Crown Resorts Limited

Crown Sydney Hotel Resort

Reflectivity Study

REP

Rev 2 | 11 March 2015

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It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

Job number 233906

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Job title		Crown Sydney Hotel Resort			**Job number** 233906
Document title		Reflectivity Study			**File reference**
Document ref		REP			
Revision	**Date**	**Filename**	Reflectivity.docx		
Draft 1	1 Apr 2014	**Description**	Outline of report. Results to be completed		
			Prepared by	Checked by	Approved by
		Name	Jorg Kramer	Haico Schepers	Haico Schepers
		Signature			
Draft 2	6 May 2014	**Filename**	Crown Reflectivity Report Draft 20140506.docx		
		Description	Results updated for revised model geometry		
			Prepared by	Checked by	Approved by
		Name			
		Signature			
Draft 3	23 Sep 2014	**Filename**	Crown Reflectivity Report Draft 20140923.docx		
		Description	Draft of Issue. General updates		
		General	Prepared by	Checked by	Approved by
		Name	Jorg Kramer	Haico Schepers	Haico Schepers
		Signature			
Issue	25 Sep 2014	**Filename**	Crown Reflectivity Report 20140925.docx		
		Description	Issue		
		Issue	Prepared by	Checked by	Approved by
		Name	Jorg Kramer	Haico Schepers	Haico Schepers
		Signature			

Issue Document Verification with Document ✓

Document Verification

Job title	Crown Sydney Hotel Resort	**Job number**	233906
Document title	Reflectivity Study	**File reference**	
Document ref	REP		

Revision	**Date**	**Filename**	Crown Reflectivity Report Rev2 20150311.docx		
Rev 2	11 Mar 2015	**Description**	Updates to project description		
			Prepared by	Checked by	Approved by
		Name	Jorg Kramer	Haico Schepers	Haico Schepers
		Signature			
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			
		Filename			
		Description			
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Contents

Executive Summary

This reflectivity study assesses the impact of solar reflections on pedestrians and road traffic participants in the area surrounding the proposed Crown Sydney Hotel Resort building at Barangaroo South in terms of reduced visibility of visual tasks. It is based on qualitative requirements of the Central Sydney DCP 2012 Provision 3.2.7. As per this provision, the report focuses on the impact to traffic participants. This assessment is performed following the methodology of David N.H. Hassall of the University of New South Wales[1].

The proposed building has been found to perform well in terms of solar reflectivity, and reflections have not been found to cause unacceptable glare according to the Hassall methodology, as long as normal specular reflectivity glazing is kept within the following limits:

- **Tower glazed facades: 32%**
- **Hotel glazed facades: 20%**

In addition the hotel façade is to incorporate shading fins in particular locations noted to limit sun disk reflections.

This result is obtained despite not taking into account mitigating effects from obscuring smaller façade elements and surrounding vegetation.

Pedestrians are easily able to adjust their view in any location where unwanted reflections may be received, reducing the impact of the reflections, and move at a rate significantly slower than that of a vehicle. For this reason it is acceptable to assume that it will be safe for pedestrians to divert their vision in order to avoid glare.

It is noted that the City of Sydney limits glass reflection to less than 20% primarily to limit impacts on drivers and pedestrians. This report demonstrates that there is capacity to extend this limit for this building under these circumstances. For surrounding buildings it may also be justified to extend this limit as the curved shape of the building will reduce potential glare reflections by scattering the reflections, and for observers at a distance the limited facet size will reduce the intensity of reflections.

[1] Hassall, D. N. H. (1991): *Reflectivity. Dealing with Rogue Solar Reflections*, Faculty of Architecture, University of New South Wales, ISBN 0 646 07086 X

1 Introduction

This report has been prepared on behalf of Crown Resorts Limited to accompany a State Significant Development Application (SSDA) for the Crown Sydney Hotel Resort at Barangaroo. The Hotel Resort is proposed in accordance with the approved Barangaroo Concept Plan (as modified) and is located within Barangaroo South.

This reflectivity study assesses the impact of solar reflections on pedestrians and road traffic participants in the area surrounding the site. It is intended to address the qualitative requirements of the Central Sydney DCP 2012 Provision 3.2.7.

The assessment in this report is performed following the methodology of David N.H. Hassall of the University of New South Wales, which contemplates potential rogue reflections giving more detailed consideration to geometry, viewing angles, and sun positions. It is described in more detail in section 0.

2 Project Description

Figure 1: Visualisation of proposed Crown Sydney Hotel Resort, viewed from south (Wilkinson Eyre Architects)

2.1 Site Location and Context

Barangaroo is located on the north western edge of the Sydney Central Business District (CBD), bounded by Sydney Harbour to the west and north; the historic precinct of Millers Point (for the northern half), The Rocks and the Sydney Harbour Bridge approach to the east; and a range of new development dominated by large CBD commercial tenants and the King Street Wharf/Cockle Bay precinct to the south.

The 22ha Barangaroo site is generally rectangular in shape and has a 1.4 kilometre harbour foreshore frontage, with an eastern street frontage to Hickson Road. The site has been divided into three distinct redevelopment areas (from north to south) – the Headland Park, Barangaroo Central and Barangaroo South, and has been subject to multiple investigations that detail the physical and natural characteristics of the site.

2.2 Crown Sydney Hotel Resort Development

The Crown Sydney Hotel Resort development will comprise a single high rise building that will include a hotel, VIP gaming and residential apartments. More specifically approval is sought for:

- Construction and use of a hotel, VIP gaming facilities and residential apartment building with associated retail and restaurant uses and a basement car park to accommodate parking and servicing allocated to the proposed uses within the development, comprising a total Gross Floor Area of approximately 77,500m^2 and a maximum building height of approximately 271 metres (RL 275);
- Associated building signage; and
- Provision of services and utilities required to service the building.

2.3 Facades

The building rises above the neighbouring properties, such that all of its principal elevations can be seen from road level.

The building consists of three key interlocking curving volumes. The overall convex double curved elevations are faceted with a large number of triangular or rectangular glazing facets.

The intent for the facades is to be predominately full height glazing. Spandrel areas are typically intended as shadow box arrangements with the same glazing as for the vision area used on the outer face.

All tower glazing will have a normal specular reflectivity no higher than 32%. The hotel glazing reflectivity is to be limited to 20%. In addition the Hotel elevations feature projecting vertical fins at different spacing. These fins are designed to limit extent of angular reflection from these elevations. The finish of fins is to be selected to have a specular component of reflectivity no higher than 20%.

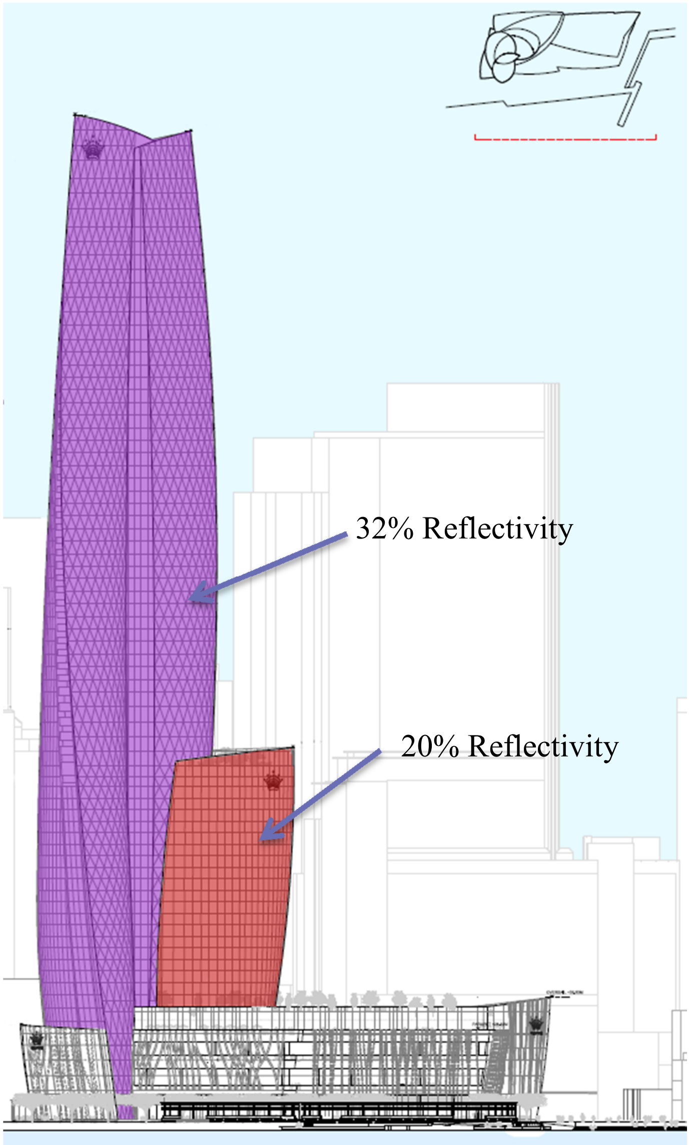

Figure 2: Intended Reflectivity of Glazing

3 Assessment of Facade Reflections

3.1 Criteria for Assessment

The method for this study follows that of David N. H. Hassall of the University of New South Wales, which has been widely used to assess reflections off building projects in Sydney. This method quantifies reflections and classifies reflections using the terms disability glare and discomfort glare. These are defined in the Hassall methodology as follows:

- Disability glare – glare from reflections which impact the observer in a way that they are unable to perform a visual task, such as reading or driving, without taking evasive action (such as turning away or raising a hand to shield the eyes). It is critical that a driver's view is unaffected by disability glare as this has the potential to cause road accidents. Note that the term 'Disability' indicates temporary impact on the ability to perform visual tasks and does not imply that the glare effect leads to long-term disability in any form.
- Discomfort glare – glare from reflections causing the observer psychological annoyance.

Calculations following this method centre on equivalent veiling luminance in the eyes of observers due to solar reflections. The terms 'veiling luminance' and 'veiling glare' refer to the effect of multiple reflection and scattering within the eye of direct light from a bright source. This produces a perception similar to a thin veil being overlaid on the visual scene, and reduces the contrast in the scene, potentially impairing visual tasks.

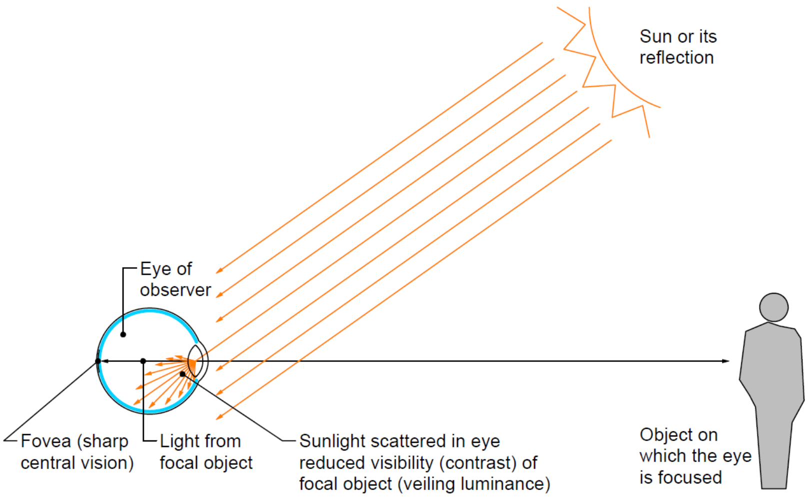

Figure 3: Bright sunlight falling into the eye reduces contrast and visibility of objects. This effect can be quantified by the equivalent veiling luminance measure.

The equivalent veiling luminance is a measure of this effect, and hence considered a measure of the visual impact of glare. Luminance is measured in Cd/m^2 (candela per metre squared) and is a representation of how bright a surface will appear to the human eye. The equivalent veiling luminance is a measure of this adjusted to account for the mitigating effect of the angle between view direction and reflected light. Where its value exceeds the level of $500Cd/m^2$, the solar reflection is considered excessive (potentially causing disability glare) in accordance with the Hassall methodology.

3.2 Methodology

The assessment of undesirable solar reflections is based on the methodology described by Hassall. This involves several steps, as outlined below.

- The size, orientation and extent of reflective objects on each facade are determined by examination of drawings provided by the architect, the site and surrounds, and expected glazing materials.
- Several observer locations are chosen for critical facades, representing locations from which traffic participants may observe the facades.
- Times at which the sun is reflected off the facade are determined, as well as the directions in which it is reflected.
- If the sun is reflected towards any observer, the equivalent veiling luminance in the eye of the observer is calculated and evaluated against the maximum allowed level of 500 Cd/m² according to Hassall. This involves calculations of the strength of solar illumination, the position of the sun in front of the facade, the apparent position of the sun reflected in the facade, and the reflected solar illumination received by the observer. If the limit is exceeded, further assessment is carried out to evaluate if other factors such as the reduced apparent size of façade facets at the observer distance make the situation acceptable or not.
- On the multifaceted facades, the sun is only reflected by individual panels at a given time. Observed from a larger distance these do not reflect the full sun disk. In these cases it is reasonable to assume that the intensity of reflections off a panel is proportionally diminished with the percentage of the sun disk solid angle that is reflected by the same panel.

  The equivalent veiling luminance of sun reflections in the façade facet planes (noted Lv_1 below), weighted by ratio of reflection solid angle to full sun disk solid angle has thus been calculated (noted Lv_2 below. See diagram Figure 4). This value is then assessed against the maximum allowed level of 500 Cd/m² according to Hassall.

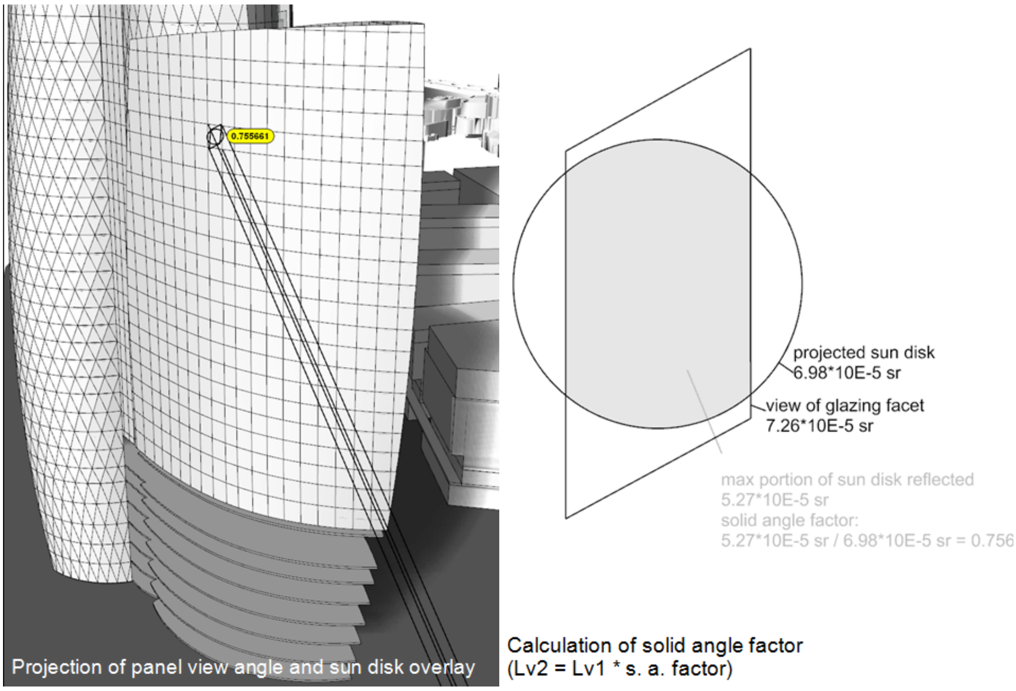

Figure 4: Weighted ratio methodology for faceted facade panels

3.3 Assumptions

- All glazed tower facades have been assumed to have a reflectivity of 32%.
- Hotel façade has been assumed to have a reflectivity of 20%.
- Building geometry is based on the 3D DA set provide by Wilkinson Eyre.
- It is assumed that to carry out the visual tasks required for traffic participation, drivers and pedestrians face parallel to the ground, and parallel to their direction of travel.

3.4 Modelling and Assessment Approach

This reflectivity study used a 3D model of the building and the surrounding topography. The 3D model was developed from the architectural 3D model as a simplified massing model, however retaining accurate orientations of façade surfaces. Relative road elevation information was taken from available 3D topography.

Facades have been analysed in true elevation angles as provided with 3D model information by Wilkinson Eyre architects. Small scale detail such as joints, any expressed framing profiles, downpipes, etc has been omitted from the model. They subtend insufficient angles in the visual field to reflect a large enough portion of the sun disk to cause unacceptable glare.

3.5 Results for Analysed View Directions

Observed model analysis outcomes for each of the locations shown using typical travel paths are summarised below. The results show critical luminance values in relation to the observer nominated as L_{v2} (see explanation below). Red lines indicate direction of travel.

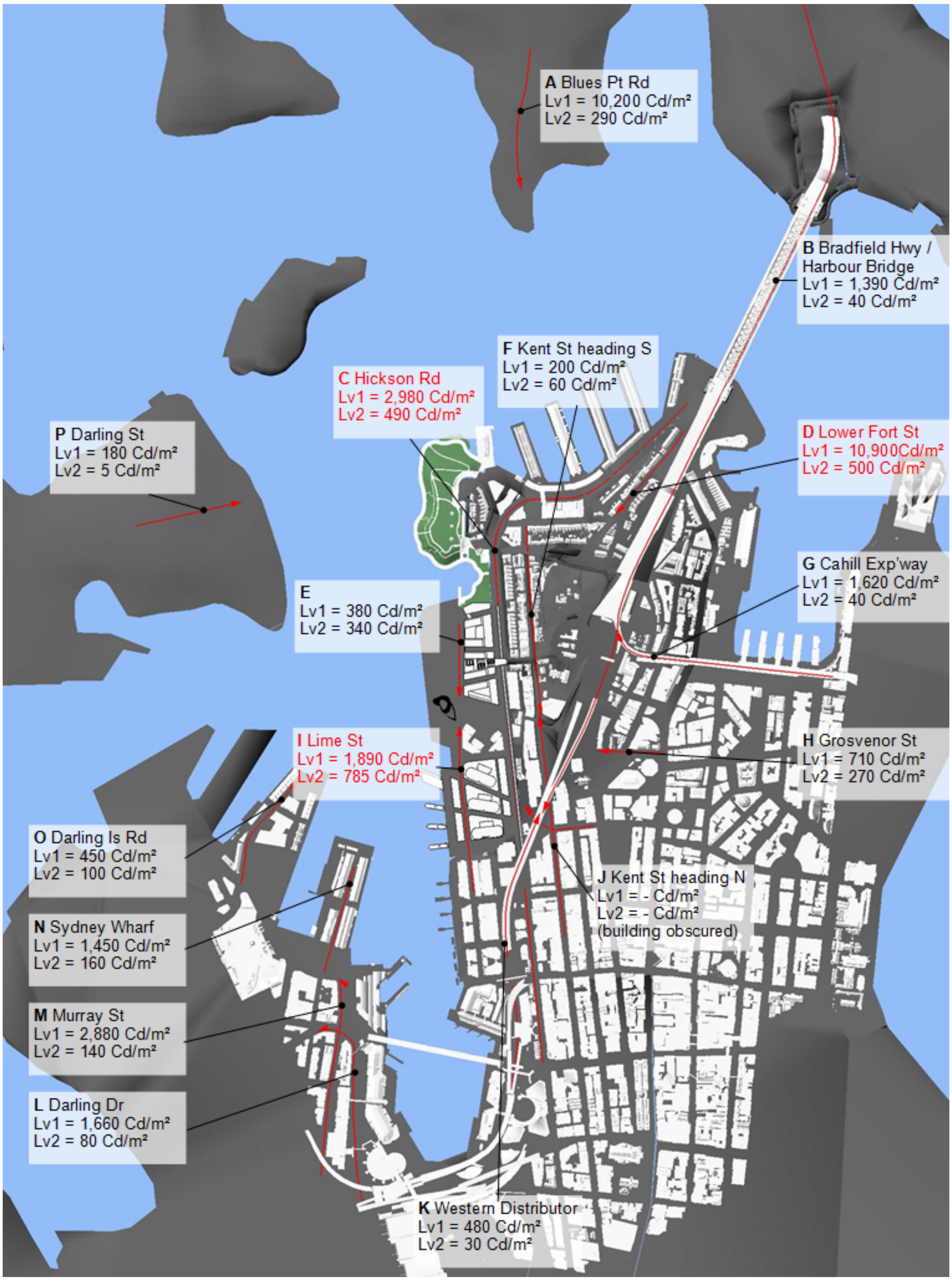

Figure 5: Maximum equivalent veiling luminance figures per observer travel path

The unique façade geometry of the proposed Crown building with a large number of facets covering overall convex double curved elevations has the following general effects:

- Sun is reflected in many directions and through the whole range of incidence angles, and can be seen from many roadways.
- The sun is only reflected by individual panels at a given time, as the façade is generally convex. Observed from a larger distance these do not reflect the full sun disk. In these cases it is reasonable to assume that the intensity of reflections off a panel is proportionally diminished with the percentage of the sun disk solid angle that is reflected by the same panel.

Two maximum values encountered along each road have been recorded:

- The nominal equivalent veiling luminance (noted Lv_1 in map diagram) of any sun reflections calculated from observer heading and façade facet orientation / inclination. These do not take into account the reducing effect of facet size and can have intensities well above the limit of acceptability
- The equivalent veiling luminance of sun reflections in the façade facet planes, weighted by ratio of reflection solid angle to full sun disk solid angle (noted Lv_2 in map diagram). This accounts for the intensity reducing effect of the diminishing apparent size of facets with distance and view angle and is the relevant figure for assessing glare impact potential on traffic.

The map above highlights in red text those locations where reflections from façade panels may cause Lv_2 intensities close to or above the limit recommended by the Hassall method, taking into account panel size. These areas;

C Hickson Road
D Lower Fort Street
I Lime Street

are discussed in more detail in the following section in relation to extent, proposed mitigation and impact of these reflections.

3.6 Key areas with reflection intensities near or above acceptable limit

3.6.1 C. Hickson Road

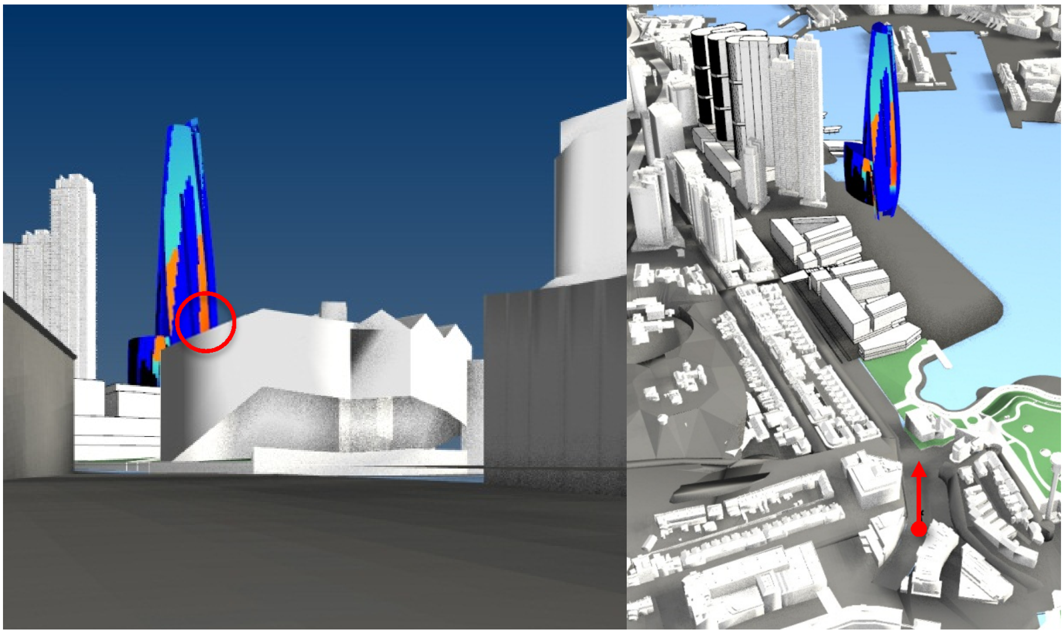

Figure 6: Perspective view from Hickson Rd and view of relative observer position

Note: Façade areas are shown orange to red where reflections (not solid angle weighted) exceed the Hassall limit of 500Cd/m². Reflections shown in blue to cyan are below this limit in intensity

Drivers heading south on Hickson Road may see reflections from the tower north façade with solid angle weighted veiling glare reaching up to close to 500Cd/m² at a façade normal reflectivity of 32%.

These reflections are seen from a large distance away and will be partially obscured by future development along Hickson road. Exposure of drivers to reflections would be brief and not continuous along the road. Drivers in this area are likely travelling at speeds of 50km/h or less. Given these mitigating factors the impact of veiling glare approaching the limit proposed by Hassall is unlikely to cause a significant risk to safety in this location.

3.6.2 D. Lower Fort Street

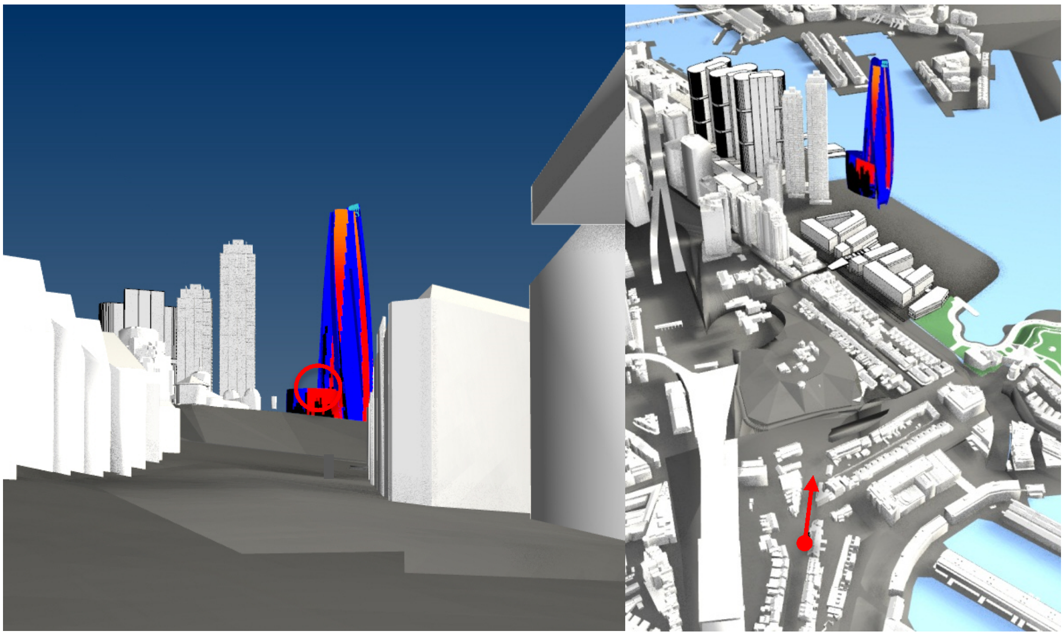

Figure 7: Perspective view from Lower Fort St and view of relative observer position

Note: Façade areas are shown orange to red where reflections (not solid angle weighted) exceed the Hassall limit of 500Cd/m². Reflections shown in blue to cyan are below this limit in intensity

Drivers heading south on Lower Fort St road may see reflections from the hotel north east façade with solid angle weighted veiling glare reaching up to 500Cd/m² at a façade normal reflectivity of 20%.

These reflections are seen from a large distance away and will be partially obscured by trees and houses on Lower Fort St. Exposure of drivers to reflections would be brief and not continuous along the road. Drivers in this area are likely travelling at speeds of 50km/h or less. The reflections are close to the lower edge of the angular elevation Hassall notes as being able to be blocked with a car's sun visor, and it may be possible to partly obscure them in this way.

Given these mitigating factors the impact of veiling glare approaching the limit proposed by Hassall is unlikely to cause a significant risk to safety in this location.

3.6.3 I. Lime Street

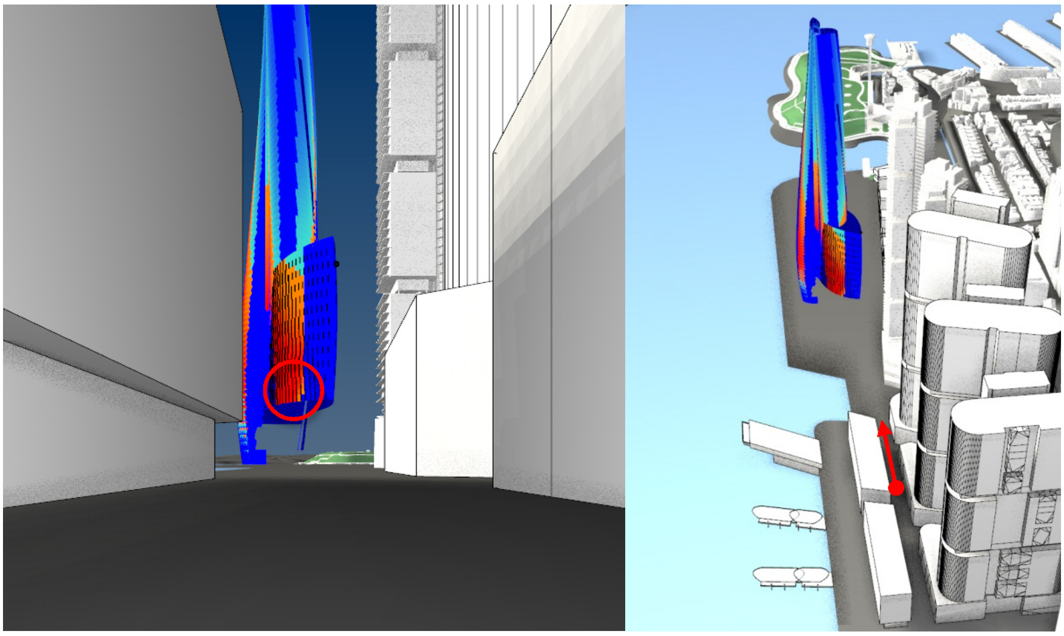

Figure 8: Perspective view from Lime St and view of relative observer position

Note: Façade areas are shown orange to red where reflections (not solid angle weighted) exceed the Hassall limit of 500Cd/m². Reflections shown in blue to cyan are below this limit in intensity

Drivers heading north on Lime St may see reflections from the hotel south west façade with solid angle weighted veiling glare reaching up to 785Cd/m² at a hotel façade normal reflectivity of 20%.

This façade uses protruding fins to limit the size of sun disk reflections to reduce veiling glare to acceptable levels.

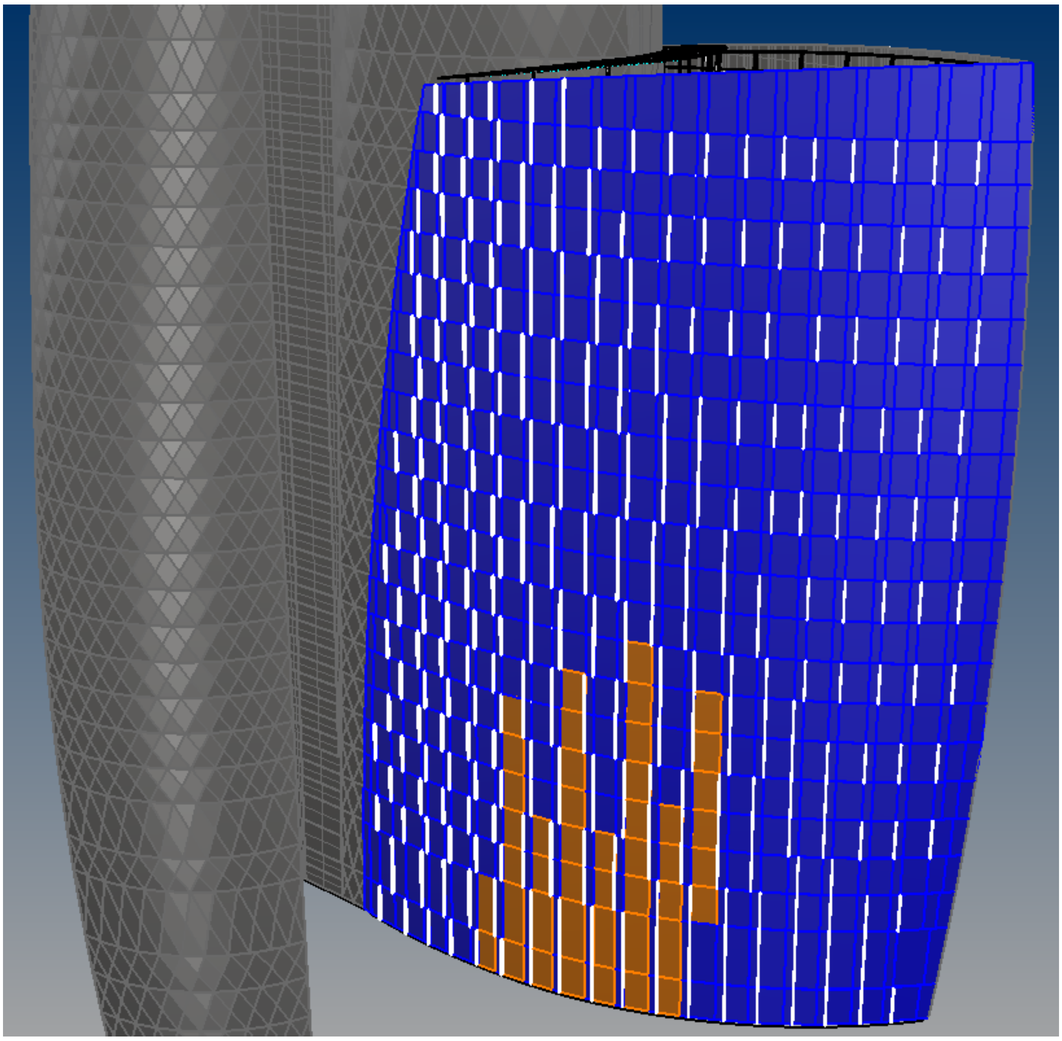

Figure 9: Hotel volume façade panels with Lv2 exceeding threshold (in orange)

Façade panels highlighted in Figure 9 above are those where reflections exceed 500Cd/m² after solid angle weighting (not taking into account effect of fins), but where these can be reduced to levels below this threshold by protruding fins. The necessary depth of fins was reviewed against Lv_2 values for the individual panels, and the angle of incidence of sun rays causing glare exceeding the threshold, which determines the reduction in reflected solid angle achieved by fins.

For each of the highlighted panels, a protruding opaque fin of minimum depth 200mm at one side of the panel is sufficient to achieve reduction below the threshold.

The fins documented in the provided model geometry fulfil this requirement. Reflections towards this observer path have thus been found to pose minimal risk of glare.

3.7 Impact on Pedestrians

From the perspective of pedestrians moving along roadways, the incidence of reflections from the building is generally similar to the examined road traffic locations.

Pedestrian observers are easily able to adjust their view and thus reduce the glare impact of reflections. They move at a rate significantly slower than that of a vehicle. For these reasons it can be assumed that it will be safe for pedestrians to divert their vision in order to avoid glare.

3.8 Impact on Surrounding Buildings

Solar reflections off the facade may reach surrounding buildings in the CBD area, as would be expected for any glazed façade in an urban context that can be reached by sunlight.

Due to the specific faceted convex façade geometry of the proposed building, reflections towards surrounding buildings will be intermittent, as there is a gap between the reflection cast by one facet and the next. Exposure to reflections from an individual facet is thus of shorter duration compared to those off more common planar façade elevations. This scattering of reflections may however also mean they are cast towards a wider range of surrounding areas, and from a given observer location reflections may be recurrent from different facets throughout longer stretches of the day.

Observed from a larger distance the individual glazing facets do not reflect the full sun disk. The apparent size of typical glazing facets on the building becomes smaller than the angular size of the sun disk from a distance of approximately 200-250m. It can thus be assumed that the reflection intensity viewed from areas further afield e.g. across the harbour is likely less than that off a more common practice planar façade of the same nominal reflectivity (Refer discussion of Lv_1 vs Lv_2 in section 3.2).

Nuisance from reflected glare is subjective, and there are no clear guidelines for acceptable limits. It is noted that the City Sydney DCP limits glass reflection to 20% primarily to limit impacts on drivers and pedestrians. This report demonstrates that there is capacity to extend this limit for this building under these circumstances. Due to the geometry effects discussed above, for surrounding buildings it may also be justified to extend this limit as the curved shape of the building will limit duration of exposure to potential glare reflections, and for observers at a distance the limited facet size will reduce the intensity of reflections.

4 Conclusion

In all cases analysed, veiling luminance has been found to remain below acceptable levels for traffic impact per the Hassall methodology, as long as normal specular reflectivity glazing is kept within the following limits:

- **Tower glazed facades: 32%**
- **Hotel glazed facades: 20%**

In addition the hotel façade is to incorporate shading fins in particular locations noted to limit sun disk reflections.

Reflections from the following areas were found to approach the veiling luminance limit in the analysis. Mitigating factors are discussed below.

- Tower façade viewed from Hickson Road. Reflections are close to limits but have not been found to exceed recommendations. In addition, concern about intensities approaching the recommended limits is mitigated by reflections being intermittent only and likely to be obscured in the future by further development in the area. Traffic in this area is not high speed.

  Reflections do not present a significant risk to drivers.
- Hotel NE façade viewed from Lower Fort St heading S. Reflections are close to limits but have not been found to exceed recommendations. In addition, concern about intensities approaching the recommended limits is mitigated by reflections being intermittent only and likely to be partly obscured by vegetation and other obstacles that could not be included in the simulation. Traffic in this area is not high speed.

  Reflections do not present a significant risk to drivers.

Reflections from the following area were found to exceed the veiling luminance limit in the analysis. Measures mitigating this are discussed below.

- At the hotel SW façade viewed from Lime St heading N, Lv2 has been found to exceed the limit of acceptability. This is demonstrated in the image on the previous page with red areas exceeding the 500 Cd limit.

  Proposed vertical fins have been designed and sized to limit the size of sun disk reflections to reduce veiling glare to acceptable levels.

It is noted that the City of Sydney limits glass reflection to less than 20% primarily to limit impacts on drivers and pedestrians. This report demonstrates that there is capacity to extend this limit for the tower potion of this building under these circumstances.

For surrounding buildings it may also be justified to extend this limit as the curved shape of the building will limit duration of exposure to potential glare reflections, and for observers at a distance the limited facet size will reduce the intensity of reflections.

Appendix A

Reference Information

A1 Architectural Drawings

The reflectivity study presented in this report was based on 3D model information provided by Wilkinson Eyre Architects in April 2014.

A2 References

Hassall, D. N. H. (1991): *Reflectivity. Dealing with Rogue Solar Reflections*, Faculty of Architecture, University of New South Wales, ISBN 0 646 07086 X