Effect of reflective building façade on pedestrian visual comfort

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Abstract. Building materials have become increasingly diverse and flexible regarding their shapes, colours and texture. These include the use of highly reflective materials for facade (e.g. glass or metal claddings) which becomes a popular concept for high-rise buildings. However, these reflective materials contribute to an increasing number of feedbacks on discomfort associated with reflected glare at the pedestrian’s level and the surrounding environment. This study aims to evaluate the impact of reflected glare from the reflective building facade on pedestrians’ visual comfort in Kuala Lumpur city area. The relationship between pedestrians and reflected glare issues is determined by applying Structural Equation Modelling (SEM) between male and female. Total of 500 questionnaires is distributed at four different locations. The six-modelled fitting test was tested and within an acceptable range. For both male and female models shows that age significantly affects sensitiveness toward reflected glare.

1. Introduction
The needs to understand the characteristics and properties of building materials is very crucial as it has a direct and indirect impact on the urban environment. The incidence of light on a building surface has cause it to be reflected, absorbed and emitted simultaneously. The exterior parts of the building either vertical or horizontal are the most exposed part by solar radiation. The surface roughness particularly will determine whether the reflected component is in a specular or diffusive manner. Once the source of light is reflected, it has implied thermal and visual performance of a building as well as towards the thermal comfort of the pedestrian [1][2][3][4]. The amount of light being absorbed (albedo) in another hand has significantly affected the surface temperature of a building thus increases the energy consumption and urban heat island problem [5][6][7][8][9].

Over the past decade, metal and glass have become preferred façade material for high rise building in many cities around the world. Aside from the physical properties of these reflective materials, the floor-to-ceiling glass façade has become a popular concept in modern architecture. The argument is that it provides abundant daylight and visual connection to the outdoors as well as the aesthetic point of view. However, there is a high environmental cost to all that glimmer; increased energy consumption due to solar heat gain and glare problem for the indoor and outdoor environment. Also, with higher glazing and reflective fraction, indoor and outdoor glare may possess a risk to the surrounding environment [10][11][12][13][14][15].
2. Outdoor Glare in Urban Setting

The high number of solar reflective building throughout dense urban developments not only can change the microclimate of the surrounding area but also can create the outdoor glare problem. Theoretically, the high reflective facade is good to keep the intense sunlight into a building, but the outdoor dweller such as pedestrian and motorist will become the victims. The reflected light or glare from vertical surfaces is most apparent on the shaded side of tall buildings, where the sunlight is reflected from the un-shaded light-coloured wall surfaces[16]–[18]. Similarly, concave and convex facades are likely to be more of a dilemma, as it can reflect high angle sunlight to neighbouring buildings and ground surfaces. It is evident that large areas of reflecting material are more likely to cause glare problems than small areas. [19],[20]. The astound case study that showcases this architectural failure is Walt Disney Hall Concert (WDHC) building [21]. The shining façade made of stainless steel has caused the pedestrians, drivers and residential nearby a significant glare and reflected heat problem. Later, even remedial work has been done on the stainless-steel facade; the reflected glare still possesses a risk to the surrounding environment.

The indoor glare has received much attention from the research scholar compared to the outdoor glare. There is still no validated methodology to determine the impact of the outdoor glare in the urban setting particularly for the outdoor dwellers. Several indices can be followed to determine the degree of the glare related problem in building for example Daylight Glare Probability (DGP) or Daylight Glare Index (DGI). Therefore any in-situ measurement that exceeds the permissible limits will be analysed easily in the model. Unlike the outdoor glare, it is yet to be explored on the impact towards the surrounding environment. The study on the human subject has been carried out to prove the existence of outdoor glare problem, but the framework is yet to be improved [22]. A similar study has been done to examine the effect of building façade reflectivity on outdoor visual comfort in the tropical climate [23]. The solar reflectivity studies using simulation tool such as Computational Fluid Dynamic (CFD) has been introduced to study the impact of expected glare from the source building [24]. Moreover, this tool claimed that it accurately predicts the path of reflected light, intensity, and associated temperature increment. Nevertheless, it may require a long process and need a powerful computer that runs it. The other lacking information in this tool is the impact of outdoor dwellers’ visual comfort.

![Figure 1. Outdoor glare from reflective building facade.](image)

Building materials have become increasingly diverse and flexible regarding their shapes, colours, and texture. The use of highly reflective materials for facade (e.g. glass or metal claddings) has becomes a popular concept for high-rise buildings in Kuala Lumpur (Figure 1). However, these reflective materials
contribute to an increasing number of comments associated with reflected outdoor glare problem. In the context of Malaysia’s building regulation on daylight reflectance of materials used on building exterior, it is still yet to be implemented. Perhaps, there is no such guideline on building façade reflectance, especially during the design or construction process. For example, Singapore has regulated that the daylight reflectance of materials used on building exterior, from compliance to be less than 20%. It is also mentioned that the external surface of a building must be designed and constructed in a means such that any reflection of sunlight off building external surface does not result in loss of amenity to occupants of other buildings in the vicinity of that building. Thus, this study aims to evaluate the impact of glare from the reflective building facade on pedestrians’ visual comfort in Kuala Lumpur city area.

3. Methodology
Structural Equation Modelling (SEM) can hypothesise any kinds of relations and interactions among research variables in a single causal framework. The presented conceptual framework of the study is shown below (Figure 2).

![Figure 2. Research Framework](image)

The squares (or rectangles; ) and circles (or ellipses; ) shown 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. As we can see in Figure 2, age, glare time, gender as a moderator and glare duration have a direct and indirect impact on sensitiveness.

The stratified sampling method has been chosen for the survey. The population surveyed was divided into three different locations (areas). These are respectively Jalan Ampang, Jalan Binjai, Jalan Tun Razak and Persiaran KLCC located in the city of Kuala Lumpur. For each zone, about 125 questionnaires are distributed. Therefore, the sample size is equal to 500 (342 questionnaires are prepared from male and 158 questionnaires for female). Gathering data are done performed between August 2018 until end of November 2018.

4. Data Analysis
The six-model fit test was used to develop the research framework of this study. This framework is based on the influence of independent variables on the dependent variable (sensitiveness) and can be observed in Figure 3. The consistency of predicted and observed data in SEM are lies in all six indices namely, 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). From the study, for all the six indices, it shows that the predicted and observed data are within the acceptable range of above 0.9 hence the research framework is accepted. Figure 4 shows the structural model between male and female. There are seven relations in the research model. As we can see in Figure 4, the structure of the model for the male is different than the female model.

![Figure 3. Model fit analysis](image)

![Figure 4. The output of the structural model for male and female.](image)

5. Discussion
This study aims to examine a multi-factorial model for the relationship between pedestrians and outdoor glare issues by applying SEM between male and female. 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. Gender is acting as a moderator, which means two different models will be presented in this paper. Moreover, the introduced framework is also designed with improvements from previous modelling studies, using a combination of different relations among research variables. Based on the SEM output which is presented in Figure 4, the R-square of the male model (0.71) is higher than the
female model (0.65) which indicates the sensitiveness variation is depending on age, glare time, glare duration, and avoidance. Three independent variables have defined in the research model which are age, glare time, and glare duration. Age in the male model has a significant impact on avoidance (0.52) and sensitiveness (0.41). However, in the female model, age has significant effects on sensitiveness (0.65). Glare time for both models has significant implications on avoidance and sensitiveness. Those impacts, glare time on both avoidance and sensitiveness, for the female model is higher than the male model. In the male model, the impact of glare duration on avoidance is not significant (0.13) but significant towards sensitiveness (0.19). Hence, in the female model glare duration is not a significant effect on both avoidance (0.07) and sensitiveness (0.05). The last relation is about the impact of avoidance on sensitiveness. For both models, this impact is negative and significant, and the value of correlation for a male model (-0.39) is bigger than the female model (-0.47). Another result from SEM analysis is that avoidance, for both models, is a mediator between glare time and sensitiveness. However, mediating of avoidance between age and sensitiveness, glare duration and sensitiveness for both models are rejected.

6. Conclusion
An awareness of the impact of the material’s selection between project stakeholders should not be done in isolation. Being in a tropical country, where a large amount of solar insolation occurs, reflected glare from the building façade will have a significant impact on the surrounding environment. Furthermore, heat will also be reflected and cause the ambient temperature to be risen and indirectly promotes the issue of urban heat islands. This study presents the application of SEM in modelling the impact of the reflected outdoor glare from reflective building facade by pedestrians in the city of Kuala Lumpur. It is detrimental to understand the behaviour and properties of building materials before they can be deployed.

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