REPORT

VOLPE C3

DETAILED SOLAR REFLECTION ANALYSIS

APRIL 28, 2023
PROJECT #2206579

SUBMITTED TO

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EXECUTIVE SUMMARY

RWDI was retained to investigate the impact that solar reflections emanating from the proposed C3 building will have on the surrounding urban realm.

Overall Impact of Reflections

The predicted impacts of the Project on its surrounds are typical of any modern building of its size and glazed area.

Thermal Impacts on People and Property

The nature of the facades of the Project ensure that reflected sunlight will not focus (multiply) within the public realm. Therefore, RWDI does not expect any significant thermal impacts (i.e. risks to human safety) to occur in the surrounding neighborhood.

Visual Glare Impact on Drivers and Cyclists

As with the addition of any glazed building, drivers travelling in the vicinity of the project were predicted to have the potential to experience visual glare. East- and westbound drivers on Broadway and southeast bound cyclists on Kittie Knox Bike Path were predicted to have the potential to experience reflections which can cause a high level of impact for both configurations.

Though these reflections were predicted to occur less than 0.8% of the daytime annually (approximately 4 hours per year) for driver receptors and 4% of the daytime annually (approximately 179 hours per year) for cyclists. Many of these impacts were predicted to reduce once future surrounding projects are built.

Further, some of these impacts were predicted at times where the sun would also be within a viewer's field-of-view, which would likely act to reduce the perceived impact of the reflections due to the much brighter direct sunlight.

Visual Glare Impact on Pedestrians and Facades

Typical levels of visual glare were predicted for pedestrians and building occupants in the vicinity of the development. Moderate to low impact reflections were predicted for pedestrians in the vicinity of the C3 building. Moderate impacts at the facades of the adjacent Volpe buildings were also predicted in up to 9% of the daytime annually (424 hours per year). However, depending on the final facade design for these buildings, the effect of the reflections on people within may be lower than what was predicted in this analysis. These types of reflections are common in an urban setting and do not represent a safety risk.

INTRODUCTION

This report provides the computer modeling results of reflected sunlight from the proposed Volpe C3 Lab building (The “Project”) in Cambridge, MA. The proposed C3 building will be located at the intersection of Broadway Street and Loughrey Walkway (as shown in Figure 1). The proposed C3 lab building is the part of the larger Volpe masterplan. It is our understanding that the Project will also be surrounded by typical urban spaces such as busy roadways, and other buildings.

RWDI was retained to investigate the impact that solar reflections emanating from the Project will have on the adjacent streets, Volpe buildings and open spaces. The study was conducted for two configurations:

1. The proposed C3 with the local with the addition of the approved MDX developments, and

2. The above configuration with the addition of the Volpe buildings C1, C2, C4, R1, R2, R3 and R4.

A preliminary set of simulations was conducted to determine peak reflection intensities and the frequency of reflection occurrence for a broad area around the Project. This served to identify areas which may experience high intensity or very frequent reflections. This information informed the selection of 7 points for Configuration 1 and additional 10 points for Configuration 2 for a more detailed analysis.

These receptor points represent drivers, cyclists, pedestrians, and building facades and the detailed results allow us to quantify the frequency, intensity and duration of glare events at the receptors as well as the sources of those reflections.

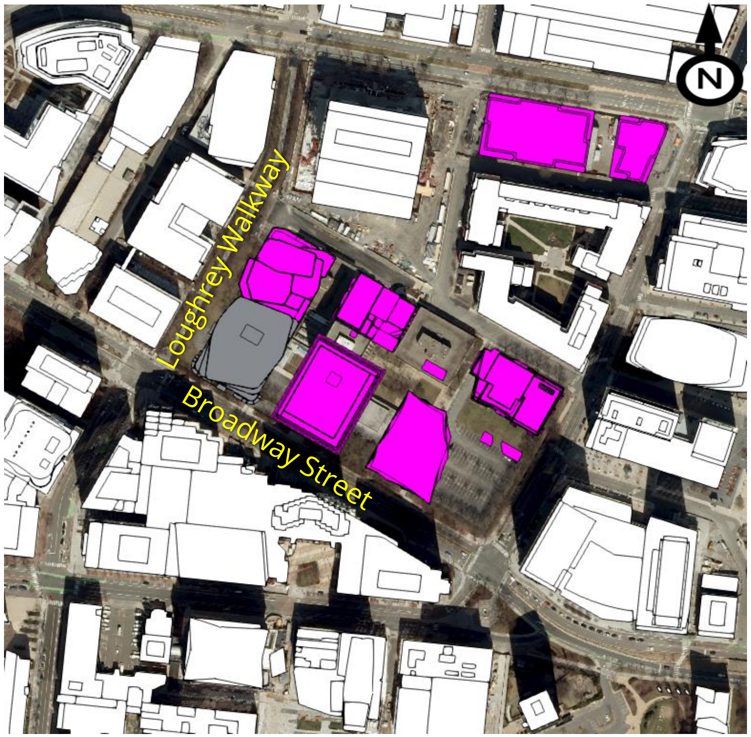

Figure 1: Location Of The Volpe C3 building (Grey) with Volpe’s Future Redevelopment (Magenta) (Map Credit: Google Earth)

Methodology

RWDI assessed the potential for reflection impacts using RWDI's in-house proprietary *Eclipse* software, in two phases as per the steps outlined below:

- The Phase 1 'Screening' assessment began with the development of a 3D model of the area of interest (as shown in Figures 3a and 3b). This was then subdivided into many smaller triangular patches (see Figure 4).
- For each hour in a year, the expected solar position was determined, and "virtual rays" were drawn from the sun to each triangular patch of the 3D model. Each ray that was considered to be "unobstructed" was reflected from the building surface and tracked through the surrounding area. The study domain included the entire pedestrian realm within 1,500 feet of the Project.
- The total reflected energy at that hour from all of the patches was computed and its potential for visual and thermal impacts assessed.
- Finally, a statistical analysis was performed to assess the frequency, and intensity of the glare events occurring throughout the year in the vicinity of the project. The criteria used to assess the level of impact can be found in Appendix B of this report.

Figure 3a: 3D Computer Model Of The Proposed Development (Grey) And Surrounding Context (Configuration1)

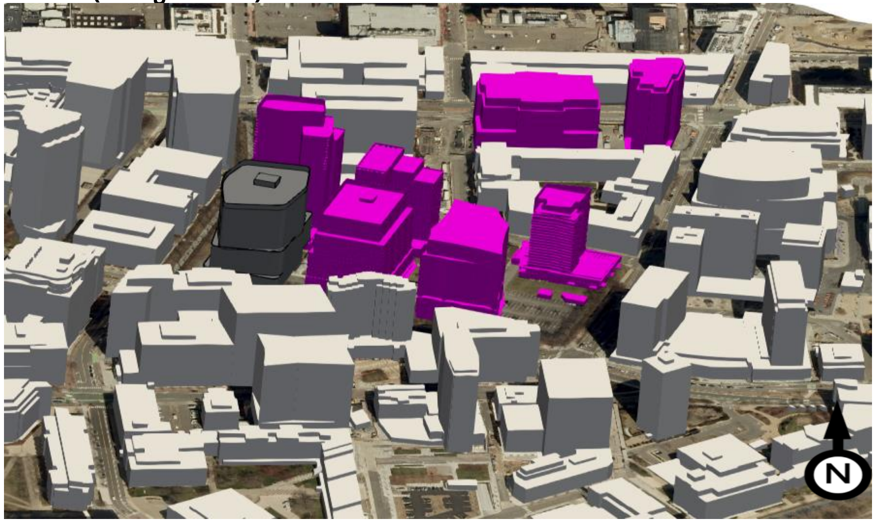

Figure 3b: 3D Computer Model Of The Proposed Development (Grey) And Surrounding Context (Magenta) (Configuration 2)

Methodology (cont'd)

- Based on the findings of the Screening analysis, multiple representative 'receptor points' were selected to undergo the Phase 2 'Detailed' analysis.
- The points were chosen to understand in greater detail how reflections from the Project will impact drivers, pedestrians and the rest of the built environment. The selected locations of the points are discussed further in the Detailed Analysis section this report.
- The Detailed analysis process is similar to the Screening analysis, except reflections are analyzed at one-minute increments for the entire year and the source of the reflections is stored for each receptor point.
- In addition to the frequency and duration of reflection impacts, the Detailed analysis allows for the prediction of when impacts can occur, how long they can occur for and the locations of problematic glare sources.

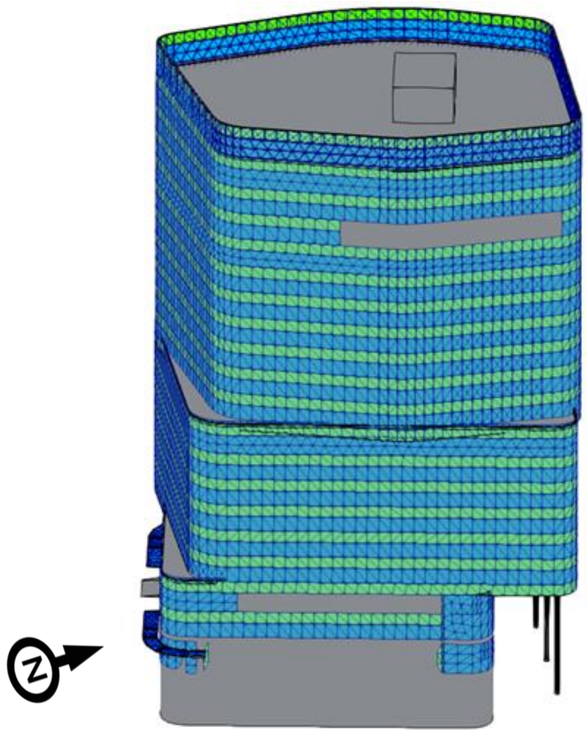

Figure 4: Close-up View Of The Model, Showing Surface Subdivisions

Assumptions and Limitations

Meteorological Data

This analysis used 'clear sky' solar data computed at the location of Cambridge Logan International Airport using the methodology promulgated by the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE). This approach uses mathematical algorithms to derive solar intensity values for a given location, ignoring local effects such as cloud cover. This provides an assessment of a complete year showing the full extent of when and where glare could ever occur.

Radiation Model

RWDI's analysis is only applicable to the thermal and visual impacts of solar radiation (i.e. ultraviolet, visible and infrared wavelengths) on people and property in the vicinity of the development. It does not consider the impact of the building related to any other forms of radiation, such as cellular telephone signals, RADAR arrays, etc.

Study Building and Surrounds Models

The analysis was conducted based on a 3D model of the Project building provided by Elkus Manfredi Architects to RWDI on March 3, 2023. The surrounding buildings were topographically corrected based on a high-resolution LiDAR survey conducted by the National Oceanic and Atmospheric Administration (NOAA) in 2013-2014. NOAA states that the horizontal accuracy of this data set is 16.5 inches at a 95% confidence level. Its vertical accuracy is stated as 4.8 inches at a 95% confidence level.

Potential reductions of solar reflections due to the presence of Vegetation or other non-architectural obstructions were not included, nor are reflections from other buildings. Light that has reflected off several surfaces is assumed to have a negligible impact. As such, only a single reflection from the development was included in the analysis.

This analysis assumed that all reflective elements are in their as-designed condition, (i.e. clean, free from damage, degradation, distortion, etc.) and that the building envelopes of all buildings are complete and uncompromised (i.e. any elements of the walls/roofs that are not designed to be exposed to sun, are shielded).

Assumptions and Limitations (cont'd)

Facade Material Reflectance

As per information received from Elkus Manfredi Architects on March 22 2023, the basis of design glazing is to have a 30% nominal visual reflectance. All glazed elements on study building were model as this glazing type.

The building facade is also understood to have terra cotta elements with a semi gloss finish. The nominal visible reflectance for terra cotta was assumed to be 10%.

Glass balustrades were also noted in the 3D model. These are unlikely to be IGUs, therefore we have assumed that they are typical laminated safety glass with a visible reflectance of 8%.

The reflectance properties of the different reflective elements are summarized in Table 1. Figure 5 illustrates the location of the reflective materials on the facades of the Project.

Applicability of Results

The results presented in this report are highly dependent on both the form and materiality of the Project's facades. Should there be any changes to the design, RWDI should be contacted and requested to review their potential effects on the findings of this report.

This analysis also assumes reasonable and responsible behaviour on the part of people in the vicinity of the project. A reasonable and responsible person would not purposely look towards a bright reflection, purposely prolong their exposure to reflected light or heat, or otherwise intentionally try to cause discomfort/harm to themselves or others and/or damage to property.

This report has endeavored to provide a robust and suitably conservative analysis of the potential effects of reflected sunlight, contextualized based on current industry and academic research, and common best practices. Regulation and enforcement of performance requirements is the responsibility of the relevant regional regulatory authority.

Assumptions and Limitations (cont'd)

LEGEND

- NON-REFLECTIVE
- GLAZING
- TERRACOTTA SEMI GLOSS
- GLASS BALUSTRADES

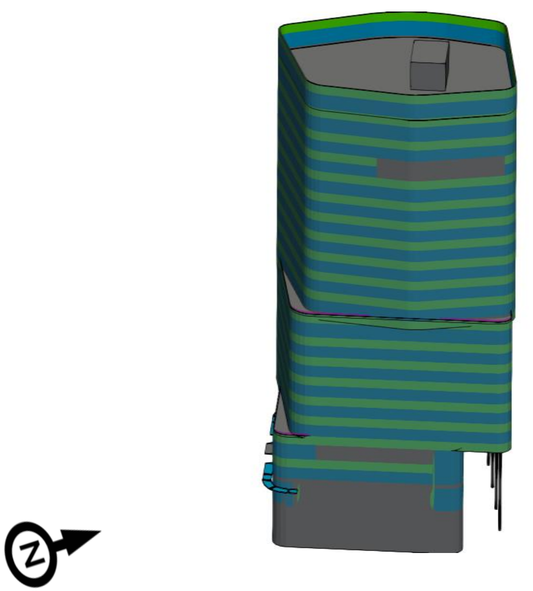

Figure 5: Locations Of Reflective Building Elements With Photovoltaic Panels (Surrounding Context Removed For Clarity)

Table 1: Nominal Visible and Full Spectrum Reflectance Values of the Reflective Building Elements

Location	Material	Visible Reflectance
Facade	IGU	30%
Facade	Terracotta Semi Gloss	10%
Balustrades	Safety Glass	8%

Presentation of Results

This section presents the screening results pertaining to the solar glare potential of the Project.

These plots (Figures 6a and 6b) identify the locations of the most frequent significant reflections emanating from the facades. In this context a 'significant' reflection is one that is at least 50% as intense as one that would cause after imaging on a viewer (refer to Appendix A).

Note that these figures do not show a specific moment in time, but rather present aggregated reflection predictions for an entire year.

In order to attain a complete understanding of the impact that reflections may have on drivers, other factors must be considered, including the duration of the reflections and when they occur. The following plots serve to illustrate the general characteristics of reflections from the development and inform the locations of the receptor points used in the detailed phase of work which will analyze these factors in greater detail.

SCREENING ANALYSIS RESULTS

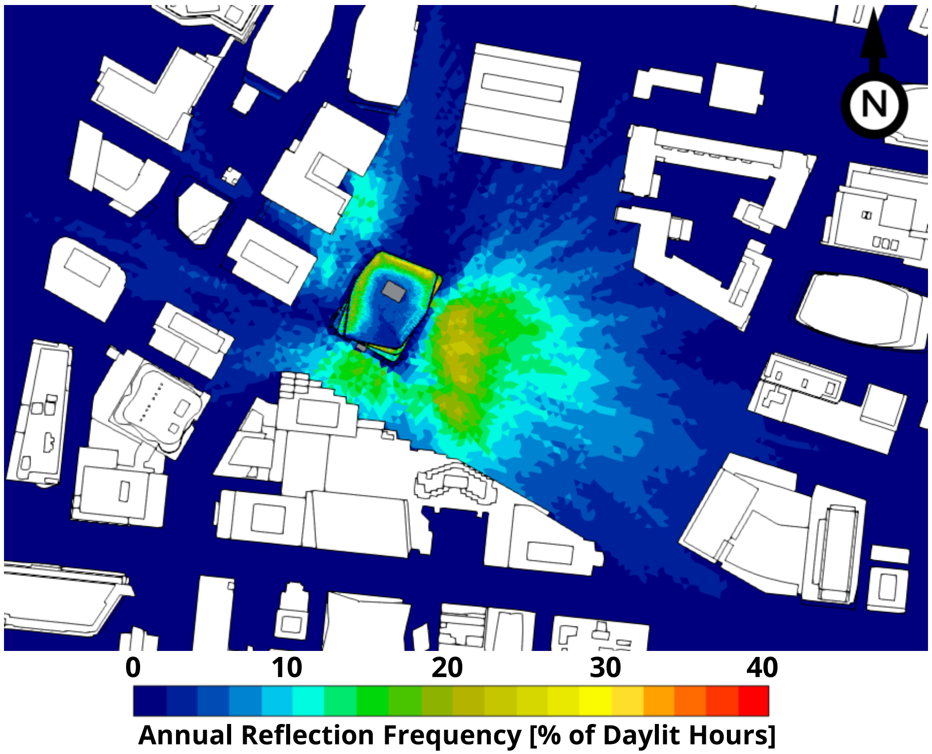

Figure 6a: Frequency (% of Daylit Hours) Where Significant Visible Reflections Can Occur (Configuration 1)

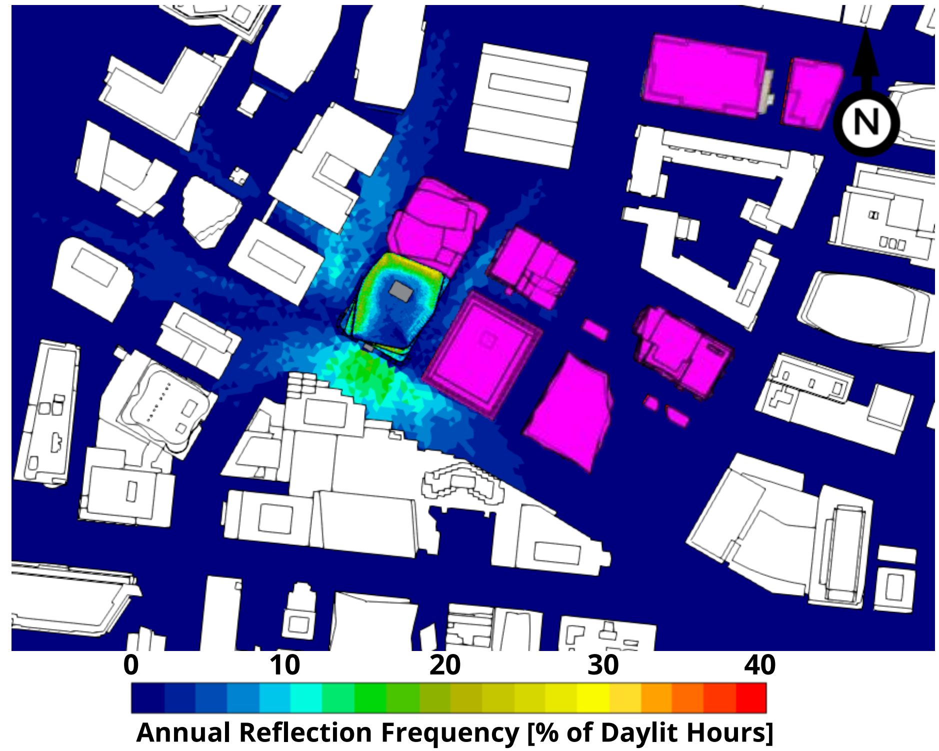

Figure 6b: Frequency (% of Daylit Hours) Where Significant Visible Reflections Can Occur (Configuration 2)

SCREENING ANALYSIS OBSERVATIONS

1. Like any contemporary building, the reflective surfaces of the Project are naturally causing solar reflections in the surrounding neighborhood.

2. The nature of the facades of the Project prevent reflections from focusing (concentrating) within the public realm. Thus, RWDI does not anticipate any heat gain issues on people or property off-site.

3. At pedestrian level, reflections were predicted to fall most frequently onto the area immediately east of the Project and to a lesser extent, west and south. The maximum frequency of glare occurrence predicted at pedestrian level is approximately 24% of daytime hours though this reduced to 7% of daytime hours once future surrounds were introduced.

4. Similarly, reflections from the Project were predicted to be confined to within 1000 feet of the building under Configuration 1 but reduced to 500 feet once future buildings were introduced. These reflections may impact eastbound and westbound drivers on Broadway Street as well as northwest bound drivers on Potter Street.

5. The occupants of the buildings located in the vicinity of the development were predicted to experience visible reflections from the study building. That being said, the reflections are unlikely to pose a risk to safety. They are likely a nuisance at most, as the occupants can look away or close blinds.

6. Cyclists and pedestrians on Kittie Knox Bike path and Loughrey Walkway were also predicted to have the potential to experience intermittent reflections. This condition is common in many urban centers and is unlikely to present a significant safety risk.

7. The exact nature of the impacts described in observations 1-6 are explored further in the following detailed analysis section.

DETAILED ANALYSIS RESULTS

Based on the findings of the Screening Analysis and the risk levels associated with reflections effecting specific areas, 7 representative points were selected for the Detailed Analysis for Configuration 1. These points are described in Table 2 and are illustrated in Figure 10. Unless otherwise noted all driver/pedestrian receptors are located at 5 feet above local grade.

Table 2: Receptor Descriptions

Receptor Number	Receptor Description
D1-D2	Eastbound drivers on Broadway Street.
D3-D4	Westbound drivers on Broadway Street.
D5	South westbound Cyclists on Kittie Knox Bike path .
D6	Westbound drivers on Potter St.
P7	Pedestrians on the Loughrey Walkway.

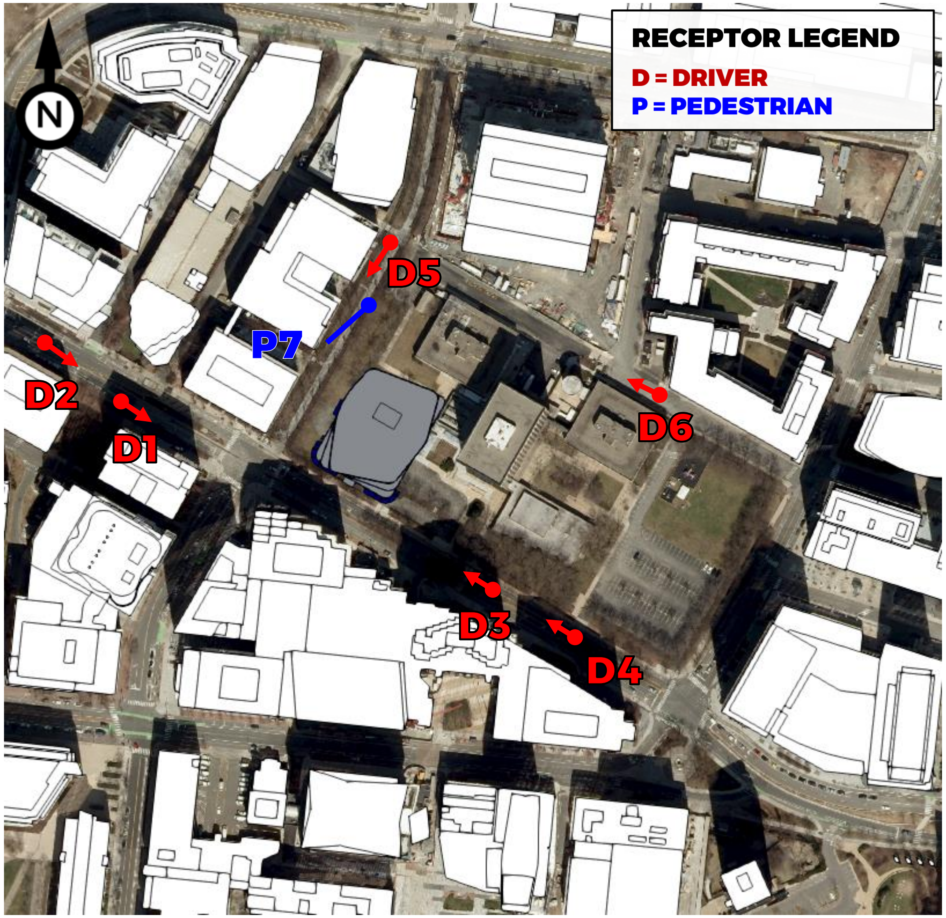

Figure 10: Receptor Locations (Map Underlay Credit: Microsoft Bing Maps)

An additional 10 points were selected for the Detailed Analysis of Configuration 2.

Table 3: Receptor Descriptions

Receptor Number	Receptor Description
D8-D9	North westbound drivers on Paved road within Volpe development.
P10	Pedestrians in the 6 Street Park.
P11	Pedestrians on the paved Walkway east of C3 building.
F12-F13	Facades of C2 Building (approximately 16th and 7th floor respectively).
F14-F15	Facades of R3 Building (approximately 11th and 10th floor respectively).
F16-F17	Facades of R2 Building (approximately 3rd floor).

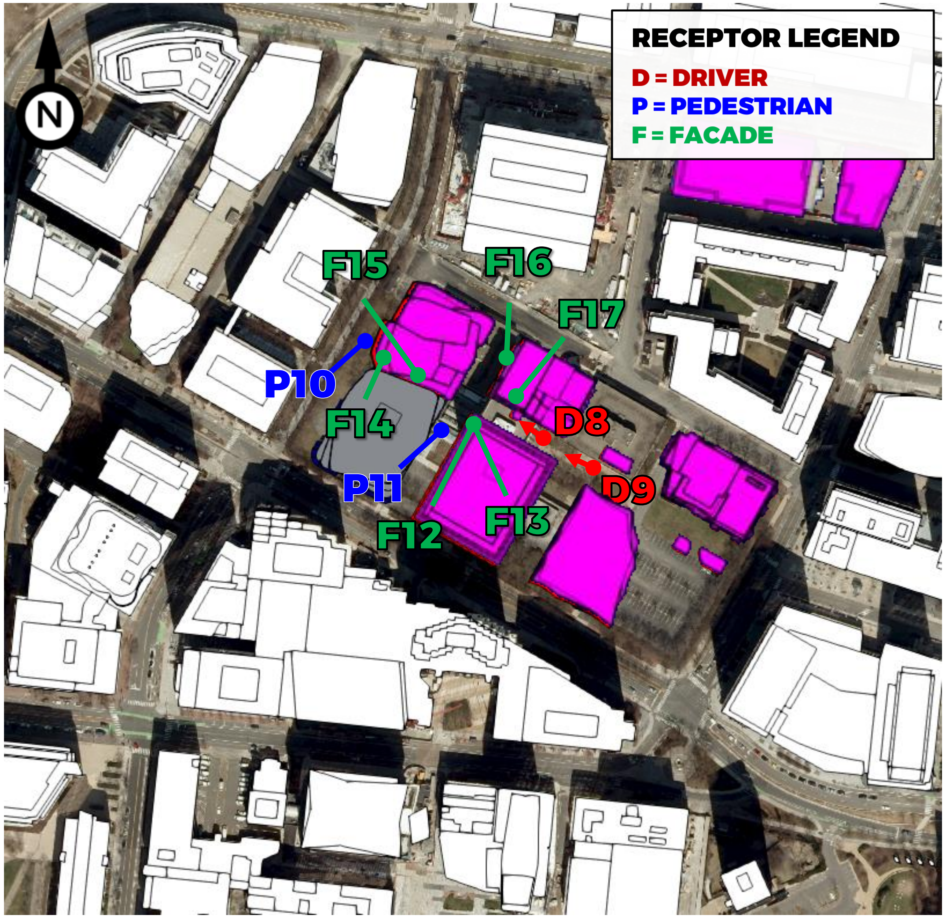

Figure 11: Receptor Locations (Map Underlay Credit: Microsoft Bing Maps)

DETAILED ANALYSIS RESULTS

Tables 5 and 6 summarizes the level of visual and thermal impact from the development's reflections at each of the studied locations. For each category (visual impact, thermal impacts on people, thermal impacts on facades/property) the point is classified as experiencing one of four impact levels:

- **Low** impacts indicate that either no reflections reach the receptor, or that reflections which do reach the location are unlikely to lead to visual or thermal concerns.

- **Moderate** impacts indicate the potential for visual nuisance, minor thermal discomfort to people, or minor heating of materials. Moderate impacts do not indicate a significant safety risk and are common in urban areas. They represent effects such as intermittent visual glare on pedestrians or occupants of adjacent buildings which can be safely self-mitigated.

- **High** impacts indicate the potential for risks to safety, either through impairing the visual acuity of a vehicle operator or through reflection intensities high enough to cause injury or property damage. When the sun is also in a driver's field of view, RWDI would expect that brightness of the sun to dominate over the less intense reflected light, likely reducing the perceived effect of high impact reflections. This situation is noted in Table 3 where applicable, as are notes on high impact reflection frequencies and durations.

- **Very High/Damaging** impacts indicate the potential for extreme risks to safety, either due to reflected energy intensities well in excess of RWDI's ceiling exposure limit or visual glare bright enough to damage the retina faster than an individual can blink.

The minute-by-minute results for each point can be provided upon request.

For further detail on RWDI's criteria refer to Appendix A.

The level of mitigation required (discussed further in the Overall Observations and Conclusions section), is determined based on a combination of factors including the predicted level of impact, the frequency and duration of the impacts, and the risk level associated with activities likely to be engaged in at the location.

DETAILED ANALYSIS RESULTS

Table 4: Summary of Overall Predicted Impacts on Receptors (Configuration 1)

Receptor Number	Receptor Type	Assumed Activity Risk Level	Assumed Ability to Self-Mitigate	Peak Reflected Light Visual Impact	Duration / Number of Days with High Impact Reflection	Percentage of High Impacts Where the Sun Is Also Visible
D1	Driver	High	Low	*High***	Longest Duration: 12 minutes Average Duration: 5 minutes No. of days: 43	*75%*
D2	Driver	High	Low	*High**	Longest Duration: 19 minutes Average Duration: 5 minutes No. of days: 101	*0%*
D3	Driver	High	Low	*High*	Longest Duration: 27 minutes Average Duration: 10 minutes No. of days: 175	*0%*
D4	Driver	High	Low	*High*	Longest Duration: 18 minutes Average Duration: 5 minutes No. of days: 70	*0%*
D5	Cyclist	High	Low	*High*	Longest Duration: 30 minutes Average Duration: 5 minutes No. of days: 365	*0%*
D6	Driver	High	Low	*Moderate*	N/A	N/A
P7	Pedestrian	Low	High	*Moderate*	N/A	N/A

***** The high impact reflections are infrequent and short in duration. ** Sun is in the field of view for the majority impacts, but not entirely

DETAILED ANALYSIS RESULTS

Table 5: Summary of Overall Predicted Impacts on Receptors (Configuration 2)

Receptor Number	Receptor Type	Assumed Activity Risk Level	Assumed Ability to Self-Mitigate	Peak Reflected Light Visual Impact	Duration / Number of Days with High Impact Reflection	Percentage of High Impacts Where the Sun Is Also Visible
D1	Driver	High	Low	*Moderate*	N/A	N/A
D2	Driver	High	Low	*High*	Longest Duration: 19 minutes Average Duration: 5 minutes No. of days: 101	*0%*
D3	Driver	High	Low	*High*	Longest Duration: 27 minutes Average Duration: 10 minutes No. of days: 88	*0%*
D4	Driver	High	Low	*High*	Longest Duration: 18 minutes Average Duration: 7 minutes No. of days: 43	*0%*
D5	Driver	High	Low	*High*	Longest Duration: 30 minutes Average Duration: 5 minutes No. of days: 365	*0%*
D6	Driver	High	Low	*Moderate*	N/A	N/A
P7	Pedestrian	Low	High	*Moderate*	N/A	N/A
D8-D9	Driver	High	Low	*Moderate*	N/A	N/A
P10-P11	Pedestrian	Low	High	*Moderate*	N/A	N/A
F30-F35	Facade	Low	High	*Moderate*	N/A	N/A

***** The high impact reflections are infrequent and short in duration

Thermal Impacts on People and Property

1. The facades of the Project ensure that reflected sunlight will not focus (multiply) in any public realm areas. Therefore, RWDI does not expect any significant thermal impacts (i.e. risks to human safety or property damage) to occur in the surrounding neighborhood.

Visual Glare Impact on Drivers and Cyclists

2. As with the addition of any glazed building, those travelling in the vicinity of the Project are expected to have the potential to experience visible reflections from it. Some reflections with a high visual impact potential were predicted. Some of these impacts may alter a driver's experience since the glare occurs at times when the sun would not be entirely within a driver's field-of-view. In particular, a driver's experience could be altered when:
   - Travelling eastbound on Broadway Street approaching the Project.
   - Travelling westbound on Broadway Street approaching the Project.
   - Cyclists travelling southwest on Kittie Knox Bike Path.

3. Intermittent high impact reflections were predicted for eastbound drivers on Broadway Street between 7:00 am and 4:30 pm EST in February, March, April, August, September and for very brief periods in December. Although these reflections can last up to 19 minutes, on average they were predicted to last only 5 minutes. This equates to possibility of high impacts in 0.26% of the daytime annually. The addition of future surrounds did not significantly change these observations.

4. High impact reflections were predicted for westbound drivers on Broadway Street between 6:30 am and 7:00 am EST and again between 4:30 pm and 5:00 pm for very brief periods starting January until May and again from August until September as well as December. However, once the future buildings were in place, reflections were limited to evenings for very short durations in April and August. Regardless of the surrounds, these impacts were predicted to be possible is less than 0.8% of the daytime annually.

5. High impact reflections were predicted for southwest bound cyclists on Kittie Knox Bike Path between 8:30 am and 4:00 pm pm EST year-round. Though with the addition of future buildings these impacts were reduced to only the afternoon hours. These reflections were predicted to last up to 30 minutes for both configurations but on average lasted up to 5 minutes. This equates to high impacts being possible approximately 4% of the daytime annually.

6. For all other driver points not mentioned above, peak visual glare impacts were predicted to be moderate under both configurations, and therefore are not expected to pose a significant safety concern to drivers.

Visual Glare Impacts on Pedestrians and facades

7. Moderate levels of visual impact were predicted to fall on all the pedestrian and facade locations studied in this analysis under both configurations. The predicted reflection frequencies and durations from the Project were typical of any contemporary building of its size and facade design.

GENERAL STATEMENT OF LIMITATIONS

This report entitled Volpe R3 Detailed Solar Reflection Analysis (dated April 28, 2023) was prepared by Rowan Williams Davies and Irwin Inc. ("RWDI") for Elkus Manfredi ("Client"). The findings and conclusions presented in this report have been prepared for the Client and are specific to the project described herein ("Project"). The conclusions and recommendations contained in this report are based on the information available to RWDI when this report was prepared.

Because the contents of this report may not reflect the final design of the Project or subsequent changes made after the date of this report, RWDI recommends that it be retained by Client during the final stages of the project to verify that the results and recommendations provided in this report have been correctly interpreted in the final design of the Project.

The conclusions and recommendations contained in this report have also been made for the specific purpose(s) set out herein. Should the Client or any other third party utilize the report and/or implement the conclusions and recommendations contained therein for any other purpose or project without the involvement of RWDI, the Client or such third party assumes any and all risk of any and all consequences arising from such use and RWDI accepts no responsibility for any liability, loss, or damage of any kind suffered by Client or any other third party arising therefrom.

Finally, it is imperative that the Client and/or any party relying on the conclusions and recommendations in this report carefully review the stated assumptions contained herein and to understand the different factors which may impact the conclusions and recommendations provided.

APPENDIX A

RWDI REFLECTION CRITERIA

Visual Glare

There are currently no criteria or standards that define an "acceptable" level of reflected solar radiation from buildings. RWDI has conducted a literature review of available scientific sources[1] to determine levels of solar radiation that could be considered acceptable to individuals from a visual standpoint.

Many glare metrics are designed for interior use and have been found to not correlate well with the glare impact humans perceive from direct sun or in outdoor environments. RWDI uses the methodology of Ho et al[2], which defines glare impact based on a physical reaction rather than on a preference-based correlation.

Based on the intensity of the glare source and the size of the source in the field of view (Figure A1), the risk of that source causing temporary flash blindness (i.e. the after images visible after one is exposed to a camera flash in a dark room) faster than a person can reflexively close their eyes can be determined.

If this 'after-imaging' can occur faster than the human blink reflex, it presents an unavoidable effect on a person based on physiology rather than preference. This forms the basis of how we determine if a reflection is 'significant'.

This methodology was previously required by the United States Federal Aviation Administration (FAA) to determine the risk of glare to pilots and other airport staff under FAA Interim Policy 78 FR 63276. While the need to use this exact metric has since been relaxed under FAA Policy 86 FR25801, RWDI still feels that it is appropriate for this work.

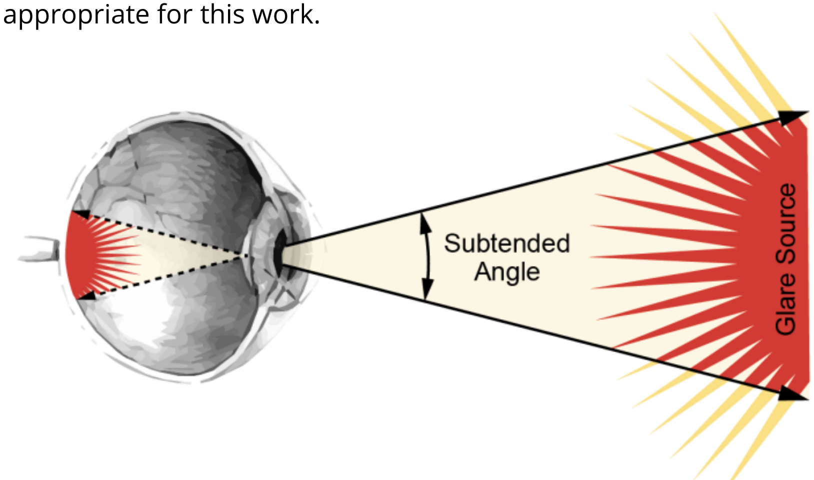

Figure A1: Schematic Illustrating the Subtended Angle of a Glare Source

RWDI REFLECTION CRITERIA

Visual Glare (cont'd)

At the screening level, we conservatively take any reflections at least 50% of the intensity required to cause after-images as a “significant” reflection to be counted in the frequency analysis. In the detailed phase of work, we use the typical threshold level.

As a reference, point 1 on Figure A2 illustrates where looking directly at the sun falls in terms of irradiance on the retina (the back of the eye) and the size of the angle that the sun subtends in the sky. This puts it just at the border of causing serious damage before the blink reflex can close the eye.

The other points in Figure A2 correspond to the following:

2. Direct viewing of high-intensity car headlamp from 50 feet / 15 m

3. Direct viewing of typical camera flash from 7 feet / 2 m

4. Direct viewing of high-intensity car headlamp from 5 feet / 1.5 m

5. Direct viewing of frosted 60W light bulb from 5 feet / 1.5 m

6. Direct viewing of average computer monitor from 2 feet / 0.6 m

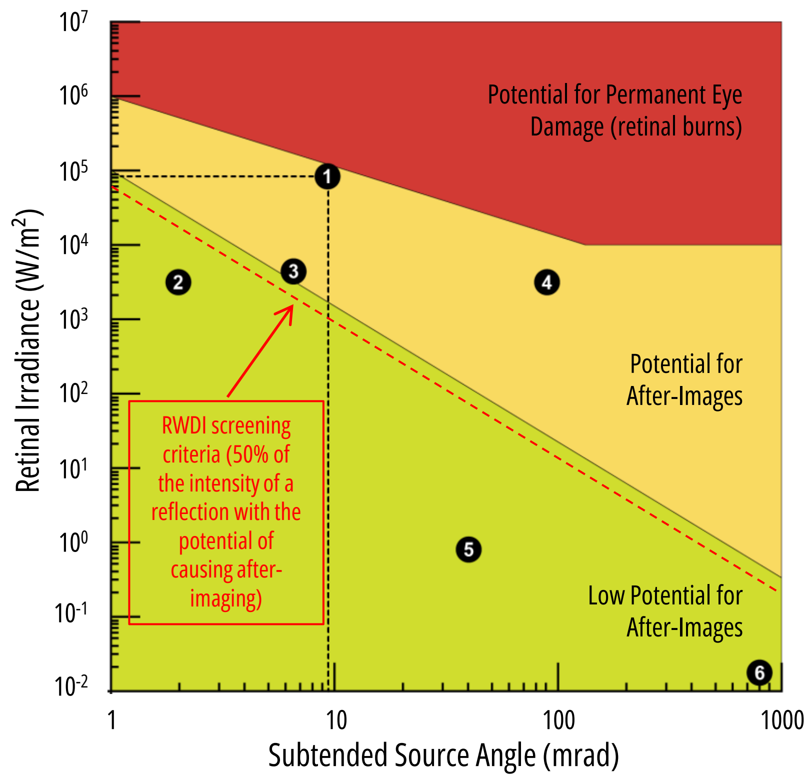

Figure A2: After-Imaging Potential From Various Glare Sources

Note that the retinal irradiances described on this page are significantly higher than the irradiance levels discussed elsewhere in this report. This is because the human eye focuses the energy on to the retina. The magnitude of the increase is dependent on the geometry of the human eye and the source of the glare, both of which are computed per the Ho et al methodology.

Visual Glare (cont'd)

Significant glare impacts on the operators of vehicles or heavy equipment pose a particular risk to public safety due to operator distraction or reduction in their visual acuity. Thus, in the detailed analysis, RWDI assigns an assumed view direction to those engaged in "high-risk" activities (e.g. driving a car or flying a plane) as well as an assumed field of view.

The assigned directions and fields of view acknowledge that an operator is particularly sensitive to reflections emanating from the direction in which they are travelling (and therefore cannot safely look away from) and that the opaque elements of the vehicle will act to obstruct reflections beyond a given angle.

For drivers, the critical angle is taken to be 20° away from the direction of view[3]. Thus, any reflections emanating from within this 20° field of view are considered 'high' impacts, whereas reflections emanating from outside this cone are classified as 'moderate' impacts. This angle is adjusted as needed for impacts on other vehicles such as aircraft[4], trains[5], and other heavy equipment[6].

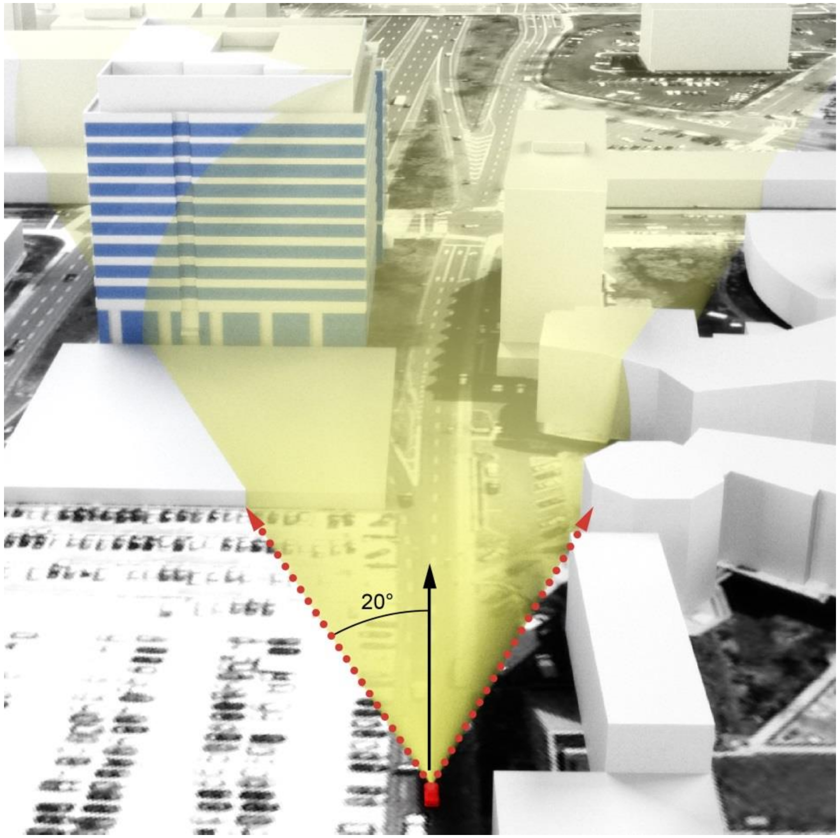

Figure A3: Illustration of a Driver's 20° Field of View

References

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4. Rogers, J.A., et al, "Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach." *Federal Aviation Administration* (2015).

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