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Projection screens and their properties

Polyvision White Paper Guide

Polyvision

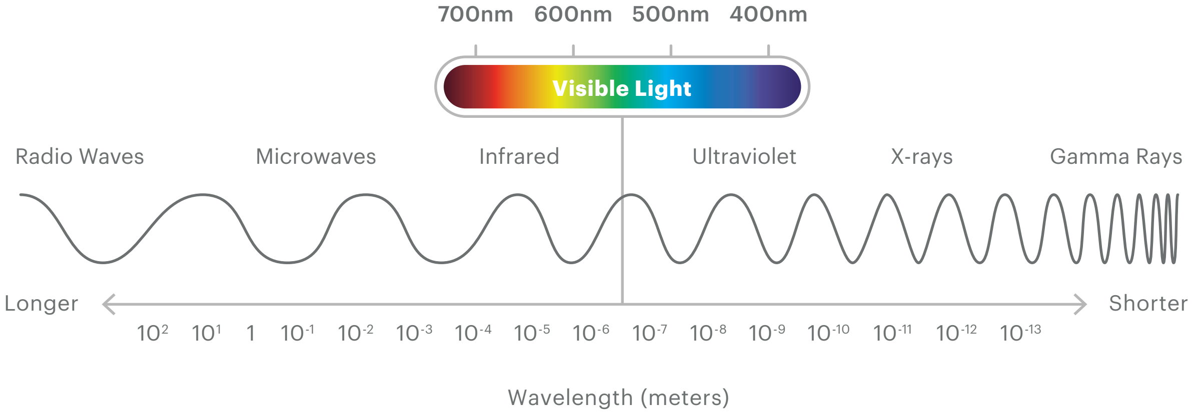
Coloring everywhere

In today's classrooms and meeting rooms, projection is used more and more to visually communicate with the audience. As the technology of projectors (also known as beamers) rapidly evolves, so must projection screens. For successful projection, it's critical to understand the properties of projection screens such as gain, viewing angle, reflectivity, light distribution, image contrast, color reproduction and gloss. The following white paper serves as a guide for projection screens and their properties.

Color & Gloss

The sun emits a spectrum of light waves—most of which are invisible to the human eye. When the sun's white light hits an opaque object, part of the light gets absorbed, while the remaining light waves are reflected. These remaining light waves determine an object's color, while the texture of the object determines its gloss. Every object, including projection screens, has a specific color and gloss, which profoundly affect its projection capabilities.

Figure 1 The electromagnetic spectrum



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Color

The human eye observes color when light reflects off of an object. Because some of the light waves are absorbed, only a portion of the visible light spectrum is reflected to the observer's eye.

Figure 2 The visible spectrum / Wavelenght in nanometers

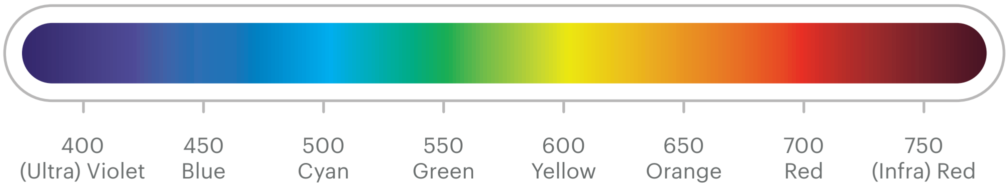
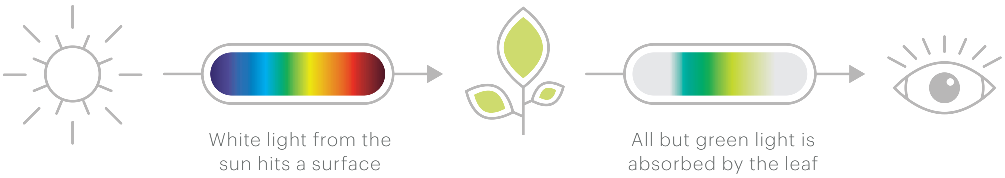


Figure 3 Reflection from a colored surface



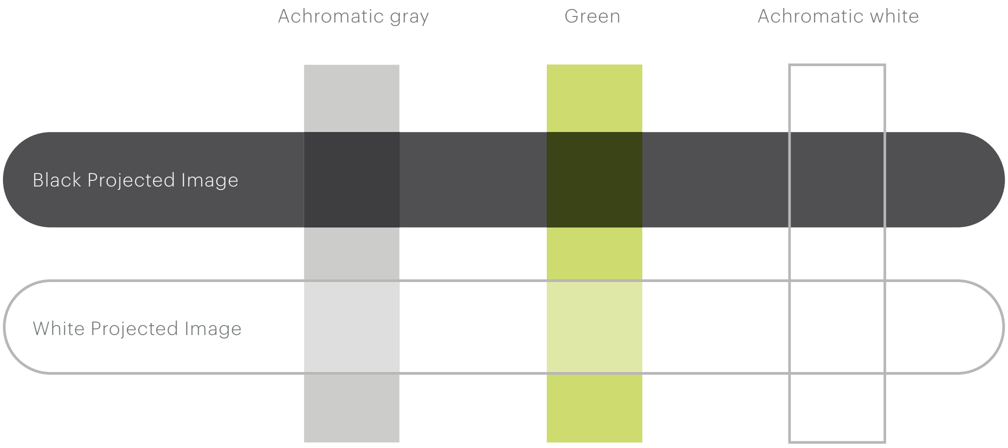
The human eye perceives the leaf above as green because it absorbs most of the visible light except the wavelengths around 550nm, which are reflected.

This is why we don't have green projection screens—because most of the light would be absorbed by the screen, causing only green wavelengths to be reflected. All other colors projected onto the screen would be filtered, distorting the original color.

The best color reproduction is produced when using achromatic surfaces, meaning surfaces without color. Neutral white to neutral gray colors are preferable. "Cool" or "warm" white or gray colors, respectively have a blue or yellow hue, which already influences the color reproduction, since they are not fully achromatic.

The picture below shows a simulation of the influence of the projection screen's color on the projected color. A green surface would distort all projected colors, while the color reproduction on an achromatic gray or white screen is more accurate.

Figure 4 Simulation of color reproduction on a projection screen



The simulation above shows that the gray screen makes projected black and white appear darker, while the achromatic white screen makes the projected black appear less dark and the white appear whiter.

Image contrast is determined by the ratio of black to white of the image being viewed. The projection screen has no influence on the contrast of the image. Rather, in a projection screen and projector setup, contrast is determined by the projector quality, not the screen.

Gloss

The way that light is reflected off a surface is even more important than what light is being reflected, especially when it comes to projection screens.

The texture of a surface determines how light is reflected off it. Surfaces with minimal roughness, such as a still body of water, appear glossy. Glossy surfaces result in a clear reflected image (see page 6: “hot-spot”)

Rough surfaces, such as a rippled body of water, are low gloss, resulting in diffused reflected light. Diffused light creates a blurred reflected image.

Figure 5 Smooth vs. rough surface light reflection / **Blue** Specular reflection / **Light Gray** Diffuse reflection

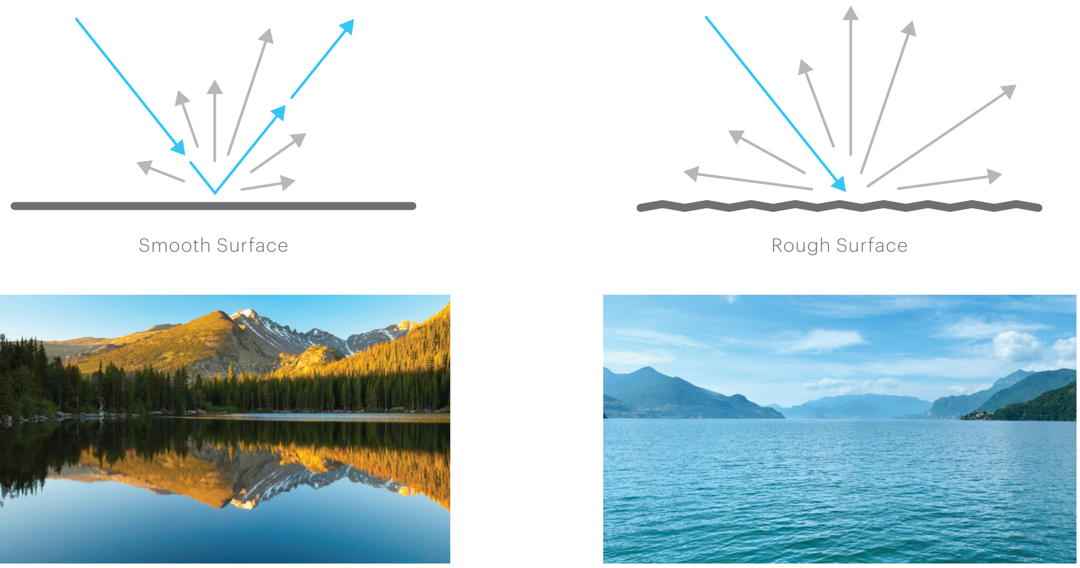


Figure 6 Light source reflection comparison

Specular reflection off a glossy surface (i.e. hot-spot)

Diffuse reflection off a matte surface

The images above show the difference between a matte and glossy surface when the same light source reflects off them.

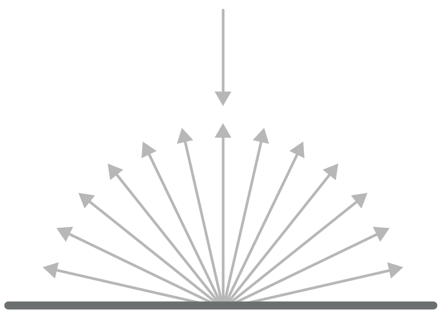
Projection surface properties

Gain

"Gain" is the ratio of light reflecting off a perfect white diffuser (PWD) at 0° incidence and 0° observation angle (i.e., perpendicular to the surface) and the light reflection of the projection surface also at 0° incidence and 0° observation angle.

The PWD is defined as a matte and neutral (achromatic) white surface, which exhibits Lambertian reflectance. Such a surface has the same radiance when viewed from any angle.

Figure 7 Lambertian perfect white diffuser



Note that the reference for "gain" measurement is actually matte (i.e. having surface roughness and close to zero gloss) and a neutral white (i.e. achromatic) as described in the previous section.

The reflectance of this ideal reference is arbitrarily set to 1.0, not only at 0° incidence and observation angle but at all angles. Therefore, a projection surface that reflects more light than this reference at 0° incidence and observation angle has a "gain" factor greater than 1.0. Conversely, a surface that reflects less light will have a "gain" factor of less than 1.0.

"Gain" is deliberately placed in quotation marks because, even though it is a long-standing value for projection screens, the word "gain" implies that the projection screen somehow increases light reflection. However, no projection screen can generate light.
At best, it can change the way light is reflected.

When the first projectors were developed, the light bulbs were significantly less powerful than they are today (note: a projector's light emission power is expressed in ANSI lumens).

In those days, projection screens that had high "gain" factors were developed because they changed the angular reflected light distribution, directing more perpendicular light to the screen, trying to maximize the amount of light reflected to the audience.

Example: the parabolic curved projection screen.
Like a parabolic mirror, it reflects light from the projector perpendicular to the screen.

Figure 8 Parabolic projection screen (curved)

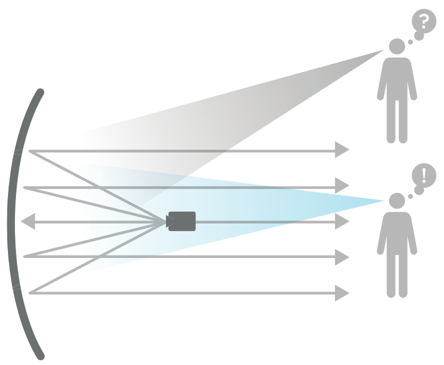


Figure 9 Flat projection screen with glass beads

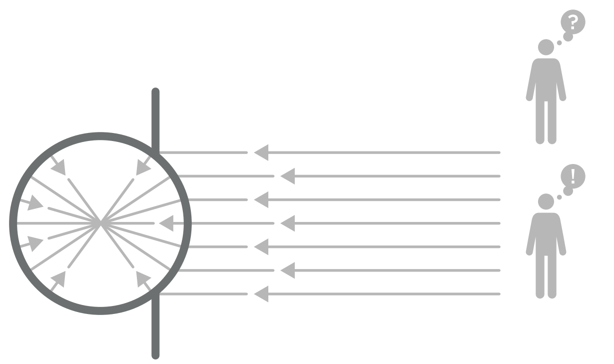


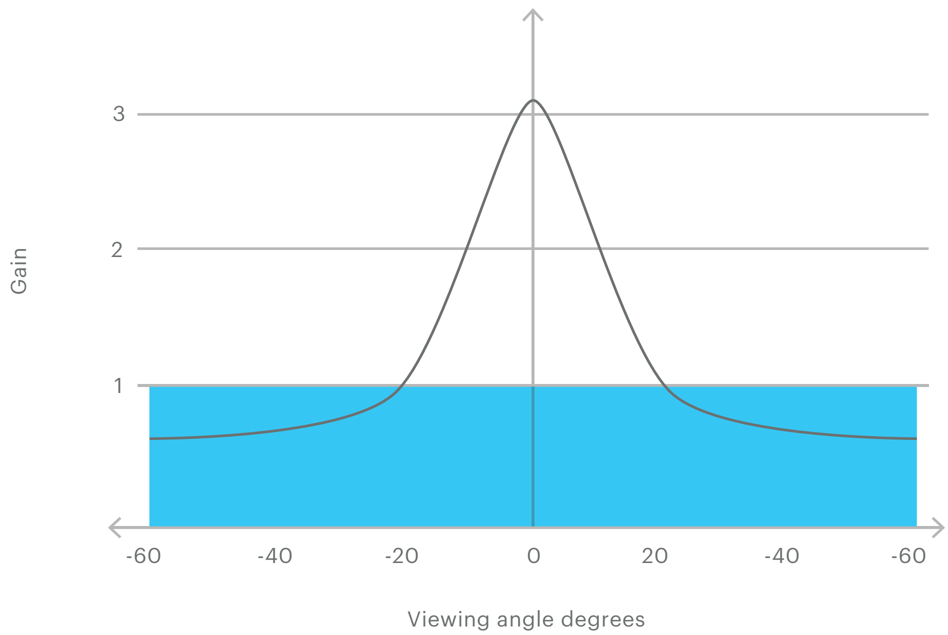
Figure 8 illustrates that this setup yields a high "gain" value, but at the expense of the viewing angle. Projection screens with "gain" are better suited for narrow rooms.

Figure 9 demonstrates the gain and viewing angles of a projection screen with glass beads embedded in the surface. The beads are intended to direct the light to reflect of the screen perpendicularly, which shows higher gain values, but poorer observation angles.

Today's projectors have more light power (ANSI lumens), meaning that an increased "gain" value is not as critical. Modern projection screens have lower "gain" values, meaning more diffused light reflection and a wider viewing angle, ideal for wider room layouts.

Additionally, "gain" isn't an accurate descriptor for projection screens because it is measured at 0° incident light and 0° measurement.

Figure 10 Gain and viewing angles of a perfect white diffuser



The graph above shows "gain" as a function of the viewing angle of a "high gain" projection screen. While the measured light reflection is three times higher than the reference PWD at 0° incident light and 0° measurement, it rapidly decreases until it's equal to the reference PWD at 20° viewing angle, and even further down below the reference PWD at higher viewing angles.

In practice, this means that one will see a bright image when sitting right in front of the screen, but at an angle, the brightness will disappear.

Again, a projection surface does not generate light; it only impacts the angular light distribution. The graph also illustrates this: the total area beneath the curve is equal to the rectangular surface area of the reference PWD at 1.0 (blue).

Finally, as described on the previous page, glossy smooth surfaces reflect light in a specular way. So, to measure the screen's "gain" at 0° incidence and 0° observation, one would simply measure the hot-spot and obtain high "gain" results.

Although this surface shows a "gain" factor of 89, it is not a good projection surface because most audiences will experience a distracting hot-spot.

Figure 11 Hot-spot example

Light distribution and viewing angle

The way light is reflected off a projection surface is dependent on its gloss level. A smooth glossy surface will reflect light primarily perpendicular to the projection surface, while a rough matte surface will reflect light in a diffuse way.

The method used to measure reflected light as a function of observation angle is called bidirectional reflectance distribution function (BRDF) according to ASTM E2387, "Standard Practice for Goniometric Optical Scatter Measurements." (See Figure 12 on page 10.)

In practice, the reflectance of light is measured with the light source perpendicular to the projection surface at 0°, and the measurement device is placed at incremental angles off the surface. This way, a graph can be generated showing the light reflection of a surface as a function of the observation angle.

Figure 12 (on the following page) is the BRDF measurement of a glossy whiteboard surface. Although the reflection curve is fairly constant over a wide range of viewing angles, at angles close to perpendicular to the surface the light reflection shoots up to well over 10, which is, in fact, the hot-spot being measured.

Figure 12 Glossy surface

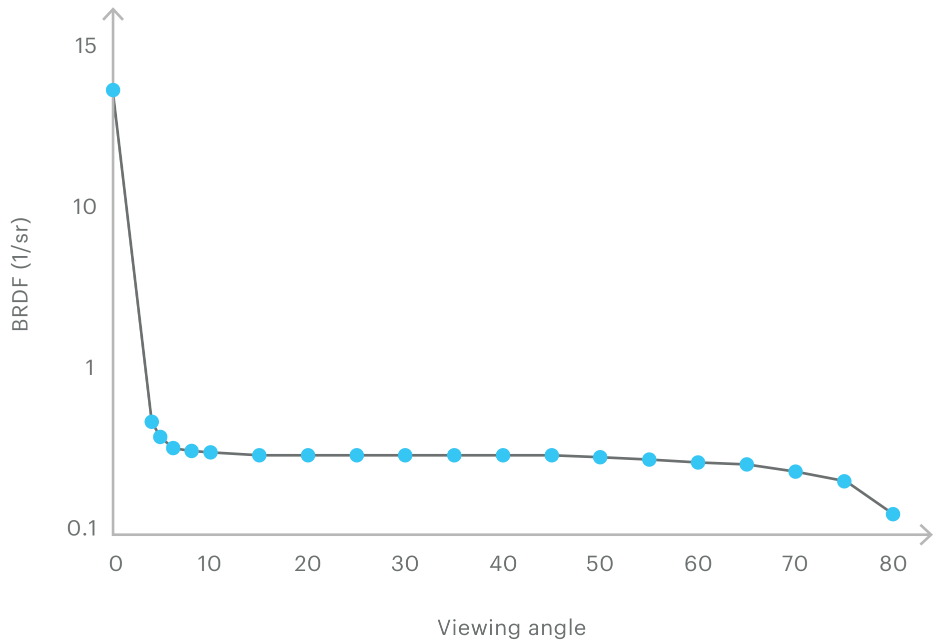
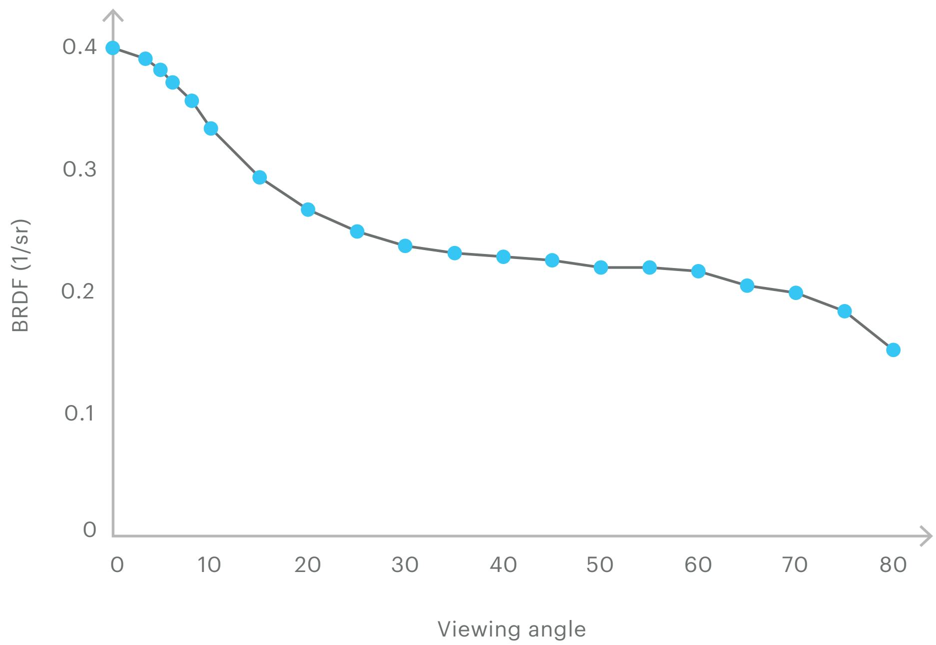


Figure 13 Matte surface



When measuring a matte surface (Figure 13 on page 10), one can see that the BRDF curve drops significantly as the hot-spot reduces to just 0.4, indicating a much more diffuse reflection of light as a function of the observation angle. This kind of surface will show virtually no hot-spot and a wide viewing angle because of its diffuse reflection.

From the BRDF function, the full width at half maximum (FWHM) angle can be determined as the viewing angle of a projection surface. It is defined as the angle at which the BRDF value drops to half of the BRDF at 0°.

It's important to be precise when evaluating results. The FWHM is lower than 4° in the top BRDF graph because the intense reflection of the hot-spot of this glossy surface drops rapidly, while the remainder of the reflection curve is constant.

The diffuse reflecting surface in Figure 13 shows a FWHM angle of 68°, which means the total viewing angle of this surface is 136° (including both the left and right of the normal to the surface).

Figure 14 Relevant properties of Polyvision's range of surfaces

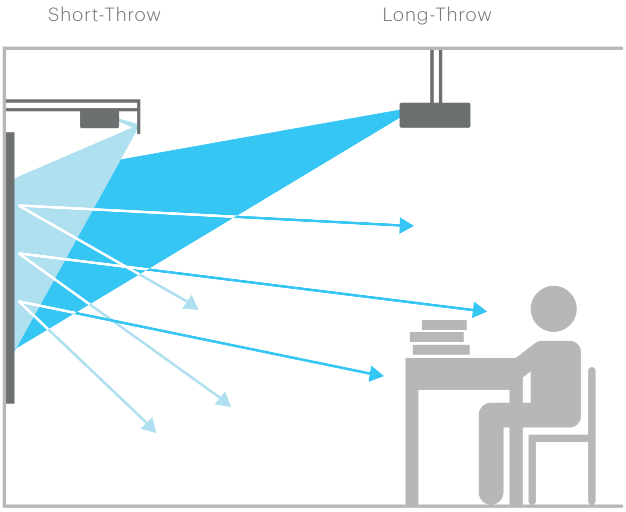
Surface	Gloss	Gloss	"Gain" Factor	Viewing Angle	Dry Erasability
	(ISO 2813 - 20°) gloss units (GU)	(ISO 2813 - 60°) gloss units (GU)	(500nm)	(FWHM) degrees°	of alcohol-based drymarkers
5650P	2	13	1.26	2*68°	Poor (DE^{94} > 4.5)
6100L	25	70	21	< 2*4°	Good (1.5 < DE^{94} < 4.5)
6100S	40	83	32	< 2*4°	Good (1.5 < DE^{94} < 4.5)
6100H	55	92	59	< 2*4°	Excellent (DE^{94} < 1.5)
6100U	70	97	89	< 2*4°	Excellent (DE^{94} < 1.5)

In addition to these projection surface characteristics, it is important to consider the projector configuration.

Projector configuration

In addition to the increased light source power of modern projectors, new configurations have been introduced that effectively reduce the hot-spot on projection screens, even when the surface being projected onto has a high gloss level. These new configurations are short-throw and ultra-short-throw projectors.

Figure 15 Short-throw vs. long-throw projection configuration



In the illustration above, the dark blue represents a ceiling-mounted projector configuration. Because the light from a ceiling-mounted projector will be reflected in a specular way (angle of incidence is equal to angle of reflection), this configuration will reflect light at a relatively sharp angle, resulting in the audience seeing a hot-spot.

In the illustration above, the light blue represents an ultra-short-throw configuration. This type of projector is configured with a mirror that will reflect the image onto the screen, such that the angle of incidence is much larger to the normal, and therefore the angle of reflection is much larger as well. This will reflect the hot-spot to the floor and not to the audience. This type of projector allows a glossy surfaces to be used as a projection screen surface without the distracting hot-spot while still functioning as a dry erase whiteboard.

Conclusion

When choosing a projection screen/projector setup, all of the above factors must be taken into consideration. Polyvision offers a wide range of surfaces that are optimized to take these factors into consideration, providing durable solutions.

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Environmental Policy: Polyvision strives for continuous improvement in all areas of environmental stewardship – responsible use of raw materials and natural resources, design processes and operation of all facilities – to protect, replenish and restore the communities in which we live and serve.