The effect of building facade reflectivity on urban dwellers in tropics.

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Abstract. With the rapid growth and use of modern architecture practices for high-rise buildings, highly reflective materials have been adopted extensively for aesthetical reasons. However, outdoor glare from highly reflective facades might cause thermal and visual problems towards the occupants of neighbouring buildings and outdoor dwellers, particularly pedestrians. In tropical countries, this negative impact can be greater due to the higher solar radiation received throughout the year. At the present, there are few building guidelines limiting outdoor glare, or daylight reflectance from a building facade. This study aims to introduce a framework for outdoor glare studies that focus on perceived glare from highly reflective facades by pedestrians in Singapore. The introduced framework includes age, glare time, glare duration, avoidance and sensitiveness. For this study, the survey is carried out with the application of Structural Equation Modelling (SEM). This paper is helpful for planners, designers, and engineers to estimate the sensitivity of pedestrians’ discomfort glare and towards the creation of sustainable architecture in Singapore.

1. Introduction
The scarcity of land in urban areas of some tropical regions has created a construction demand for high-rise buildings in an increasingly dense manner, creating simultaneously benefits and problems to the urban sustainability of these regions. To understand the concept of being sustainable, it is essential to understand the behaviour and properties of building materials. For example, the use of materials with lower albedo and impermeable surfaces will result in more heat being absorbed from the sun’s radiation, thereby raising the temperature in urban areas [1].

Building facades have been extensively designed and built with highly transparent and reflective materials that receive much attention in R&D. However, these materials may cause severe outdoor glare problems and further increase the surface temperature of the ground and neighbouring building [2]–[8]. The reflectance value of some facade materials can go up to 40%, which can impose a severe impact towards pedestrians and road users. When sunlight hits a reflective surface of a building, it will reflect, absorb and transmit the radiation simultaneously. Furthermore, the amount of light reflected will depend on the surface and type of material used, the building geometry and the facade form [8]–[11]. A prominent case depicting this issue is the Disney Concert Hall in Los Angeles [2], where the
use of shimmering stainless steel materials combined with concave facade geometries had worsened the reflected glare to the surrounding areas. Other related cases that shown similar incidences are the “Walkie Talkie” building, 20 Fenchurch Street in London [12] and the Vdara Hotel in Las Vegas [13]. Both buildings have concave facades that concentrate and reflect incident solar radiation, creating a “death ray” when the sunlight hit the glass facade at certain angles. This intense reflected sunlight is focused into a small areas on the surrounding, generating more urban heat. Therefore, it can significantly affect the urban microclimate, influencing both the visual and outdoor thermal comfort of the inhabitants.

Several models have been developed to quantify interior glare inside buildings [14]–[16], but less attention has been given to external glare. While some countries have developed guidelines to limit outdoor glare/daylight reflectance from building facades, no clear standard or parameters have been established. For example, some Australian cities have developed prescriptive measures to limit glare, which includes normal reflectance limits of than 20% for glass or all facade elements [17]–[20]. These guidelines are also followed by Singapore [21] and Hong Kong [22] on limiting external reflectance. Outdoor glare may also cause a problems to road safety if it has not been properly estimated during the design stage. The two types of glare that have been studied and evaluated the most are discomfort and disability glare, however both types are mostly assessed for visual performance inside buildings, compared with outdoor dwellers, where the impact of glare concerning pedestrian can be further intensified if they look directly at the source.

In tropical urban regions, glare and heat problems can have a more significant effect on urban outdoor dwellers, due to the greater incidence of solar radiation compared to temperate climate regions. Thus, there is a necessity to have recommendations in form of guidelines/standards so that architectural designs do not come at the cost of comfort and safety. In a tropical country such as Singapore, most of the new high rise buildings have been designed with 100% fully glazed or translucent materials. Some buildings have been built using high reflective curtain walling materials similar to glass (Figure 1). These materials have caused visual and the thermal discomfort on the surrounding outdoor environment. The Building Construction Authority (BCA) of Singapore reported that there were an increasing number of feedbacks on discomfort associated with reflected glare from neighbouring buildings [21]. Currently, BCA has updated the regulations on daylight reflectance for materials used on the building facade. The new regulations have changed from a prescriptive based of less than 20% daylight reflectance to a performance based method that requires the external surface of a building to be designed and constructed without affecting the surrounding areas.

![Image](image_url)

**Figure 1.** Outdoor glare from reflected sunlight in Singapore.

Regression modelling, factor analysis, and correlation analysis are the most familiar statistical techniques applied to analyse road users’ glare. Nevertheless, for the estimation of dependent or output variables, there are some concerns when using regression analysis. The multicollinearity of independent variables is the main preventable issue of regression analysis. Furthermore, this issue has an effect on separate predictors but no impact on predictive power. In other words, in multiple regression techniques, there may be a well-fitted model, but correlated predictors may not produce
trustable results for research model coefficients. Moreover, regression modelling does not facilitate estimating causal and indirect effects in a single and integrated equation.

In the last decades, Structural Equation Modelling (SEM) is an improved modelling technique, has been applied as a better statistical method of analysing normal and causal relationships with lack of multicollinearity among latent (construct) and measurement variables. Hence, the purpose of the current paper is to introduce a new framework which can provide an overall evaluation of observed and non-observed (latent) research variables by the combination of age, glare time, glare duration, avoidance and sensitiveness with SEM technique.

2. Methods
SEM is a robust method to hypothesize any kinds of relations and interactions among research variables in a single causal framework. Based on the objective of the study with capability of SEM, the present figure 2 illustrates the conceptual framework of the study.

![Figure 2. Research Framework](image)

The squares (or rectangles; □) and circles (or ellipses; ⊙) represent observed and unobserved (latent) variables respectively. In the above figure 2, age, glare time, and glare duration act as independent variables, avoidance is a mediator, and sensitiveness is the dependent variable. In figure 2, age, glare time, and glare duration have direct and indirect impact on sensitiveness.

3. Sampling
The stratified sampling method has been chosen for the survey. The population surveyed was divided into four different locations (areas). These are respectively Marina Boulevard, Robinson Road, Chulia Street, and Shenton Way located in the city of Singapore. For each zone, 60 questionnaires were distributed. Therefore, the sample size is equal to 240. Data collection was performed between February 2016 and April 2016. The classical methods of standard SEM analysis are focused on the sample covariance matrix.

4. Data Analysis
The research framework developed can be observed in Figure 3. Prior to study the influence of independent variables on the dependent variable (sensitiveness), six model fitting tests were applied, to evaluate the consistency between the predicted and observed data matrix in the research equation. These indices were respectively Goodness of Fit Index (GFI), Relative Fit Index (RFI), Incremental Fit Index (IFI), Tucker Lewis Index (TLI), Comparative Fit Index (CFI), and Normed Fit Index (NFI).
For an acceptable model fitting, the value of the indices should be above 0.9. Figure 3 represents the model fitting results based on the SEM application. The results confirm that the defined indices values are within acceptable ranges. Therefore, the model fitting of the research framework is accepted.

![GFI (goodness of fit index)](GFI)

![RFI (Relative fit index)](RFI)

![IFI (Incremental fit index)](IFI)

![TLI (Tucker Lewis index)](TLI)

![CFI (Comparative fit index)](CFI)

![NFI (Normed fit index)](NFI)

Figure 3. Model fit analysis

The structural model for the research framework is determined and shown in Table 1. There are seven relations in the research model. Their impact was evaluated using the AMOS software.

Table 1. The output of the structural model.

| Path                      | Standardized Coefficient | C.R. | p   |
|---------------------------|--------------------------|------|-----|
| Age → Avoidance           | 0.56                     | 7.329| <0.001 |
| Age → Sensitiveness       | 0.44                     | 5.451| <0.001 |
| Glare Time → Avoidance    | 0.23                     | 3.142| <0.001 |
| Glare Time → Sensitiveness| 0.29                     | 3.881| <0.001 |
| Glare Duration → Avoidance| 0.11                     | 1.612| 0.113 |
| Glare Duration → Sensitiveness| 0.18                   | 2.312| 0.031 |
| Avoidance → Sensitiveness | -0.33                    | -4.113| <0.001 |

5. Discussion

The aim of this study is to examine a multi-factorial model for the relationship between pedestrians and outdoor glare issues by applying SEM. The research framework contains four measurable variables (age, glare time, glare duration, and sensitiveness) and one latent variable (avoidance). The sensitiveness is the main dependent variable; the age of the road users, glare time, and glare duration status are the main independent variables, whereas avoidance is considered the mediator between the dependent and independent variables. As shown in Table 1 the impact of pedestrian age on avoidance and sensitiveness has the highest significance compared to glare time and glare duration on dependent and mediator variables. Glare time also has a major impact on avoidance and sensitiveness. Glare duration has a significant impact on sensitiveness. Interestingly, avoidance has a significant negative impact on sensitiveness. According to the findings, R² of the introduced model is 0.71, which means that 71% of a sensitiveness variation is dependent on age, glare time, glare duration, and avoidance.

The current study is limited by the cross-sectional data analysis, which does not allow influential temporal connections between research variables. The main suggestion is that this research should be carried out with longitudinal data, which can provide more robust and precise data analysis. The
computation system in SEM has the main concern with normality assumption. In some data structures, the tested multivariate normality is not accepted based on normality tests. Thus, several scholars [23],[24] rely on Bayesian approach in SEM which is confirmed to have the capability to overcome the non-normality issues.

6. Conclusion
The main contribution of this study is about the application of SEM in estimating the perceived outdoor glare from highly reflective building facade by pedestrians in the city of Singapore. By applying SEM, a framework for outdoor glare evaluation that can fill in the modelling gaps that exist in regression analysis is presented. For a better sustainable development, planners, designers and engineers should understand the relationship between microclimate and glare holistically. It is hoped that this complicated relationship and predictive evaluate of glare should not be a reason to embolden the government initiatives for promoting sustainable design.

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