DEVELOPING A PREDICTION TOOL TO IMPROVE THE SHADING EFFICIENCY OF THE PEDESTRIAN ZONES

by

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LIST OF SYMBOLS

ΔT	Time zone
1B/E	Single East wall
1B/N	Single North wall
1B/NE	Single North-East wall
1B/NW	Single Northwest wall
1B/S	Single South wall
1B/SE	Single Southeast wall
1B/SW	Single Southwest wall
1B/W	Single West wall
2B/E.W	Double East -West walls
2B/N.S	Double North -South walls
2B/NE.SW	Double Northeast -Southwest walls
2B/NW.SE	Double Northwest -Southeast walls
3B/E.S.W	Triple East -South -West walls
3B/N.E.S	Triple North -East -South walls
3B/NE.SE.SW	Triple Northeast -Southeast -Southwest walls
3B/NW.NE.SE	Triple Northwest -Northeast -Southeast walls
3B/S.W.N	Triple South -West -North walls
3B/SE.SW.NW	Triple Southeast -Southwest -Northeast walls
3B/SW.NW.NE	Triple Southwest -Northwest -Northeast walls
3B/W.N.E	Triple West -North -East walls
4B/N.E.S.W	Quadruple North -East -South -West walls
4B/NE.SE.SW.NW	Quadruple Northeast -Southeast -Southwest -Northwest walls

F-0	Floor directed toward the North
F-45	Floor directed toward 45 degrees from the North
X	The length and width of the square floor of the pedestrian zone
α	Altitude angle
γ	Azimuth angle
δ	Solar Declination Angle
μ	Latitude
ϕ	Longitude

LIST OF ABBREVIATIONS

ECOTECT	A three-dimensional modeling software developed by Autodesk
ELTSHE	Expansion limit corresponding to the targeted shading efficiency
EOT	Equation of Time
GMT	Greenwich Mean Time
H	Solar Hour Angle
h	Gnomon height equal to the Wall's height
HSA	Horizontal shadow angle
L	Wall's shadow length
Le	Shadow length of the East wall
Lg	Gnomon shadow length
Ln	Shadow length of the North wall
Lne	Shadow length of the Northeast wall
Lnw	Shadow length of the Northwest wall
Ls	Shadow length of the South wall
Lse	Shadow length of the Southeast wall
LST	Local Solar Time
LSTM	Local Standard Time Meridian
Lsw	Shadow length of the Southwest wall
LT	Local Time
Lw	Shadow length of the West wall
n	Number of days since the start of the year
SHE	Shading efficiency
TC	Time Correction Factor
TSHE	Targeted shading efficiency

PEMBANGUNAN KAEDAH AMALAN BAGI PENAMBAHBAIKAN KECEKAPAN PEMBAYANGAN UNTUK ZON PEJALAN KAKI

ABSTRAK

Semenjak suku abad ke dua puluh, arus perkembangan pembangunan dalam bandar-bandar seantero dunia telah menjadi penyebab dominan kepada fenomena rebakan bandar. Dalam latar belakang ini, ruang-ruang perbandaran yang berkembang secara melampau telah mempergiatkan lagi impak negatif radiasi solar yang tinggi dalam wilayah-wilayah beriklim panas yang secara tidak langsung menyebabkan zon pejalan kaki diabaikan. Terdapat perkembangan dalam literasi yang menggariskan bahawa ruang perbandaran yang mampat adalah pendekatan yang paling diutamakan yang menyebabkan rebakan bandar dan radiasi solar yang tinggi. Zon pejalan kaki yang mampat dapat mengurangkan pengembangan melampau dan mencegah radiasi solar dengan menggalakkan teduhan sepunya. Sementara itu, pengawalan morfologi terhadap zon pejalan kaki telah dikenalpasti sebagai penyumbang faktor utama untuk menaiktaraf teduhan dan mengehadkan pengembangan melampau. Morfologi zon pejalan kaki dijelaskan dengan tiga parameter; perkadaran, orientasi dan vegetasi. Parameter-parameter ini telah dicirikan oleh pemboleh ubah dalam fabrik bandar seterusnya menghasilkan perbezaan kecekapan teduhan di zon pejalan kaki. Selain itu, syarat-syarat teduhan terhadap pejalan kaki adalah berbeza disebabkan teduhan mempunyai sifat fizikal yang dinamik yang berubah mengikut hari dan musim, bergantung kepada spesifikasi lokasi geografi. Justeru, variasi dalam morfologi parameter dan keperluan teduhan telah menyebabkan pengawalan terhadap pengembangan melampau dalam zon pejalan kaki menjadi isu yang rumit. Oleh itu, majoriti kajian telah menggunakan simulasi yang menggunakan perisian-perisian

penilaian teduhan yang berbeza. Walaupun teduhan tersebut boleh dikira dengan tepat menggunakan perisian-perisian ini, namun perisian-perisian ini hanya boleh dianggap sebagai alat analisis. Perisian dan alat analisis yang sedia ada tidak menyediakan peraturan kekangan pengawalan pengembangan melampau terhadap zon pejalan kaki sehingga limit yang efektif untuk mengekalkan teduhan tersebut sebagai mesra pengguna. Oleh itu, terdapat keraguan dalam penyediaan dasar khas untuk menaiktaraf teduhan di kawasan pejalan kaki. Kesannya, kajian ini telah menghasilkan alat ramalan untuk menetapkan garis panduan terhadap kekangan dengan mengenalpasti had pengembangan yang sepadan dengan tahap kecekapan teduhan yang disasarkan. Tahap kecekapan teduhan mewakili peratusan kawasan teduhan kepada jumlah keseluruhan ruang lantai zon pejalan kaki sementara itu, tahap kecekapan teduhan merujuk kepada syarat-syarat teduhan yang lebih baik kepada pejalan kaki. Alat ramalan ini dihasilkan berdasarkan tiga algoritma bersepadu iaitu algoritma kedudukan matahari, algoritma dan panjang bayang serta algoritma had pengembangan. Seterusnya, alat ramalan ini diuji di kawasan Muscat, Oman Kajian ini menghasilkan kesimpulan bahawa prestasi teduhan di zon pejalan kaki bergantung kepada kombinasi konfigurasi morfologi yang efektif dalam had pengembangan yang tertentu. Tambahan pula, kajian ini menyediakan penyelesaian yang sistematik berdasarkan penyusunan semula konfigurasi zon pejalan kaki dengan merujuk kepada pokok-pokok. Pokok-pokok boleh bertindak sebagai pengubah alam sekitar dalam mengekalkan teduhan di zon pejalan kaki kepada tahap yang boleh diterima. Keputusan daripada simulasi ECOTECT telah mengesahkan keberkesanan alat ramalan ini untuk menghasilkan garis panduan terhadap kekangan yang menilai dan menaiktaraf kecekapan teduhan di zon pejalan kaki.

DEVELOPING A PREDICTION TOOL TO IMPROVE THE SHADING EFFICIENCY OF THE PEDESTRIAN ZONES

ABSTRACT

Since the last quarter of the twentieth century, the rapid growth in many cities throughout the world was the predominant cause of the phenomenon of urban sprawl. In this backdrop, The over-expanded urban spaces let to intensify the negative impact of the high solar radiation in the hot climate regions that caused abandoned pedestrian zones. There is a growing body of literature highlighted the compacted urban spaces as the most prioritized approach against urban sprawl and high solar radiation. The compacted pedestrian zones reduce the overexpansion and mitigate solar radiation by promoting mutual shading. Meanwhile, controlling the morphology of the pedestrian zone have been identified as an essential contributing factor to improve shading and limitate the overexpansion. The morphology of the pedestrian zone was described by three parameters proportions, orientation, and vegetation. These descriptors are characterized by being variable within the urban fabric, resulting in a difference in the shading efficiency in the pedestrian zones. Besides, the shading requirements toward pedestrian also vary since the shading is a dynamic physical phenomenon that changes in daily and seasonally basis to a specific geographic location. Hence, the variability of the morphology descriptors and shading requirements have made controlling the over-expansion in the pedestrian zone a complicated issue. Therefore, the majority of the studies have utilized computer simulation using different shading assessment software and tools. Although the shading can be calculated using these software and tools at a high level of accuracy; however, they are considered as an analytical tool. The available software and shading assessment tools did not provide regulatory

constraints to control the overexpansion pedestrian zone to an effective limit that keeps shading feasible for the pedestrian. Hence, there is an uncertainty of providing a tangible policy to improve shading in the pedestrian zones. Consequently, in this study, a prediction tool was developed to set regulatory constraints by identifying the expansion limit corresponding to the targeted shading efficiency. The shading efficiency represented the percentage of the shaded area to the total floor area of the pedestrian zone, while the targeted shading efficiency indicated the preferable shading requirements for the pedestrian. The development of the prediction tool was conducted base on integrating three sequenced algorithms, which are sun position algorithm, shadow length and position algorithm, and expansion limit algorithm. Then the developed prediction tool was tested in the Muscat coordinates. The study concluded that the shading performance in the pedestrian zone was due to a combination of effective morphology configuration within a particular expansion limit. Moreover, the study provided systematic solutions based on reconfiguring the pedestrian zone by the trees. The trees can behave as an environmental modifier to maintain the shading of the pedestrian zone within an acceptable level.

Then ECOTECT software has utilized to validate the effectiveness of the developed prediction tool for evaluating and improving the shading efficiency in the pedestrian zone. The ECOTECT has been selected because of its capabilities that allow the user to simulate and compare the shadow casting ability for both unshaded and shaded scenarios. The results of ECOTECT simulation validated the effectiveness of the prediction tool to provide regulatory constraints to evaluate and improve the shading efficiency of the pedestrian zone.

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

The preservation and encouragement of livable cities as an approach to pedestrianization have long been a prioritized agenda of sustainable urban development. However, the pedestrianization is facing the problems of the automobile dependency trend with the recent rapid development growth. Besides, the urban sprawl and global warming exacerbated the challenges of the trend toward sustainable and livable cities (Yassin, 2019).

The combination of the negative impact of urban sprawl and high levels of solar radiation have made the outdoor environment uncomfortable for pedestrians. These including the increasing problems of pollution due to the predominance of vehicular mobility and the decline of vital pedestrian activities (Pollalis, 2016; Jamei and Rajagopalan, 2017). The recent researches have emerged that it is essential to design the metropolitan area for people rather than for cars (Blaga, 2013; Asadi-Shekari *et al.*, 2015; Zayed, 2017; Dičiunaite-Rauktiene *et al.*, 2018).

One of the priorities towards the sustainable development of urban space is by improving the urban quality of the pedestrian zone (Amirtham and Devadas, 2007; Tan *et al.*, 2015; Yang *et al.*, 2015; Chatzidimitriou and Yannas, 2017; Zhou and Chen, 2018; Ma *et al.*, 2019). Increasing mutual shading in pedestrian areas is a vital strategy to prevent or mitigate the negative impact of urban sprawl and solar radiation (Arnfield, 1990; Middel *et al.*, 2014; Sanusi *et al.*, 2017).

Many studies have endeavored to find solutions to improve environmental quality of the pedestrian zone and reduce the urban sprawl. The compact urban spaces have introduced as an approach to control the over-expansion and promote mutual shading (Lichtenberg, 2011; Taleb and Abu-Hijleh, 2013). Meanwhile, other studies have quantified the most influential aspects to control the over-expansion in the pedestrian zone. For example, the overexpanded pedestrian zone can be controlled by modifying the morphology's descriptors of the pedestrian zone, which are proportion, orientation, and vegetation (Jamei *et al.*, 2016; Lin *et al.*, 2017; Jamei and Rajagopalan, 2019). However, the variation of the preferable shading requirements for pedestrian has made the improvement of shading in the pedestrian zone more complicated. The full shaded pedestrian zone does not necessarily consider as an ideal solution because the shading is preferable in a hot season while the sunny area is preferable in cold seasons (Abreu-Harbich *et al.*, 2014; Chatzidimitriou and Axarli, 2017; S.Darbani *et al.*, 2018).

The variability of the morphology for the pedestrian zone and the preferable shading requirements of the pedestrian have made the majority of the studies have utilized the simulation software. This also included the analytical approaches using computer-based simulation methods by different software and tools. The analytical approach using simulators can give a comparison among different scenarios of the shading patterns (Lin *et al.*, 2017). However, there is a lack of providing a regulatory constraints regarding controlling the expansion limit to keep the shading feasible for the pedestrian because of the lack of availability of software or tools provided these constraints.

Therefore, the novelty of this study is to develop a prediction tool to identify the expansion limit of the pedestrian zone corresponding to the targeted shading efficiency. The shading efficiency represented the percentage of the shaded area to the total floor area of the pedestrian zone, while the targeted shading efficiency indicates the preferable shading requirements for the pedestrian.

Then the prediction tool was tested in Muscat/Oman. The purpose of this testing was to establish regulatory constraints that can be utilized to evaluate and improve the shading efficiency for different morphologies of the pedestrian zones in Muscat. The regulatory constraints have established by identifying the expansion limit and the effective configuration among the morphologies of the pedestrian zone. It was decided to test the prediction tool base on the Muscat coordinates because Muscat is located in the Tropic of Cancer. The Tropic of Cancer has special significance as the regions that locate on or near this tropic receive the majority of the solar radiation. Moreover, the earth largest countries or cities at or near the Tropic of Cancer (Exton, 1992; Walsh, 2009). Therefore the findings of the extracted regulatory constraints can be generalized to a wide range of regions on the Tropic of Cancer.

A further novelty in the study was providing systematic solutions to improve the shading efficiency of the pedestrian zone of selected case studies in Muscat. The trees were utilized in this study as environmental, and sustainable barriers to divide the over expanded pedestrian zone into multiple segments of effective morphology within the outputted expansion limit of the prediction tool. Then the effectiveness of the prediction tool and the applicability of the suggested improvement were validated using the ECOTECT computer software.

The urban designers, landscapers, and the decision-makers can use the developed prediction tool to establish the regulatory constrains at any geographical location in the global. These constraints can be utilized to design the innovative pedestrian zone and also to improve the shading in the existing pedestrian zones.

1.2 Problem Statement

Automobile dependency is seen primarily as an issue of environmental sustainability due to the consumption of non-renewable resources and the production of greenhouse gases responsible for global warming. Automobile dependency is the concept that some city layouts cause automobiles to be favored over alternative forms of sustainable transportation such as bicycles, public transit, and walking (Newman *et al.*, 2016). The trend of automobile dependency is expected to increase as the future population is projected to increase significantly in most of the cities around the world (Nieuwenhuijsen and Khreis, 2016). The pedestrianization is an approach to modify the urban area to be more oriented to the society and the sustainability of urban life. The pedestrianization is aimed to reduce automobile dependency through gentrification environmental quality of the pedestrian zones to promote pedestrian activities. (Zayed, 2017).

However, the rapid growth in the twentieth-century urbanization has fragmented the urban space causes to what has been called urban sprawl. Many researchers have quantified the urban sprawl as one of the prime dilemmas of the metropolitan cities (Chitrakar *et al.*, 2016; Sushinsky *et al.*, 2017; Hamidi *et al.*, 2019). What makes the matter worse, the urban sprawl increase the high solar radiation exposure, especially in the hot climate regions. Such conditions lead to increase the thermal stress for the pedestrian (Ewing *et al.*, 2014).

The shading is the prime factor that effects on mitigating the negative impact of solar radiation (Okeil, 2010; Vanky *et al.*, 2017; Olgyay *et al.*, 2019). The compact morphology of the pedestrian zone for more mutual shading has been considered the most prioritized solution toward smart urban growth (Lichtenberg, 2011). The shading in the pedestrian zone can be promoted by controlling the over-expansion in the morphology of the pedestrian zone. According to Lin *et al.* (2017), the morphology of the pedestrian zone can be quantified by three descriptors (the proportion, orientation, and the vegetation). A substantial body of the literature has investigated the impact of the proportion, orientation, and vegetation on the thermal environment of the pedestrian. The majorities of these studies have utilized the computer simulation method because of the variability and the complexity of morphology of the pedestrian zone. The researches have compared different proportions, orientation, or vegetation scenarios to simulate the shading performance using different simulation programs or tools.

Although the computer simulation method can calculate the shading in a high level of accuracy, however, the shading requirements for the pedestrian has varied daily and seasonally. The optimal shading (full shaded area) does not necessarily lead to an optimum solution because of the shading in some time not preferable, especially in the colder seasons. Furthermore, the shading also could promote the pedestrian activity in specific daytime (morning, midday, and the afternoon). Consequently, the recent analytical approach using computer simulation has lead to contradictory guidelines for controlling the expansion limit in the pedestrian zone because it does not provide regulatory constraints for expansion limit considering the pedestrian shading requirements. These regulatory constraints include a set of rules that can control the morphology descriptors (proportion, orientation, and vegetation) of the pedestrian zone for effective shading improvement of the pedestrian zone.

The town planners and decision makers will be better informed with a predicting tool to control the over -expansion of the pedestrian zone and provide constraints for the effective developments. However, there is a significant lack of availability of software or tool to control the over-expanded pedestrian zone