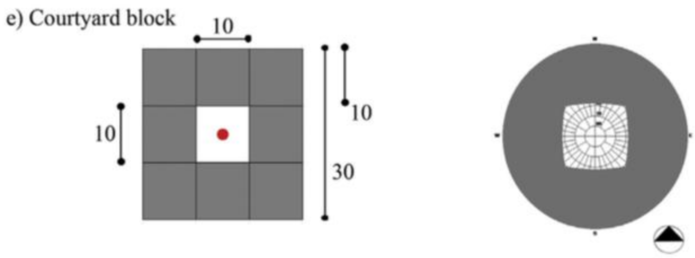

Figure 8. Courtyard block and SVF, source: Mohammad Taleghani

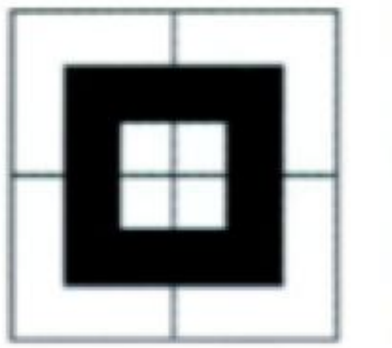

Figure 9. Pavilian courts, source: Marti

Similarly, the singular blocks show high SVFs indicating a disadvantageous pedestrian thermal comfort level; however, from social perspective of the same configuration, it sure is a pleasant space for wide and open view field. In this case, the worst thermal condition in summer may be not so unpleasant for any user if considering the broadened view field. (Figure 10, Figure 11)

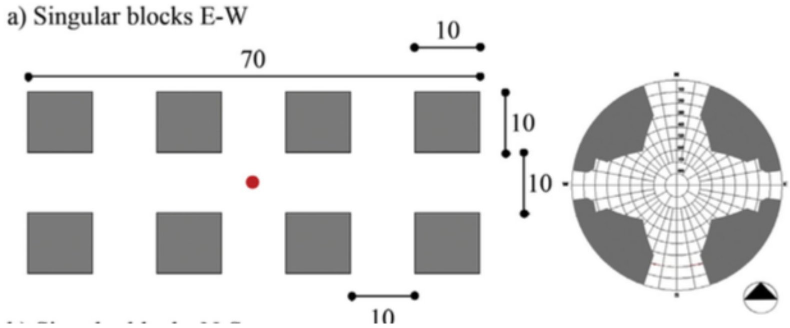

Figure 10. Singular block and SVF, source: Mohammad Taleghani

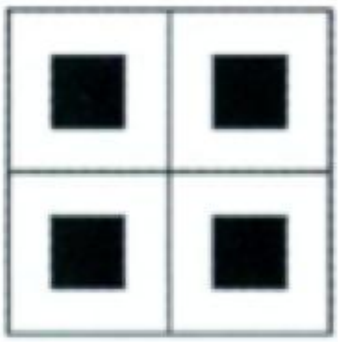

Figure 11. Pavilian, source: Martin

5.2. A Proposal for Adaptive Urban Green Spatial Design

While a city configuration may work in the summer, it may not be as beneficial in winter. Therefore, the proposed optimal urban allocation depends to a large extent on the local background and geographical characteristics of the investigated area. In the hot summer, the level of shading and exposure to solar radiation determines the comfort level of the pedestrian comfort. Thus, the compact urban configuration will result in less exposure to direct, diffuse, and reflected radiation at the pedestrian level through the horizontal street surface. However, the same urban configuration will adversely affect wind behaviour and block solar entry and negatively affect pedestrian thermal conditions. Since the neighborhood is a small urban unit, climate-adaptive planning on this scale will help urban planners create comfortable living environments on an urban scale.

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