Automation in Construction 22 (2012) 90–101

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Evaluating environmental implications of density: A comparative case study on the relationship between density, urban block typology and sky exposure

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ARTICLE INFO

Article history:
Accepted 8 June 2011
Available online 16 July 2012

Keywords:
Density
Urban street block
Precinct
Typology
Environmental performance
Sky exposure factor
Sky view factor

ABSTRACT

This study is an exploration of the relationship between density, built form typologies and their respective environmental qualities. A methodology was proposed to facilitate the investigation of the environmental implications of density and the search of alternative built form typologies with good environmental performance potential that can be further explored in the context of high density development. The utility of the proposed methodology was demonstrated through a preliminary case study on several representative urban blocks and residential precincts by focusing on one environmental performance variable, i.e. exposure to the sky. The results indicate that the existing environmental performances as indicated by facade and ground level sky exposure vary across the representative built form typologies under study. Moreover, the performances of the cases selected react differently to variation of density due to increase of building height. The differences in existing performances and sensitivities to density variation between the cases investigated in relation to their built form are discussed. The findings suggest that, when targeting at higher development density, the proposed methodology can assist planners and urban designers in their search for alternative urban block typologies that provide different spatial configurations with equally good or even better environmental performance.

1. Introduction

The debate on the merits and effectiveness of relatively denser and more compact urban development pattern as an approach to achieve the goal of urban sustainability as compared with low-density, resource-consuming urban sprawl has been going on for a while in the realm of academic research as well as design and planning practices [1–5]. In the context of the cities in Asia and many other developing countries that are characterized by large population, limited buildable land and fast urbanization rate, high density urban development may seem to be inevitable.

As a city-state with very limited land resources, Singapore is renowned for its large scale urban public housing program which helps to accommodate over 80% of almost five million population in satellite towns equipped with full-featured facilities and a good living environment. Over the years, several conceptual planning models and various residential building typologies have been implemented to facilitate the development of high-density public housing new towns (Fig. 1). Considering that the future built environment in Singapore is likely to remain high density, there is a need to investigate whether alternative built form typologies can be explored of which the environmental performances are as good as or even better than the existing ones.

This study presents the findings of an investigation in which a new methodology is applied in the search of alternative built form typologies with good environmental performance potential. The utility of the methodology is demonstrated through a preliminary case study exploring the relationship between density, built form typologies and their respective environmental quality on both the level of urban open space and building facade. For the purpose of this paper, we will focus on one aspect of the study. We will examine, through comparison, the "performance" of selected built forms in terms of level of exposure to the sky in order to explore the

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doi:10.1016/j.autcon.2011.06.011

Fig. 1. The evolution of the public housing new towns in Singapore. (Image courtesy of the Housing Development Board of Singapore).

environmental implications of different built form typologies under different density scenarios.

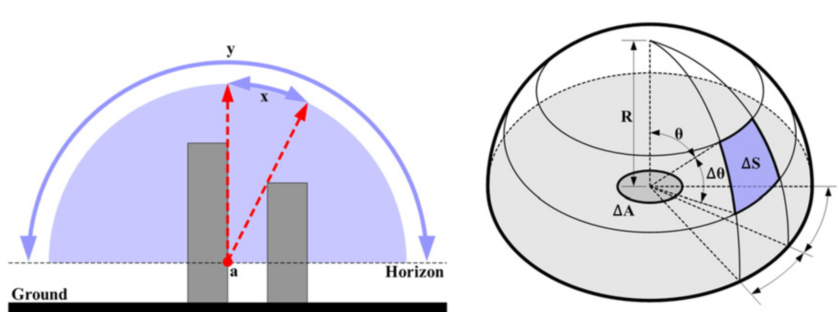
2. Literature review on the measurement of sky exposure

The investigation of the environmental performance of urban environment is multifaceted. Previous studies focusing on dense urban context have addressed the environmental implications of high density development from various perspectives, such as the relationship between different built forms and spatial arrangements in high density context on urban ventilation [6–8], daylight availability [9–11], thermal comfort [12,13], acoustic environment [14], and urban climate [15–17].

In a dense urban environment where buildings are located in close proximity and the level of visual obstruction due to the presence of large built volumes is relatively high, the view towards the sky and surrounding environment is usually significantly obstructed. The impacts of the decrease of exposure to the sky are twofold. From an environmental perspective, reduction in exposure to the sky may lead to decrease in daylight access in both open spaces and building facades to an extent that people's visual comfort is compromised and artificial lighting is required even during day time. From a psychological perspective, decrease in exposure to the sky may lead to increase in perceived confinement of space that may have negative impacts on people's satisfaction to the living environment. A higher degree of exposure to the sky, on the other hand, might be beneficial to daylight access for urban open spaces and building interior and enhance perceived spaciousness of urban open spaces. However, an increased sky exposure may also lead to excessive solar radiation on urban surfaces, which leads to more frequent use of mechanical cooling and ventilation and therefore higher building energy consumption. In the tropical climate, high-level sky exposure without proper shading may also compromise the thermal comfort of people. Therefore, the level of sky exposure serves as an important indicator of the environmental quality in a high-density urban context since it is closely related to daylight availability, insolation level and spatial perception and experience, which in turn influence both building energy consumption and people's psychological wellbeing.

In terms of the quantification of sky exposure, a thorough literature review suggests that the term Sky View Factor (SVF) has been widely used to represent the degree of exposure to the sky from a given point. However, two definitions have emerged in studies by researchers from different backgrounds. For some researchers in architecture and urban design, SVF was defined as the proportion of the sky visible from a point to the overall sky dome [18,19]. Based on the assumption that every part of the sky is equally important, SVF was calculated as the ratio of the solid angle of the sky patch visible from a certain point to the solid angle of the hemisphere centered at the same point. For ease of reference, this is named the "geometric definition" of SVF in this paper. For geographers and climatologists, Sky View Factor is defined differently as the ratio of the radiation received (or emitted) by a planar surface to the radiation emitted (or received) by the entire hemispheric environment [20], and this is widely acknowledged as having implications on the phenomenon of Urban Heat Island [21–24]. SVF is derived from the concept of "view factor", which is "a geometric ratio that expresses the fraction of the radiation output from one surface that is intercepted by another" [25]. Following the concept of view factor, the importance of each part of the sky is weighted by the cosine of the angle between the zenith and that part of the sky, rather than being treated equally. In other words, SVF gives more weight to the part of the sky near the zenith and less to that close to the horizon [26–29]. This is called the "cosine-weighted definition" of SVF here for ease of reference. Fig. 2 illustrates the two different definitions of SVF.

The SVF as calculated based on the two definitions could be significantly different and therefore the term should not be used interchangeably. A test simulation using generic tower blocks arranged in a 5x5 grid with 5 different spacing levels was conducted. The SVF values of equally-spaced sensor points on the facades of the central block were calculated using the two definitions. The results indicate that SVF calculated based on the "cosine-weighted definition" is generally higher than that calculated according to the "geometric definition". The difference between the two values can be as high as



$$\psi_s = \frac{1}{\pi R^2}\int_{S_v} \cos\theta dS$$

Fig. 2. The geometric definition (left) and cosine-weighted (right) definition of Sky View Factor (the right diagram is redrawn according to [26]).