

Projection mapping

How to build a proper projection system for 3D projection mappings?

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Introduction

Projection mapping is a video projection technique that creates the optical illusion of movement on static objects and buildings. The artistic play with light transforms virtually any surface into an immersive canvas, creating attention-grabbing stages that captivate large audiences.

Projection mapping can be used for advertising, live concerts, theater gaming, trade shows, decoration..., really any environment where you want that extra stopping power!

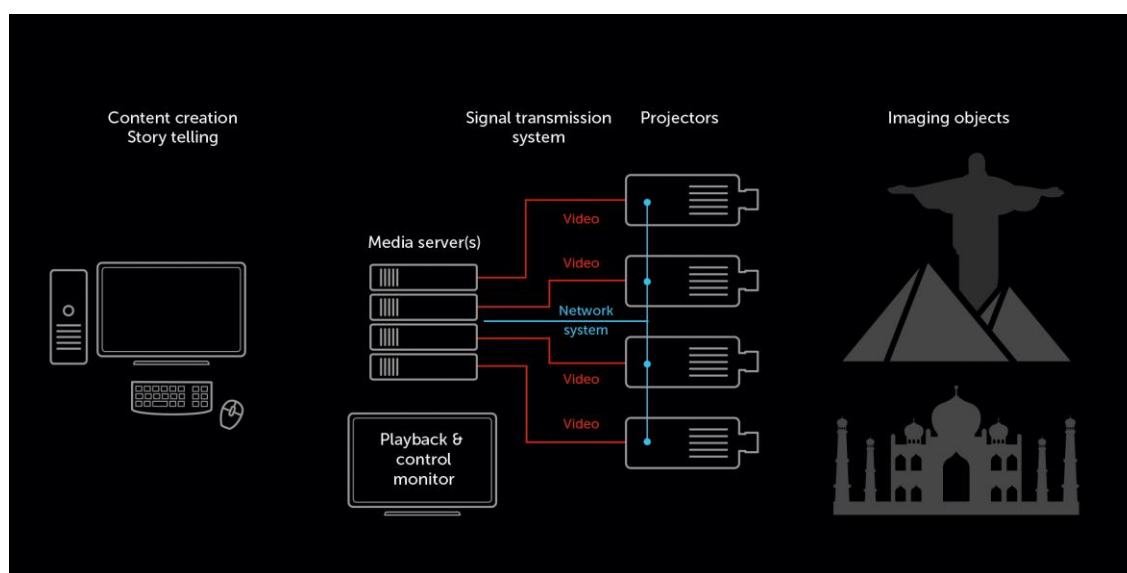
Unlike any other medium, projection mapping takes storytelling to the next level. Its impressive and compelling form allows you to draw the attention of large crowds, and keep it, even from a distance.

It goes without saying that there's a significant difference between projecting a 2D image onto a flat and uniform screen and projecting onto medieval façades or monumental constructions.

3D imaging naturally adds some extra challenges to the projection. The surfaces of 3D objects can vary in form, color, structure, etc. It's important to keep these things in mind throughout the process to make sure your projection mapping is eye-catching.

From idea to stage

A full projection mapping project includes a lot of subsystems with different functionalities, like a projection device, audio system, AV control/play system, signal transmission system, network system, and so on.



From the creative design of mesmerizing video content, to the preliminary virtual renderings and intricate preparations of the installation, to the jaw-dropping live performance. When each part of the chain supports the others, it brings your projection mapping to the next level.

In this white paper, we'll focus on the projection system only, which is one of the most important parts of a projection mapping project.

5 things to consider when building an effective projection system for projection mapping

I. The four W's of your project

1. Why?

What's the primary purpose of your projection mapping? Is it a public service project or a commercial project? Who is the investor? All these factors will impact your next steps and approach to completing this project.

For instance, if the projection mapping is a public service project, your investor will likely be a government body or organization. Projection mappings for commercial purposes, e.g. advertainment, focuses more on ROI – meaning you'll have to win the investment back from tickets sold.

2. What?

What is the story you want to tell, the content you want to visualize? Is it storytelling using only audio/video content, or a complete lighting show combining projection and other conventional lighting systems? Are there any other props involved besides the projection image? And is there an additional live performance during the projection mapping?

3. Where?

Have the imaging objects been decided upon? Will the projection mapping take place indoors or outdoors? Is there enough space to set up the whole system including projectors, speakers, media servers, the power supply system and cabling?

How about the environmental factors: humidity, altitude and temperature? What protection measures are needed to keep your equipment and its mechanics safe? Where will the viewers be located (viewpoint) and where will the projectors be installed? We'll come back to these questions and their impact on the choice of projectors further in this whitepaper.

4. When?

This question tackles the commercial aspect of your project. Will the projection mapping play around the clock or just one single evening/night? Is it a permanent fixed installation system or a temporary rental set-up? Based on the different business models, there are different approaches to implementing the project.

Additionally, you need to think about seasonal variables, e.g. rain/snow/wind?

Once most of the above questions are answered, you can start to calculate the project cost and ROI, and analyze your budget.

II. The nature of the imaging object

To make the right content for your projection mapping, you must know a lot about the properties of your imaging objects, including shape and size of the projection surface, reflectivity, focus plane etc.

If the imaging object is an irregular shape, for example, a sculpture, church, or the wall of a big building, on which you want create an autostereoscopic effect by using the natural depth of the imaging object, it's better to have the 3D model of the object to optimize the post-production of the content.

Conducting an onsite survey is a must to know the details of the imaging object, to check the projection surface and other parameters, and to think about how to map the objective.

III. Ambient environment

This one goes back to the questions in the 'where-question' in the first part of this paper. Environmental factors like ambient light, humidity, temperature will affect the requirements of your projector. For example, a high amount of ambient light asks for a projector with a higher brightness level to maintain a high-quality image and increase the wow factor of the projection mapping.

IV. Viewpoint

Here too, the onsite survey is very important. It is not only about making sure the imaging object is OK to project on, but also to seek the best possible positions to place the projectors.

The perception of human vision

The visible pixel size

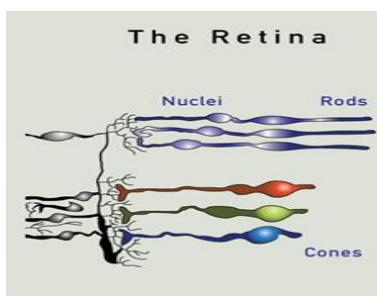
What is the visible pixel size or perceived pixel size? Let's take the HD (1920 x 1080) and 4K UHD (3840 x 2160) resolution as an example. In the table below you can see the size of each pixel in mm:

Image width (m)	10	15	20	25	30	35	40
Pixel size (mm) 1920 x 1080	5.2	7.8	10.4	13.0	15.6	18.2	20.8
Pixel size (mm) 3840 x 2160	2.6	3.9	5.2	6.5	7.8	9.1	10.4

The visible pixel size is an important factor of the system design, the selection of playback equipment and projectors, and audiences' visual experience.

How does the human eye perceive brightness and color?

Light entering our eyes reaches the retina, a thin layer of photosensitive cells made up of approximately 120 million rods and 6 million cones. Cones are responsible for vision in bright light, and are divided into three types, each of which is most sensitive to three different wavelengths of light centered in the short, medium, and long regions of the visible spectrum. In bright light, the cones are used to determine both color and luminance information. Rods are used in low light situations and are sensitive to variations in luminance.



- The rods only detect light and dark
- The cones detect color
- The rods are more sensitive than the cones and start losing the ability to differentiate between colors when it becomes dark

Information travelling from the eye to the brain is reorganized into three channels: a luminance channel, and two opponent color channels that correspond to red–green and blue–yellow.

What's the smallest size a human eye can see or distinguish between two small objects (two pixels, or two lines with different brightness)?

Visual acuity is a measurement of our ability to see detail. It defines the extent to which information densities can be perceived. Acuity is measured with visual angle, the angle subtended by an object on a viewer's retina specified in arc-degrees, arc-minutes ' (1° = 60'), or arc-seconds '' (1' = 60''). Given an object size "s" and a viewing distance "d", visual angle "θ" can be calculated as " $\theta = 2 \arctan(s/2/d)$.



Subtended visual angle θ , based on an element's physical size s and viewing distance d .

minimum visual angle = the angle which the minimum separable subtends at the eye; 60 arc-seconds is usually taken as standard for a normal eye.

Below are some visual acuity limits for basic visual properties.

Property	Description	Acuity
Point acuity	Resolve two point targets	1'
Grating acuity	Distinguish bright and dark bars in a uniform gray patch	1-2'
Letter acuity	Resolve letters, 20/20 vision means a 5 arc-minute letter can be seen with 90% accuracy	5'
Stereo acuity	Resolve a just-noticeable depth difference through binocular disparity	10"
Vernier acuity	Resolve if lines are collinear	10"

Based on the information above, it's possible to calculate the pixel size relative to the viewing distance.

Property	Minimum visual angle	Pixel size (mm) @10m distance	Pixel size (mm) @20m distance	Pixel size (mm) @30m distance
Point acuity	1'	2.91	5.82	8.73
Grating acuity	2'	5.82	11.64	17.45
Letter acuity	5'	14.54	29.09	43.63
Stereo acuity	10"	0.48	0.97	1.45
Vernier acuity	10"	0.48	0.97	1.45

Blending and warping

If you can't find a perfect place to situate an on-axes projection within the acceptable lens shift, the image will be distorted. You need to consider the pre-distortion by embedding the warping function of a projector or correcting content through a playback system.

The same goes for multi-channel projection mapping systems which require blending capacities. Additionally, blending will influence the quantity of required channels because the blending zone will also occupy certain amount pixels.

V. Content

Knowing your content is key for the system design. How many pixels would make up the total resolution of the canvas (projection mapping surface)? From that the total system resolution can be calculated, and you can further break down to calculate the required resolution per channel/projector

For instance, a total system resolution is 19,200 x 2400 pixels. It could be 5 channels with 4K resolution (3840 x 2400) per channel, or 10 times 2K per channel. (This example doesn't include the pixels of the blending zone.)

These key parameters will further influence the post-production of the content and how to choose the correct projector and playback system, etc.

Choosing the right projector

Before we elaborate on the most important projection differentiators, let's have a look at an exemplary spec sheet (Barco's UDX-W40). It is important to have a good understanding of the projector's specifications in order to make the right decision when choosing the correct projectors.

Specifications		
Projector type	WUXGA 3-chip DLP digital projector	
Resolution	1920 x 1200	<i>Native output resolution</i>
Technology	0.96 DMD™ x3	<i>Chip size</i>
Brightness	40,000 center lumen / 39,000 ansi lumen / 43,000 ISO	<i>Ansi lumen = average 9 ansi points ISO follows ISO21118 international standard</i>
Contrast ratio	2,200:1	<i>Full on/off contrast (without dynamic)</i>
Aspect ratio	16:10	<i>Native aspect ratio</i>
Lenses	TLD+ 0.37, 0.65-0.85, 0.8-1.16:1, 1.25-1.6:1, 1.5-2.0:1, 2.0-2.8:1, 2.8- 4.5:1, 4.5-7.5:1, 7.5-11.5:1.	<i>The available option lenses with different throw ratio</i>
Optical lens shift	Vertical: between -100% to +130%, depending on lens Horizontal: +/- 40%, depending on lens Motorized zoom and focus with lens memory on TLD lenses Motorized lens shift (with position memory on all lenses)	<i>Lens shift calculation based on half screen</i>
Light source	laser phosphor with inorganic phosphor wheel	
Light source lifetime	20,000 hrs	<i>Decay to 50% of initial brightness</i>

I. Brightness

What is the minimum required brightness for a 3D mapping? There is not one simple answer to that question. Brightness can be as low as 10 lux and high as 300 lux. One key aspect is the ambient light conditions. As mentioned above, higher projection brightness is needed to compensate for bright environments.

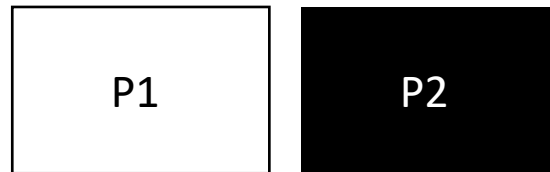
But the brightness decision also depends on a lot of other things like the customer/project requirements (and the available budget). For example, if the plan is to broadcast the projection mapping, you'd better opt for a higher brightness model. To meet the basic viewing and television conditions, the higher the projector brightness, the better. Same goes for filming using mobile phones.

Tip: The contrast simulator on our Barco lens calculator pages can give a indication of the lux needed for your project based on the screen/imaging object size, ambient light and reflection values. The calculator then allows you to simulate the project with different projectors with different brightness.

P.S.: Some projector manufacturers need to make a trade-off between brightness and lifetime of light source. Read the spec sheet carefully to make the right decision.

II. Contrast ratio

$\frac{P1}{P2}$ is the formula to calculate the natural contrast of a projector by using the measurement of a fully white and a fully black screen



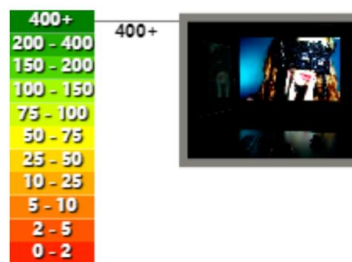
However, $\frac{P1+P_{ambient}}{P2+P_{ambient}}$ is more realistic if taking the ambient light into account

Brightness and contrast on screen

A projector with a higher brightness output will help against the ambient light, but ambient light still has a big impact on the contrast ratio. In the examples below, we see contrast on screen changing a lot with different ambient lights even if the projector light output is not changed.

Contrast

Contrast on screen **2000:1**
 Lux: 3750
 Image brightness: 1194 Nits



Contrast

Contrast on screen **9.3:1**
 Lux: 3750
 Image brightness: 1194 Nits



III. Resolution

Projector manufacturers offer different types of products with popular resolutions 2K or 4K and aspect ratios 16:10, 16:9 or 4:3 which could almost cover all uses. When choosing a projector, the key is to match the resolution of the content. It makes sense to use a 4K projector if the input signal is also 4K resolution! Otherwise, you can't benefit from the extra pixels.

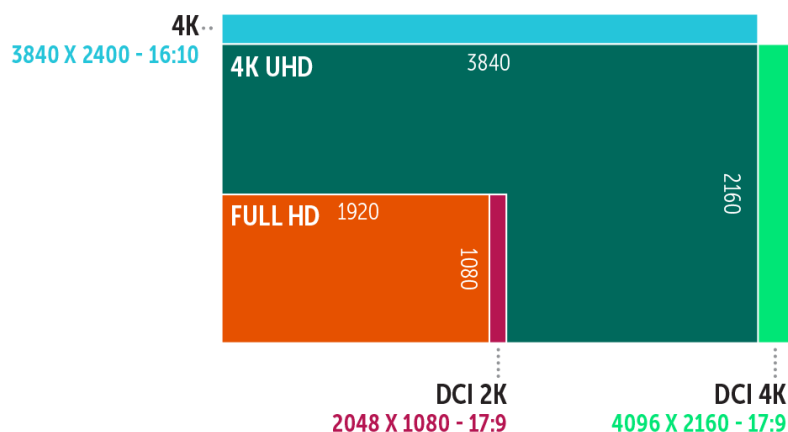
However, don't just go for more pixels. Even if the video material is a 4K image with a 4K projector, the audience may not be significantly aware of the additional resolution because of the sensitivity of the human eye relative to the viewing distance as mentioned above. Video is a moving picture, the general audience will pay more attention to the story and the color of the scene, and the sensitivity to the resolution is not high. Therefore, how and when the audience can perceive the extra resolution is very important, because then the audience can enjoy a pleasant viewing experience brought by the higher resolution.

Total resolution vs. resolution per channel

Furthermore, you should review 2 important resolution parameters in your project. One is the total system resolution and the other is resolution per channel. The total system resolution could be 8K resolution and break down to four 2K channels or two 4K channels, which will impact the choice of projectors.

The different 4K resolutions

- In the ProAV industry, the aspect ratio is typically 16:10. 4K is therefore $3840 \times 2400 = 9.2$ million pixels
- 4K UHD is four times that of HDTV (16:9 and 1920×1080), approximately $3840 \times 2160 = 8.3$ million pixels
- DCI 4K (4096×2160) is a digital cinema specification with an aspect ratio of about 17:9 with 9.1M pixel



It is important to keep in mind when going 4K all the way, you need a full 4K set-up, including 4K content, 4K playback system, 4K storage system, 4K signal transmission system, 4K post-production etc. This will require a higher investment...

The advantages of a 4K projector

- 4K projection delivers smaller pixels than 2K projection when working on the same surface resulting in higher image quality with more detailed information
- 4K is four times as detailed as 2K, if the same pixel size is broadcast. As such, there is only need for one 4K projector instead of four 2K projectors, meaning less projectors needed and a big reduction in costs.
- As a result of the reduced number of required projectors, there is less blending work required and it's easy to position projectors and align the system. With fewer blending zones, you avoid pixel and brightness waste.
- A 2K projector can never be used for 4K content, but a 4K projector can downgrade to be compatible with all lower resolutions. This makes a 4K projector a valuable asset in rental portfolios.

IV. Colors

While making the content, a specific color space is implemented. The playback media server and projector must support the color space which was used when creating the content in order for the correct color of the image to come through/be seen.

The high-quality projector with higher brightness and life-like color reproduction performance can override the background color of the imaging objective. Certainly, the lighter the background color of the image objective, the better. Projectors with a wider color gamut also perform better in high ambient light environments.

V. Design

Some things to pay attention to with regards to the projector design are:

Compact size

The benefits of a compact design are evident: reduced shipping and labor costs, and easier installation process. However, to create a compact and rugged projector design, the manufacturer has to have the expertise and know-how to balance the high brightness, low noise, efficient cooling, thermal management and so on without any compromise of performance.

Future-proof video interfaces

Look for multiple video input interfaces with the latest protocols to provide flexible connectivity, supporting, for example, the latest HDMI2.0, DP1.2, 12G SDI, HDBase-T, Fiber-Network Input, etc.

Embedded image processing

Real-time and high-quality warping and blending on 4K images allows high quality mapping on asymmetric surfaces. Using the Barco Projector Toolset software or by accessing the projector's embedded web server, you can achieve real-time warping on anything up to 4K imaging, not only with simple blanking, four corner and BOW (both symmetric and asymmetric), but also with anything from 2 x 2 up to 33 x 33 points with real-time geometric correction that maintains sharpness and content details. Easy user interfaces enable quicker installation and correction and ensure you maintain sharpness and content details at all times.

Peripherals

Smart peripherals guarantee flexibility, safety, cost & time savings, and easy maintenance.



Lenses

A good projector manufacturer should be able to offer more options in all-glass, high-quality lenses. The full range of lenses are the key to flexibility in the design and installation of the setup.



Key parameter is throw ratio to choose the correct lens which is defined as the distance measured from the end of the lens to the projection screen, divided by the width of the image. The minimum throw distance is determined by the lower end of the focus range of the lens.

Note: Throw ratios can differ depending on the size of the DMD chip used in the projector. As the parameters of the throw ratio of a lens are different for different sizes of DMD chip or projection output resolutions, please use the Barco lens calculator to calculate the actual specifications for each setup.

Easy control and communication

Barco Projection Insights is a cloud-based IoT platform that will enable more efficient projector fleet management through remote monitoring of projector parameters.

Optimized fleet management - The IoT platform will allow you to get rid of time-consuming and error-prone manual administration thanks to the automatic cloud-based storage of projectors' usage data and light-source run-times. The platform will allow you to manage and control your entire fleet in a more efficient way. Keep track of the past, to make the best decisions in the future.

Efficient Diagnosis - The IoT platform will allow for remote device diagnosis. The live dashboards will give real-time information on the operating and environmental conditions of the projectors. Diagnose and solve issues before they turn into failures thanks to the e-mail warning notifications and help your customers more effectively with prompt remote assistance.

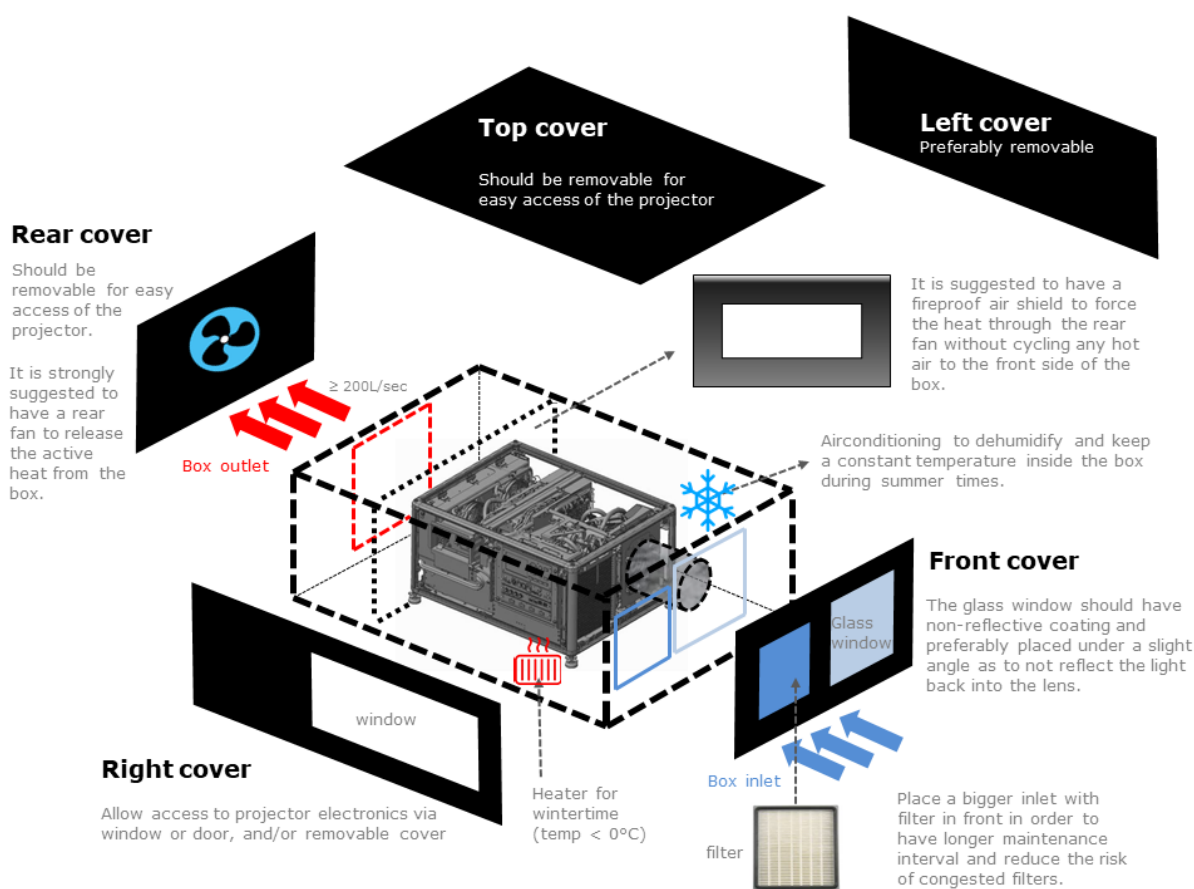
Plug and play - You will be able to access the IoT platform on any device with internet access, whether it's your laptop, mobile phone or tablet. The integrated cellular module will minimize the set-up-time as there's no need for cables, extra networks or gateways. And the IoT platform data can also easily be combined with your own tools and processes.

Outdoor protection

An outdoor box or projection booth are measures you can use to protect your projector from water, dust, changing temperatures, humidity, etc. during outdoor projection mappings.

A projector is designed to operate in free airflow, with cold air coming in the front side of the projector and hot air freely flowing out the back side of the projector. The projector can be put inside a box or installed in a dedicated booth, as long as this free airflow is secured and all the hot air can be released via the back of the projector (so without cycling any hot air into the front of the projector which would distort the image and overheat the projector itself).

Designing an outdoor box



For more details check our "Guidelines for designing an outdoor box for our UDX series projector" on myBarco.

Other things to keep in mind when placing your projector in an outdoor projection booth besides a good air flow and ventilation system:

- Power supply system: projectors need an individual & stable power supply
- Temperature & humidity control system
- Good optical glass for the projection window
- Weight capacity of the booth – what is the total weight of projectors and other equipment?
- Anti-static floor & safe wiring

Summary checklist

1. The nature of the imaging object
 - Dimension, surface, shape
 - Color and material
 - Reflectivity (including system reflectivity) and uniformity
2. Ambience & environment
 - Ambient light, temperature and humidity
 - Weather and altitude
 - Any obstacles in between the projector and imaging objects
 - What is the best viewing distance and viewing angle? How big is the viewing zone?
3. Basic parameters of projection
 - Illumination/brightness, contrast, resolution, color range, lenses
 - Where to install the projectors? Projection angle? Distance? Height?

References and further reading

- ✓ White paper: display specs and human vision by Goran Stojmenovik by Barco Product Manager
- ✓ From light to color: how design choices make the difference by Barco Projection Product Manager Koen Van Belle
- ✓ Guidelines for designing an outdoor box for our UDX series projector by Barco Projection Product Manager Fu Bo.
- ✓ High-brightness projectors for outdoor projection by Barco Projection Product Manager Fu Bo
- ✓ Barco user insight guide
- ✓ Projector toolkit user guide