Video Mapping

A Degree Thesis

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by

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Abstract

The aim of this thesis is to establish a solid base for the eventual realisation of a Video Mapping event on the occasion of the 50th anniversary of the UPC and the ETSETB.

A Video Mapping, or Projection Mapping, is an audiovisual technique that uses any kind of surface to project animation based or real footage visual content on them to make an impact on the viewer.

The project consists of a necessary theoretical basis of such audiovisual technique, a presentation of the conditioning factors and a final proposal I make, which takes into consideration everything previously mentioned, for carrying out the project.

Resum

L'objectiu d'aquesta tesi és establir una base teòrica sòlida per a la realització eventual d'un Video Mapping amb motiu de l'50 aniversari de la UPC i l'ETSETB.

Un Video Mapping, o Projection Mapping, és una tècnica audiovisual que utilitza qualsevol tipus de superfície per projectar contingut visual amb una narrativa, basat en animació o material real per impactar a l'espectador.

El projecte consisteix en l'exposició d'una base teòrica necessària d'aquesta tècnica audiovisual, una presentació dels factors tècnics condicionants i una proposta final que faig, que té en compte tot l'esmentat anteriorment, per dur a terme el projecte.

Resumen

El objetivo de esta tesis es establecer una base teórica sólida para la realización eventual de un Video Mapping con motivo del 50 aniversario de la UPC y la ETSETB.

Un Video Mapping, o Projection Mapping, es una técnica audiovisual que utiliza cualquier tipo de superficie para proyectar contenido visual con una narrativa basado en animación o material real para impactar al espectador.

El proyecto consiste en la exposición de una base teórica necesaria de dicha técnica audiovisual, una presentación de los factores técnicos condicionantes y una propuesta final que hago, que tiene en cuenta todo lo mencionado anteriormente, para llevar a cabo el proyecto.

This thesis is dedicated to my family, who have been always by my side, supporting me and giving me strength during the whole degree.

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1. Introduction

1.1. Project background

The initial proposal of the project was made by UPC to the student. The aim of this project was to create a functional prototype for the video mapping event on the occasion of the 50 years of both the ETSETB and the UPC. It was divided into the following three parts:

- Being able to translate the agreed message the school wants to transmit into a solid artistic AV creation.
- Getting to know the technological limitations of the projection and adapting the AV content to these limitations.
- Make a production plan including aspects such as exploration of the market, budgets, hardware and software available...

Due to the Coronavirus outbreak, I was not able to meet with the university board directive to keep on discussing what the final video should be like. Being in quarantine does not allow to shoot outdoors, which was fundamental in terms of delivering a successful final project. Therefore, after several weeks of uncertainty, me and my tutor decided we should adapt the scope of the project to the current situation.

1.2. Subject of study

The subject of this thesis is the *Video Mapping*, also known as *projection mapping* or just *mapping*. It is an audiovisual technique that uses any kind of surface (from objects and walls to buildings' facades or other architectural elements) to project animation based or real footage visual content on them, to create some optical illusions. It started becoming popular during the first decade of the XXI century, mainly in publicity, entertainment and technological research environments.

1.3. Interest on the theme and Current Situation

Personally, I have been attracted to the visual arts for a long time. I am very interested in storytelling through images, that is why I find video mapping such an interesting theme for me. In the end, the essence of it is to tell a story through images. I am also very keen on cutting edge technology, and in particular using it for artistic purposes. I believe that video mapping is a very advanced multidisciplinary form of expression that comes out as a result of a significant evolution of art and technology and it has many creative and narrative possibilities.

1.4. Goal and Hypothesis

The goals of this thesis are the next three. First of all, given that there are very few academic studies that talk about video mapping, what is it and how can it be classified, the first purpose of this thesis is to establish a theoretical basis of such technique. The second purpose is to locate and/or gather all the necessary information that becomes a conditioning factor for the project, such as the message that wants to be sent, technical factors such as the location where the video mapping is going to take place or the materials needed to execute it. Finally, the third goal of the project is to present a complete proposal where, after discussing all this previously mentioned information, a final draft of the project is presented, which also includes an approximate budget.

Therefore, this project can serve as a solid base for a materialisation of the project if the event were to be carried on the next term by any other student.

2. Elements

Light, perspective and sound are the three most vital elements to take into account when designing and creating a video mapping.

2.1. Light

Light is the most important element of the three previously mentioned used in a video mapping. Light allows the spectators to see and define the space in front of them, as well as the colors and textures of the projections. It creates depth in the images and, therefore, the tridimensional volumetry necessary to create an optical illusion.

“The typical dictionary definitions of ‘light’ (noun) are: ‘The natural agent that stimulates sight and makes things visible; also, a source of illumination, especially an electric lamp.’”[1]. These two definitions work perfectly for how video mapping uses light: it uses a source of illumination (projector) to stimulate sight making things that were invisible, visible.

2.1.1. Physical Aspects

“Light or visible light is electromagnetic radiation within the portion of the electromagnetic spectrum that can be perceived by the human eye. Visible light is usually defined as having wavelengths in the range of 400–700 nanometers (nm) between the infrared (with longer wavelengths) and the ultraviolet (with shorter wavelengths).” [2].

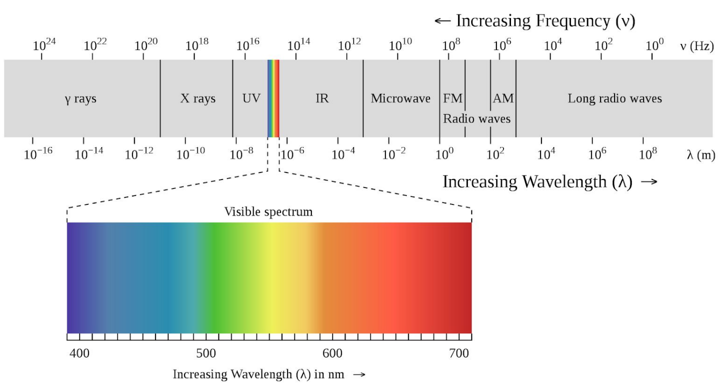

Figure 1. The electromagnetic spectrum, with the visible portion highlighted

Nevertheless, what is essential to understand to create an eye-catching visual experience is how light behaves when it interacts with matter. Several phenomenon can happen when light's photons hit an object of a certain material:

- Photons give their energy to the material (absorption).
- Photons give their energy, but photons of identical energy are immediately emitted by the material (reflection).
- The wave is scattered by the material (dispersion).
- Photons may not interact with the material structure (transmission).
- During transmission there are changes in velocity (refraction).

All this phenomenons will have an effect on how the video mapping is seen. For example, usually if there is absorption, dispersion, transmission or refraction, the projection will lose definition and brightness. Therefore, the maximum reflection is seeked, because that means that all the photons coming out of the projector's light bulb hitting the object's surface are bounced back to the public's eyes.

2.1.2. Psycho-sensorial aspects

One of the goals of a video mapping is to create a sense of immersion for the viewers into an experience that stimulates their brain. "Light may stimulate our perceptual apparatus through type and range of exposure to a lighting source and its colours, inducing specific emotional states or behaviour in the human: this specific type of stimulus is able to excite, move, impress, communicate, heal and generate wellness, creating a sense of harmony and syntony with the surrounding environment" [3]. Light (or darkness) and colours (or the absence of them) are therefore inducers of feelings to the viewers.

As it can be seen in cinema, lighting can draw the attention to anything, or it can divert it. It can make something look more beautiful than it is by highlighting its best characteristics or hiding its less attractive ones. Light can also create new unexisting spaces as well as atmospheres of a determinate mood. "The human being is also attracted by a sense of mystery and complexity, that arises from the discovery of a new and unknown environment, being inclined to prefer "unconventional" solutions, in which light, with its many shades and graduations, leads the individual through the process of exploration towards the unknown" [3].

Light has been analyzed not only by a perceptive point of view, but also as a driver of cognitive, emotional and behavioural responses by the perceiver. Even the dark (i.e. the opposite of light) has been analyzed, describing the effects of sensory deprivation or light manipulation on the perceiver, that may be used to increase the aesthetic enjoyment of the viewer, as in the case of Light Art installations.

All this psychological effects of light have to be taken into account by the creator of the video mapping, as it can be used in advantage to maximise the sensorial and emotion response of the people watching it, who will then leave to their homes with much more lasting memories of what they saw.

2.1.3. Basic characteristics of light

To be able to perceive there has to be contrast and opposition. According to Michel-Eugene Chevreul's law of simultaneous contrast, we perceive a color in contrast to another one, or the light in contrast with the dark. Therefore, if the general luminosity is low but there is an element that is much lighter, this one will stand out in contrast with its environment. Also, the more direct is the light projected from the source to the surface, the clearer are the shadows and the shapes created by it. A resource widely used in 3D video mapping is the cast shadow. It is what we all conceive as a regular shadow: when an object blocks the light and casts a shadow, such as a tree in the light casting its shadow in the ground. Even the degraded that the shadow creates in the object's body gives it corporeality and spatiality. Video mappings make use of these resources to alter the viewer's perception and achieve the illusion wanted. [4]

Taking into account all this, it is reasonable that the chromatics of the surface that is mapped affect heavily to how the video is perceived. Therefore, the materials used to build structures that are mapped ought to be of a light color if not white, and very little saturated so that the contrast is better perceived and the colors are much closer to what has been created with the computer. [4]

Not only the color of the surface makes an impact on the final result but also the texture, which through the projection, can be modified. This process is known as skinning.

Last but not least, the light pollution of the location where the mapping takes place is also a crucial factor to consider. Even though the projector is incredibly powerful, if there is light coming from other sources in the environment, the mapping loses contrast and the overall result is of poorer quality.

Therefore, as it has been said, light can and should be used to our advantage to create mind-blowing visual effects such as giving life to inanimate objects by modifying their shapes and textures in a plausible way.

Figure 2. Usage of cast shadows to create an illusion

2.2. Perspective

Throughout history, the way humans have represented perspective have changed. Sometimes it has been done following strictly how we perceive it and sometimes it has been done in a more freely and abstract way.

“Illustration I” is a diagram drawn by Giacomo Barozzi da Vignola in 1583. It illustrated how to use basic geometry to draw a picture in linear perspective. This technique basically consists in the systematic decrease of the size of elements that move away and the convergence of the lines in a vanishing point that is established in the horizon line. Afterwards, even Leonardo Da Vinci contributed to the exploration of perspective. He coined the name of atmospheric or aerial perspective, to the use of color as an element that generates depth, adding cloudiness to the distance. [5]

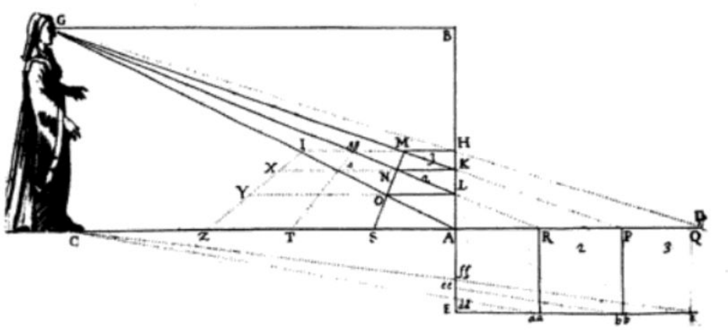

Figure 3. “Illustration I”. Giacomo Barozzi da Vignola, 1583

Nevertheless, perspective is considered to be first discovered by Brunelleschi in 1425, based on Euclid's laws of optical geometry. Along with the discovery of antiquity, they both have been marked as the beginnings of the Renaissance. More recently, the importance of such discovery and its influence in the evolution of art has been downgraded. However, there are many studies that follow up on the argument that perspective not only changed the way Western Europeans conceived of their art during the Italian renaissance but also had enormous influence on future developments in science and technology. [6]

Six hundred years later, the video mapping, a completely different and innovative way of “painting” pictures in a surface brings back the concept of perspective to elaborate a more complex piece of art. In addition to rationalizing the space shown, perspective can also be used to create a sense of depth and to draw the attention to a certain spot. Objects in a mapping might, at first, be represented as they really are to then create a completely different reality tricking the senses of the ones watching to make them believe the volumetry has changed.

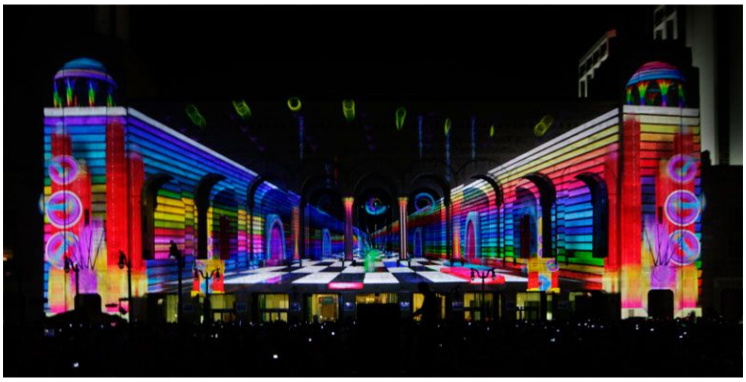

Figure 4. Use of perspective in a Video Mapping

One major drawback to this technique is that in order to actually appreciate the 3D perspective effect, the video mapping has to be watched from a particular point of view. Moreover, before starting the creation of the video mapping, the position of the projector from which it will be projected must be known because it is from such point that the video will be created. As the video is often projected in surfaces that are not plain, it must be created with a distorsion to counteract the one that would appear if a not pre-modified image was to be projected.

The end of the XIX century and the XX century is the stage of art history that has lived the most number of styles and artistic currents. All these vangards are of enormous originality. The artists were constantly rehearsing and investigating new forms, materials and concepts. Art for them was not a representation of reality but a presentation of their own reality through their more personal point of view. Therefore, it does not need to treat a known theme nor reflect three dimensions. The movement and dynamism brought up by futurism, decomposition of space made by cubism or the presentation of dreamy imagined spaces by the surrealists are some examples of big influences on the approach to perspective that mappings have nowadays. [7]

Figure 5. Umberto Boccioni, 1913. Dinamismo de un ciclista

Figure 6. Pablo Picasso, 1910. Girl with a Mandolin

Figure 7. Salvador Dalí, 1931. La persistencia de la memoria

The appearance of cinema really pushed forward the appearance and the artistic status of mappings. The form of cinema most similar to mappings was the one that not only wanted to tell a narrative to the public but also to immerse them into it. During the XX century many artists started being interested in this objective, such as George Mèlies in 1902. In 1926, Cinemascope was invented as a way to compress images in the filming roll and then expanding them in projection, obtaining a much wider image, but it did not interest the cinema industry until the 1950's when they had to compete with television. However, much before this boom, many artists had already experimented with optic illusions such has the painter Hans Holbein in The Ambassadors. In this painting, if looked from in front of it an unrecognisable shape is seen. However, when looked from a side or through the reflection of a spoon, a skull can be perceived. Therefore, the perception of the shape is transformed by varying the spectator's position.This phenomenon is called anamorphosis and is one of the main pillars of projection mappings.

Figure 8. The Ambassadors (1533), Hans Holbein.

More recently, many other artists have used anamorphosis to achieve astounding results. Julian Beever paints with chalk in the sidewalks situations in which he accomplishes to erase that 2D barrier. Felice Varini is known for intervening in spaces that have depth and perspective to actually erase that perspective when viewed from a certain point of view. One of his latest works in the castle of Carcassonne for the 20th anniversary of it being UNESCO heritage is considered one of the biggest artworks of the world.

Figure 9. Julian Beever. A slight accident in a Railway Station in Zurich.

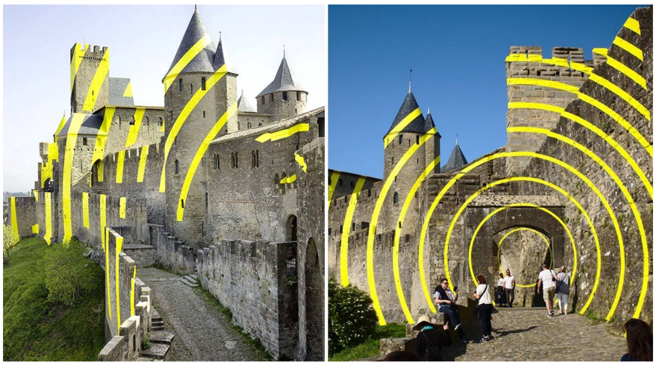

Figure 10. Felice Varini, Carcassonne (2018)

The two other geometrical transformations used in video mappings to make the content match three dimensional and variable surface, apart from anamorphosis, are:

- homography: the relation between two points of two different spaces, in such a way that each point of a space corresponds only to its homograph of the other space. It can be used to project on surfaces that are not perpendicular to the projector, eliminating the perspective and getting a plain image.
- homothety: transformation of the plane or space that expands or contracts the geometric shape keeping its corners intact. This technique can also be used to correct the variabilities of the projected surface, to get a corrected image.

2.3. Sound

The video mapping is an audio visual immersive experience. “The synesthetic possibilities of human perception, and the range of emotional responses by each individual exposed to the light, grow if—besides the impact generated by a light source—we also add a sound stream, such as a piece of music.”[3]. Therefore, the ‘audio’ part of the show should also be addressed. Depending on the kind of video mapping it has been done, different considerations need to be done.

- If the mapping is part of a musical performance, it is normally synchronous with the music being played and it potentiates the artist’s music and figure.
- When it is an element of the scenography of a theatre play it rarely seeks attention from the spectator. It usually seeks being part of the physicality and organic feel, trying to complement the other characters in the play and the plot.
- When the mapping is an art installation or architectonic mapping, the sound accompanies and maximizes the impact of the mapping. They merge into one, looking for a sense of unity because in this case the mapping is not a part of something bigger, it is the whole art work by itself.

In all of these cases, music will set the rhythm and make us feel stronger emotions while getting us more involved in the narrative. Sounds will make it look more real and plausible. To achieve the best results, it is preferable to have speakers installed in strategic positions and pointing certain directions.

These experiences can be even more enhanced by using Binaural or 3D Audio, which allows the creation of immersive spatial audio experiences for headphone listeners. [8] There are many different types of “immersive sound”, but the one that fits the requirements of a video mapping is the Dolby Atmos Sound System (https://www.dolby.com/technologies/dolby-atmos/). Thanks to this system, 3D sound is now possible without the need of earplugs or headphones. Having a sound system like this means that at some point, most of this immersive experiences, will be elevated to even a higher level of immersion thanks to this 3D audio system.

3. History of Video Mapping

There are many different stories about the origins of video mapping and the truth is that all of them might be correct because there is not a unique origin but many influences that gave birth to it. Being a relatively new technique which did not receive its name until a few years ago, it is hard to name the first video mapping ever done. However, what it does make sense is to talk about some aspects that influenced it.

Some theories claim that the most ancient influence of video mapping is the camera obscura, an optical phenomenon which is said to have been used as far back as 10.000-40.000 BC. Similar techniques were used in Ancient Greece, then in the XVII century in Europe, such as the Magic Lantern. In the XIX century, special effects were recreated in theatre performances and the cinema really pushed forward the appearance of the video mapping in the XX century.

The majority of people might associate video mapping to projecting an image on a building's facade, but that is a rather incomplete description to its actual possibilities. It is a technique, a tool to express something. It can also mean projecting over animals, trees, vegetation, bodies, in theater or dance performances, installations or to give experiences such as projecting on high cuisine dishes before eating them. There are many types of mappings nowadays, and they can be classified taking into account three different parameters:

- goal: corporate or artistic
- the object: architectonic or stage
- the content: on a photography, on a 2D model, on a 3D model.

See more in Appendix I (pg 39).

4. Technology used in Video Mappings

The evolution of video mappings is tied to the development of technology. Thanks to the exponential development of the image processing capacity of computers and the accessibility to modeling software, the development of digital architectonic models are beginning to be used in this artistic technique and is combined with the techniques and software of the VJs to generate a live visual event, that grows in complexity through time.

The main technological developments that contribute to the elaboration of a video mapping are:

- Obtention of the projections space geometry
- Mapping and Animation Software
- Powerful projecting (even in daylight)
- Edge Blending

Edge blending is a technique that allows us to create a bigger projection through the use of multiple projectors, therefore it is useful to know how it works. It is used to describe the process of visually combining several projected images to make a single seamless image. It is done to increase the size or the resolution of the image projected. At first, the logical option might seem to be aligning all the projectors without any overlapping, what is called image butting. However, it is nearly impossible to exactly align up the projectors, therefore some will overlap and some will have a gap. Furthermore, although the same model is being used for all projectors, there might be slight light differences between them.

What is done in edge blending is create an overlap region where the images from two projectors collide. This allows better control of the overall image, but reduces the image size and definition. In this region, the brightness is double because two projectors are projecting the same image. To contrarrest this, the images must be blended together. To do so, the luminance of one side has to drop off gradually while the one on the other side has to increase gradually. Then the transition between projectors is much more soft and the differences between projectors are very hard to notice.

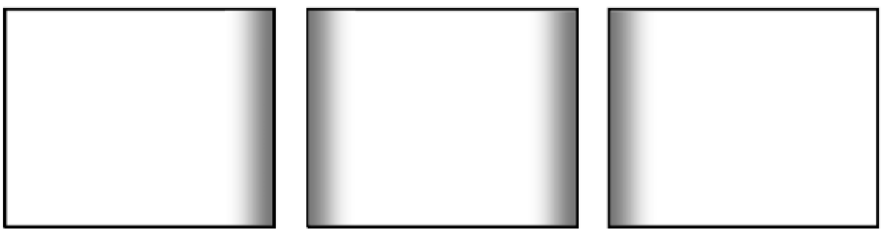

Figure 11. Blending in the overlapping regions gradually produces a visually correct image.

To control the amount of edge blending there is a gamma function $o = i^{\gamma}$, where o and i are the output and input values in the range [0..1] and γ is the gamma value. The obtain the best results, the overlap should be large and the gamma value should be low. This setting would create a very slow transition from one projector to the next. [9]

5. Creation of a Video Mapping

5.1. Work phases

The process of making a video mapping is very flexible and every creator can follow his or her own path. In its essence it is an audiovisual piece like a short film or a music video, with its differences. Therefore, a generic guide of the elaboration of a mapping can be done. Below are the steps I would have followed to make the video mapping.

- Phase One. Planning

Like in any other audiovisual piece, the first phase consists in a written documentation of the theory bases, visual references and technical learning of the student, product of the research done, as well as interviews with the client who has placed the order, in this case the UPC, to decide exactly what is the message that wants to be sent through the mapping.

In this preliminary phase, a visit to the location of the mapping is also highly recommended to make measurements, decide the placement of the projector/s, analyse the shadows of the building and define the scope of the project.

- If the surfaces is too complex, the scope has to be narrowed and decide which elements are going to be projected and which not, decision that affects the complexity of the narrative as well.
- Take as many measurement of the building and its surroundings as possible, including the dimensions of the surface to be projected, the distance from the projector to the building, length of the cable to get good signal...To do these measurements, the laser distance tool is a very useful device that measures the distance between two points instantaneously, as well as the height of something, using the Pythagorean theorem. Ideally, the video projector should be placed at the center of the zone you wish to cover, and as close as possible to your projection surface so as to maximize luminosity. [10]
- Take pictures of the surrounding area apart from the front of the building. These will be helpful to organise production aspects such as public entrance and security, cable paths, possible scaffolding stabilisation for the projector, objects that might block the light, etc…. The most important picture is the "perspective photo", taken as close as possible to the projector's angle and with the same lens. It will be used for the creation of the prototype of the mapping. If this picture cannot be taken, the surface needs to be modelled with a 3D software.

In this phase there are different steps to follow depending if the mapping is 2D or 3D. If the mapping is 2D, only the most external limits of the building's surface are measured.

However, if the mapping is 3D, all the shapes and contours of the surface have to be taken into account and added to the 3D CAD (Computer-Aided Design) model. In the case there is no updated 3D CAD model of the building's surface, one should be done from scratch by laser scanning it. Laser scanning a building is a very common process done in the construction industry. It requires a very specialized and expensive hardware. That is why usually a professional laser scanning company does the 3D model of the building for the mapping. It normally takes between four hours to two days depending on the complexity of the surface and the result can have an accuracy of up to 2 microns.

- Phase Two. Light and Pixel Planning

In the case of the 2D mapping, now that the size, shape and dimensions of the canvas is determined, this data has to be transferred into a software to create a 3D render. In the case of the 3D mapping, the render has already been done in the previous phase. In both cases, the data in the 3D render should include the number and position of the projectors used, as the software shows the brightness level and pixel density obtained on each point of the mapping depending on how many projectors are used. The brightness is expressed in luxes (one lumen per square metre) or foot-candles (one lumen per square foot). The device that does this measurement is the light meter.

Figure 12. Lux meter or light meter

- Phase Three. Content Creation

Once all the maths of are done, the content that will be projected has to be done. This phase is very flexible because there are many different kinds of content to be created for a mapping: graphic animation, live action, a combination of the two, 2D, 3D… Regardless of what content is created, the perspective of the audience should always be considered when creating it. It needs to be optimised to ensure the best experience and contrarrest the optical effect that can occur depending on the perspective of the audience. For example, if the public is going to look up at the images projected, then the video should be recorded from a low perspective to emulate their point of view. [11]

This website [12] has resourceful library of videos that can be used to fill up gaps in your story if the budget or time constraints do not allow you to create everything from scratch.

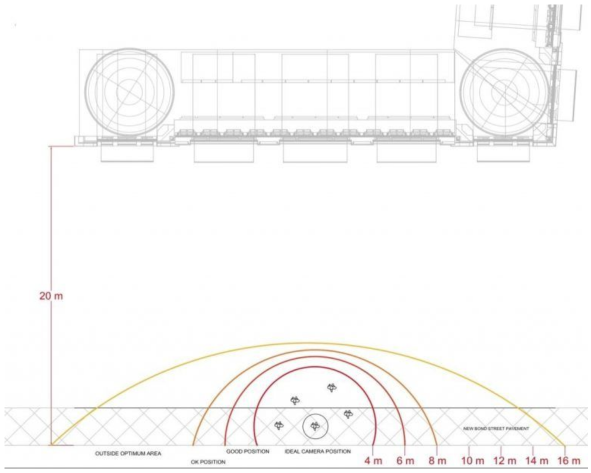

Figure 13. Map of the location and the optimal position for the audience

- Phase Four. Setting up

The last phase consists on setting up in the real world the setting simulated in the digital drawing, including the positioning of the projectors. Ideally, they would be lined up and with the same distance between each other, but the location hardly ever allows it. Therefore, some adjustments will have to be made, always trying to achieve a 10-15% of overlapping between projectors to get seamless edges between projectors transitions. In this setup process, it is highly recommended to build a safe, stable and weather-proofed environment to avoid setbacks.

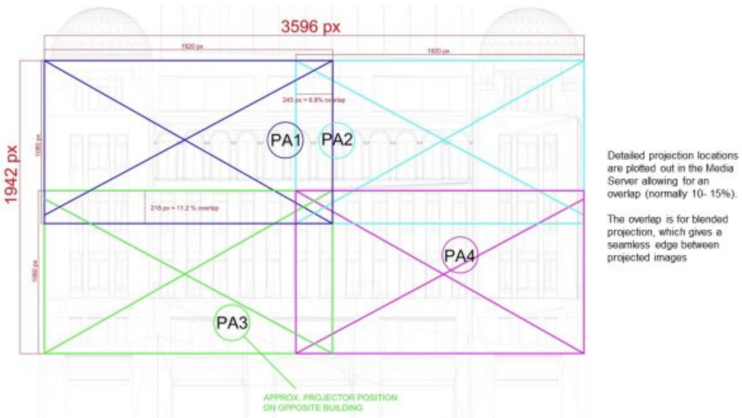

Figure 14. Detailed projection locations plotted in the media server with a 6,8% overlap [11]

5.2. Content

The script and the visual style need to be defined. A same surface can host infinite narrative and aesthetic options, telling many different stories. It is interesting to look for ties between the narrative concept of the mapping and the surface on which is being projected, as it enriches both the projection and the space.

As previously mentioned, there are many types of content that can be part of a video mapping. The most common proposal, found in many mapping festivals, is 2D and 3D animation made with animation softwares such as Adobe After Effects. The possibilities with animation are many: visual effects integrated into the shapes of the surface such as lines, colouring, filling, shaking…

However, a very interesting proposal is a mixture of real live footage and animation, as it is able to tell more complex and real stories than just with animation.

5.3. Hardware and Software

Having defined the steps to follow to create a video mapping from scratch and execute it, a special guide for the software and the hardware used in the process is required as there are numerous options for more than one of the steps. There are two main goals that must be accomplished by means of this software and hardware: first, obtain a digital model, bidimensional or tridimensional, of the architecture or object of the projection and second, work on that model with animation design and effects to fit the projection accurately to the surface.

5.3.1. Hardware

With reference to hardware, needless to say a projector and a computer are needed. The projector's characteristics and requirements are going to be addressed in the next section of the document. Then, the only question that remains regarding the computer is: Mac or PC? It goes without saying there is no correct answer but the choice can have a long term impact on your work. On the one hand, Apple has many easy to use apps and is built with high-end components, so it should last longer than a PC. However, there is a lack of user upgradeability and it comes at a higher cost. On the other hand, PC's come at lower prices, full user upgradeability and can have custom media servers installed as well as two video/graphic cards running simultaneously (which might get you better performance but actually is not clear to be worth it).

"A media server is a computer appliance or an application software that stores digital media (video, audio or images) and makes it available over a network." "Usually, it is a high-spec home computer with increased RAM or hard drive technologies such as RAID arrays or solid-state drives. They are then supplied with software which allows the control and manipulation of video content, much like VJ software. One of the primary functions of these machines is to allow current show control technologies to control the playback of video content. Thus, a media server system may include inputs for DMX512-A, MIDI, Art-Net or similar control protocols.” [13]

5.3.2. Software

The same ambiguous situation happens when it comes to deciding a software for your mapping. Each one of them has some pros and cons. However, based on the user’s reviews on the internet, it is clear that the best softwares are Madmapper, Millumin and Touch Designer. Therefore, these are the ones that are going to be analysed. Resolume Arena 4 has many positive reviews as well, but I found it is more oriented towards live music performances.

- Madmapper

The most powerful and acclaimed software is Madmapper. It is versatile, resourceful, simple and free to download. It can be used for for architectural video mapping, art installation, stage design and live shows and it has many features:

- Multiple projectors: Connect as many projectors as your computer can handle, and use multiple graphic cards at the same time.
- Masking: Create masks and link them to surface.
- Video effects: Use shader-based video effects to pimp your media, adjust contrast/brightness or perform real time luma/chroma keying.
- Online library: Share your materials with an ever-growing community through an in-app online library, free
- Mesh warping: Configurable precise Bezier Warping grids, in perspective
- 3D calibration: Import and calibrate 3D objects. Match the projector’s perspective, affine the point of view precisely, with error % feedback. Adjust the geometry in screen space.

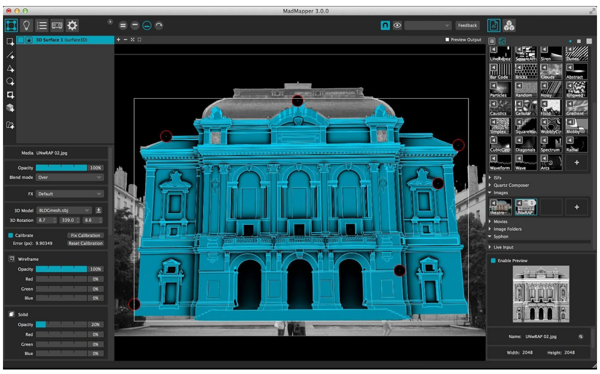

Figure 15. 3D calibration feature in MadMapper

- 3D lighting: Digitally light a textured 3d object, with adjustable shadows and light position.
- Soft edge: Manage multiple seamless projectors using Soft Edge
- Live video input: Use supported devices such as BlackMagic frame grabbers to input live footage from a broadcast pipeline, media server or CCTV camera.
- Spatial scanner: Transform your esdk compatible Canon camera and your projector into an on-site 2d scanner. Get what “the projector sees”, at the pixel level, using Structured Light.
- LED mapping: Control array of LED bars, matrices or isolated pixels. In any shape or any arrangement.

Madmapper offers four options for working with it. A demo, which is free, with only these limitations: a watermark in the input, preview and output, the scan produced by the Spatial Scanner is limited and cropped to 1/4th of its resolution and the Connected lighting will blink once every minute when using MadLight. A one month rental option for 35€ or three months for 89€. A perpetual license for 2 computers 359€ plus taxes. Finally, there is also an educational license for 2 computers for 259€ plus taxes. [14]

- Millumin

Millumin 3 is a complete solution to create audiovisual shows ranging from theater and dance to video mappings and interactive installations. Its most remarkable features are the following:

- Sequencer: Millumin creates the show via a sequencer, including states and transitions.
- Timeline: it also includes a timeline editor with animated keyframes, curves and segments. Such timelines can then be added to the sequencer.

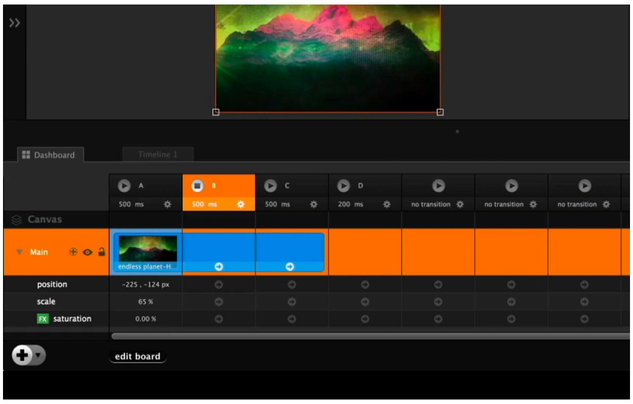

Figure 16. Sequencer feature in Millumin

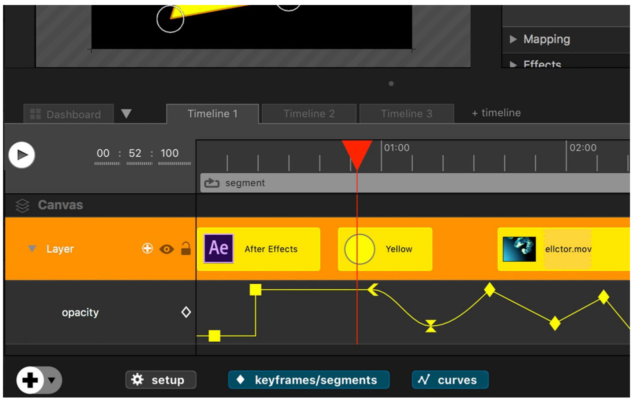

Figure 17. Timeline feature in Millumin

- Video Mapping tool using masks and warping tools to adapt our images to the surfaces.
- Lights: control any DMX/Artnet device, create light-plots, light transitions...
- LED mapping: convert pixels into DMX and control LED strips or light ramps with video media.
- Multi screen: project video on multiple screens, and blend projectors together with soft-edges.
- After Effects: it lets you preview an after effects composition without having to render the whole clip.
- Interactions: MIDI, OSC, TUIO, Artnet, DMX, timecode, gamepad, keyboard, Arduino, Kinect, LeapMotion, etc.. to control Millumin.

Millumin offers three options. A demo, which is free during 30 days, then a watermark is added to the output; a one month rental option for 120€ ; a permanent license for 599€ and an educational six month renewable license for 39€. [15]

- Touch Designer

Touch Designer is a node based visual programming language for real time interactive multimedia content used by artists, programmers and performers to create performances, installations, and fixed media works [16]. Its features are:

- Application Building: both application engine and user interface are integrated into the same environment, which allows to create very personalised and complex interfaces for a custom show, or a simple functional prototype depending on the need of the project.
- Interoperability: adapted for working with Ableton Live, Max/MSP, Substance Designer, Notch, vvvv, OpenFrameworks, Resolume, web apps and others.
- Real Time 3D and compositing: create content inside the programme, like 3D.
- High performance media systems: from 1080p to 4K, only limited by the machine's GPU.
- Projection Mapping: very large list of features that allow full customisation for any show, including the basics “Stoner tool” that shapes the output and the “Projector Blend”.
- Lighting and Live Shows: Control systems used in any kind of live shows.
- VR Support: All of Touch Designer's features are compatible with the built-in VR tools, that allows to see your work from a different perspective, pre-visualize it or create something new like interactive 360 movies or multi camera stitching.
- Extensibility and Customization: Phyton is the default scripting language, offering full control and customizability.

Touch Designer offers four options: a non commercial for personal use or learning (not for paying projects) for free; an educational option for schools, faculty and students (not for paying projects) for 300$; a commercial option fully featured and for use in paying projects for 600$ and a pro option with every feature and access to Pro Support for 2200$.

- Animation/Content Creation Software

The most used software for the creation of animated visual content are Photoshop, Illustrator, After Effects, & Cinema 4D, OpenFrameworks, Isadora, Max MSP, vvvv, and Processing.

5.4. Projection

A video mapping can be projected on many buildings ranging from small music venues, clubs and festivals or historical and larger buildings and monuments. Depending on the surface you want to project on, several projectors may be needed. However, in most cases one projector will be enough. The key factors to take into account when deciding which projector suits best the project's needs are:

Throw Ratio/Lens: it is the width of the image relative to the throw distance."[17]. For example, if the lens has a 1:1 ratio and the distance between the projector and the building is 1 metre, the image is going to be 1 metre tall. A smaller throw ratio gives a wider image. This value ranges from 0'3 to 12. The bigger the number, the longer the throw distance. "A projector zoom lens will have two different throw ratios, one for the minimum zoom setting and one for the maximum zoom setting."[17]

$$\text{Throw ratio} = \frac{Throw\ distance}{Image\ width}$$

By knowing two parameters of this formula, the third one can be easily found out. For example, if you want a projected image of 5 meters wide and your maximum throw distance is 6 meters, your projector should have a throw ratio of around 1'2.

Resolution: A projector's resolution is the number of pixels, from side to side and top to bottom that makes up the projected image. "Higher resolution projectors makes your image clearer. Projecting on bigger surfaces will require you to use Full HD (1920×1080), whereas on a smaller object you could use smaller resolutions."[18]. If the project has a bigger budget, a 4K video projector will provide an even better image quality, if the content has been created in such quality. These are the existing video projectors resolutions in the market:

SVGA = 800 x 600 (800 pixels across and 600 pixels down)
XGA = 1024 x 768
WXGA = 1280 x 800
WUXGA = 1920 x 1080
720p = 1280 x 720 (HD)
1080p = 1920 x 1080 (HD)

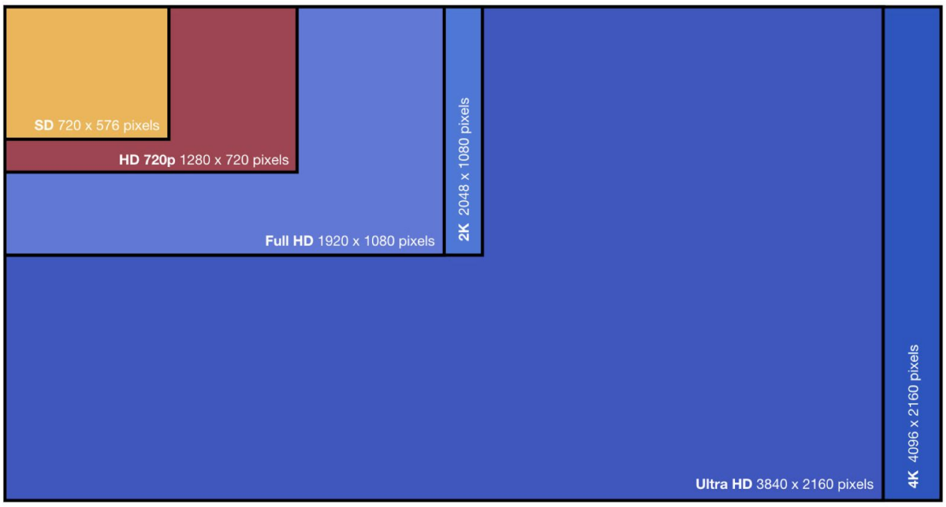

Figure 18. Visual comparison between the different resolutions [18]

<u>Brightness:</u> “The brightness of a projector is referred to in Lumens. Larger scale events will require high-brightness projectors (14K+ Lumens), whereas for smaller objects event a 7K Lumens (ANSI) projector will work. One lumen is approximately equal to the amount of light a lit candle will produce. A standardized procedure for testing projectors for brightness has been established by the American National Standards Institute (ANSI).”[18]. Video mappings should happen in dark locations or at night, as it is impossible to do it in broad daylight even with 20k lumens.

<u>Contrast ratio:</u> this value refers to the “luminosity difference between white and black in absence of color.”[19]. A video projector cannot project perfect black, that is why this color is usually replaced with a very dark grey. The bigger the ratio, the better the contrast, which means the better the image quality. Therefore, 1000:1 ratio provides better contrast levels (and image quality) than 500:1.

<u>Cables and connections:</u> “HDMI and DVI are called “digital” connections and allow for a better image resolution. On the other hand, a VGA cable is less expensive, but the image quality will be lower.”[19]. The length of the cable should not be longer than 10-20 meters, as it might result in lower-quality projection because of signal loss. To avoid this, repeaters can be used to boost the signal. Either way, the use of shielded cables is strongly recommended.

Transport and precaution: the projector must have cooled down before unplugging it and packing it because "sudden power failures can damage the projector's lamp."[19]. With LED or laser projectors it is not necessary.

The frequency of the projector: it is measured in Hz and has a range of between 50-60 Hz. This value is not relevant for the projection unless it is going to be filmed. Then, the frequency of the projection should be the same of the camera recording, to avoid the appearance of vertical scan lines in the recording. Either you can change the display settings of the computer's operating system or the settings of the camera used for the recording.

Lifespan of the projector: "Historically speaking, the light sources of video projectors are basically lamps. This is a very fragile part and luminosity tends to decrease over time."[19]. That is why more options have surfaced and are competing in the market. These are LED projectors and Laser projectors. The first ones can offer a maximum of 3.000 lumens and have a lifespan 5 times longer than the lamp projectors: 10.000-20.000 hours in average. In addition to this, they are lighter and smaller than those with regular lamps. Laser projectors can go up to 20.000 hours and over 6.000 lumens. Note that there are also several projection technologies. The most common ones include DLP, 3-DLP, LCD, and 3-LCD.

However, the projector is not the only element in a projection mapping. These are two other key factors to consider:

Light conditions: the level of light of the area where the projection is taking place should be the lowest possible. Natural and artificial light directed to the surface where the video is being projected should be avoided, as it will lower the quality of the image, even with high contrast settings. Therefore, a dark environment becomes essential for a successful projection.

Material of the projection surface: Depending on the type of video mapping, differents materials for projection surface are seeked. Typically, it should be a "light-colored surface of matt materials to reduce light reflection to the minimum. If, on the contrary, a shinier material is used, the image quality will decrease and the projector light's reflection might appear."[19]. However, in some occasions the video mapping does not require very high definition to be fully appreciated and uses transparent or translucent materials. For example, in corporate video mappings or in artistic installations, some level of transparency might be wanted. Moreover, if the projector being used has a short focal distance (throw ratio < 0'5) it is recommended to avoid flexible projection surfaces such as fabric, as any slight movement of it might distort the image.

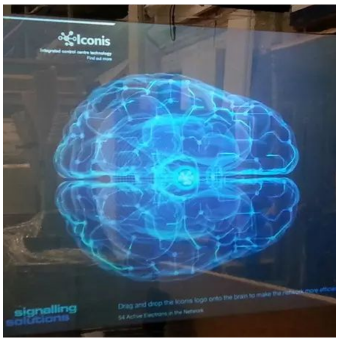

Figure 19. Corporate video mapping (translucent)

Figure 20. Multi channel video installation (translucent)

Figure 21. Ideal Barcelona (matt)

Figure 22. Video mapping al Ajuntament de Barcelona (matt)

<u>Where to position the projector?</u> Depending on the projector focal length, zoom and projection angle, the maximum and minimum distance between projector and wall can be defined. Ideally, the projector should be placed in the center of the area that wants to be projected and as close as possible to the object to get the most brightness possible.
The website Projector Central has a very useful guide for plenty of models of projectors of different manufacturers (https://www.projectorcentral.com/projection-calculator-flash.cfm).

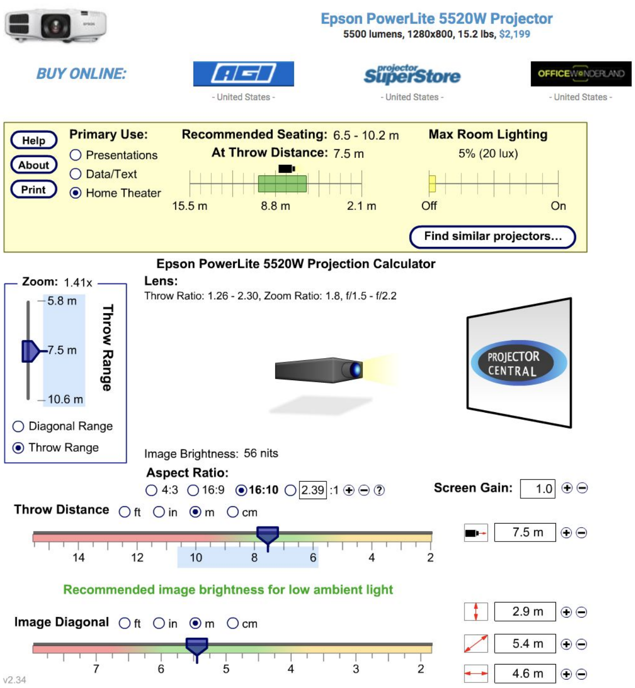

Figure 23. Features of a projector at Projector Central

6. Proposal

Taking into account the information gathered in two meetings that took place the February 10th and 21th with my thesis supervisor, Josep Ramon Casas, and the director of ETSETB, Josep Pegueroles, and all the information exposed previously in this document, I elaborated this proposal for the video mapping that specifies all of its aspects, both the creative and the technical ones.

- Creative Proposal

The video will last approximately 3-5 minutes and will consist of two parts. Although they are not separate, each of the parts will have a markedly different style.

A looking to the past (2 minutes). The first part will be based on images and videos from the UPC archive as well as a voice-over that will guide the viewer through the most important milestones in the history of the UPC, curious facts and in general the trajectory of the University during these 50 years. It will have a fast and fluid rhythm, and the text that the voice-over will read will be agile, light, will have a certain musicality but at the same time will be serious, which will allow us to go through 50 years without boring the viewer.

Projection to the future (2-3 minutes). Once we reach the year 2020/2021, the second part of the video begins. This part will be mostly based on material recorded by me along with the help of a film crew from the AVED student association and some other external collaborators. It will contain background music and most likely also a voiceover. It will have a pace not as fast as the first segment, but will be more cinematic and with images that convey passion, future, confidence, work and innovation. The maximum beauty of the images will be sought so that they transmit all these attributes. As the name of the segment indicates, it will show the essence of the University in the present and especially its focus on the future.

In this part we focus on the ETSETB. We want to show how telecommunications have contributed to society as we are engineers and our job is to provide solutions to society that make life easier for people. Therefore, we will show about 4-5 contributions that telecommunications engineers have made to society, so that everyone understands, once and for all, what Telecos consists of. To show the widest possible range and as a guide, I take as a starting point the 4 specialties that exist in the degree of Telecos: Audiovisual systems, Electronics, Telematics and Telecommunications. Taking into account these four branches and the values of the UPC (social responsibility, equal opportunities, sustainability and cooperation and solidarity) as well as innovation, the future and the imagination, we create 4-5 situations with one or more protagonists each, which represent how telecommunications have improved some aspect in people's lives.

After doing some research, the applications that are going to be filmed are:

- *Audiovisual Systems + Social Responsibility: training with **Virtual Reality glasses** that accelerates and improves the treatment of ill people (e.g. in wheelchairs).*
- *Electronics + Sustainability: **Mapping ocean noise** to reduce noise pollution or **3D Printers**.*
- *Telematics: **AI** (Siri, Alexa ...).*
- *Telecommunications: **5G** Satellites or **Mars Curiosity Rover with UPC chip**.*
- *Data Engineering: **Supercomputer MareNostrum***

The objective is to show great contributions that telecommunications engineers can make, without necessarily having the UPC involved, as it would greatly limit the options and therefore the images that come out, as we would not have much freedom at the time to decide what to record and how, and if we want to achieve a 'cinematic' or 'television' look, some or all of these scenes should be created on a set with actors and good lighting. However, it is interesting to show some projects in which the UPC is involved (such as MareNostrum or ocean noise mapping) along with other great inventions/projects that are being carried out in the world in the field of telecommunications (such as VR for treating ill people), to have a more personalised video.

- *Technical proposal*

The video mapping is going to take place in the front wall of the library BRGF. As it is made of glass, it will have to be covered in a self-adhesive optical film for front projection applications, as the glass is a very transparent material. The company Pro Display (https://prodisplay.com/products/front-projection-film/) offers a self-adhesive front projection film that can be simply applied to glass in minutes using water and a squeegee. I have chosen the projector PT-RZ970BU because it is very powerful (9.400 lumens) and can project an image of up to 12,75m x 7,97m, which already suits our needs. It will have to be located at a distance of 21 metres approximately from the building, to get the bigger image with the sufficient brightness.

Figure 24. BRGF Library

3. Budget

To carry out this project it is only necessary an engineer with creative skills and a computer. The cost breakdown for the project is shown in Table 1. [20] [21]

	Concept	Quantity
Engineer	Project Duration (weeks)	20
	Average dedication hours (hours/week)	15
	Total dedication (hours)	300
	Junior engineer (€/hour)	10
	Engineer cost (€)	**3.000**
Material	**Option 1**. Self-adhesive optical screen film for front projection applications: 10m x 1,8m roll (€)	2.342
	Four rolls (€)	**9.372**
	Installation Kit (Squeegee, Spray Bottle, Gloves) (€)	**17,8**
	Application Fluid (€)	**8**
	Option 2. 10,4m x 5,4m Screen (€)	**350**
	Panasonic PT-RZ970BU (€/day)	850
	3 days (€)	**2.550**
Software	Madmapper (€)	**0**
	TOTAL **Option 1** **Option 2**	14.947,8€ 5.900€

4. Conclusions and future development:

After reimagining and readapting the scope of the project to the current situation, the project's three main goals have been achieved successfully.

A theory base of the Video Mapping technique has been acquired through an extense documentation. It includes how its three main elements (light, perspective and sound) affect the final result; its main influences through the history of art and the technology that is used through the process. All the conditioning factors for carrying out the project have been presented, including the steps to follow to create a Video Mapping, the material needed and all the technical requirements to take into consideration when executing the project. Finally, I have made a proposal of how I would have realized the project. This proposal contains a creative part, where I present the script, and a technical part where I present my choice of location and material for the event to take place, as well as an approximate budget to complete the project.

If the Video Mapping is going to be completed by another student in the future, this thesis will guide him/her through the process.

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Appendices:

Appendix I. History of Video Mapping

Origins and Evolution

There are many different stories about the origins of video mapping and the truth is that all of them might be correct because there is not a unique origin but many influences that gave birth to it. Being a relatively new technique which did not receive its name until a few years ago, it is hard to name the first video mapping ever done. However, what it does make sense is to talk about some aspects that influenced it.

Some theories claim that the most ancient influence of video mapping is the *camera obscura*. It is an optical phenomenon which causes an image of the outside of a dark room to be projected inverted in the opposite wall inside through a little hole in the wall. It is rumored to have inspired paleolithic cave paintings, dating as far back as 10.000-40.000 BC.

In Ancient Greece the same technique was used between the years 1450 BC to 392 AD in the rites of initiation into Eleusis religion. It eventually became the center of the ancient world and the predominant religious group in the Mediterranean, which at that time was the center of the antique world. These rites, which growed popularity until initiating up to three thousand followers at once, consisted on face-to-face experience with the gods. This experience was done with the camera obscura principle, projecting images of ancient gods from a small sacred and dark building with a fire lit inside onto the exterior for the astonishment of the followers.

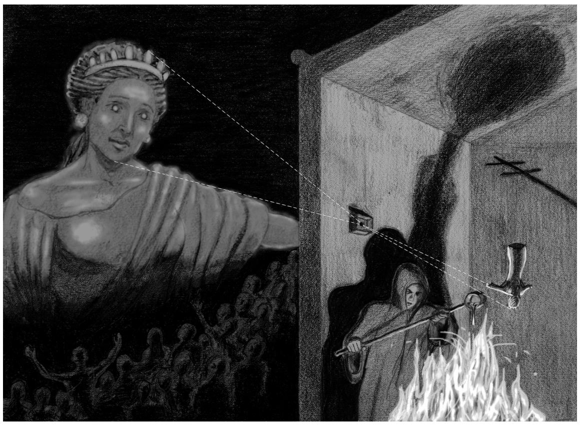

Figure 25. Camera Obscura in Eleusis initiation rituals

The same principle was used to build the Magic Lantern in the XVII century. It was in essence a camera obscura but it was much smaller and handier. It ended up replacing the camera obscura as a projection device used for entertainment shows such as presenting images of palaces, ballet dancing and battling with swords to the Parisian society in 1656.

In the end of the XVIII century phantasmagoria became widely popular. Created by the belgian Éttienne-Gaspard Robert, it consisted of several magic lanterns of different types, projecting phantasmagoric images onto solid and gaseous materials from different points of view and with wheels to move them around.

The technical developments of the XIX century improved and sophisticated this invention with more powerful lanterns and improved lenses. They were used in theatre performances to recreate special effects on stage. It was the first time that a projection was done onto something not being a plain surface: they were projecting on an object on stage, very often a doll.

Also in the XIX century photography was invented. Then the Lumière brothers invented cinema in 1895 and they started projecting it. These huge technological opportunities opened up a universe of collaborations between different audio visual representations, specially between cinema and its "older brother", theatre such as creating fictitious scenarios and extending the existing with a technique called *matte painting*. Projections used in theatre plays were not only scenography items but also key content on the development of the play, as it contributed to its narrative in a didactic and active way. It was then that artists began to ask themselves how could they make profit out of technology, which was starting to be seen as more than just a tool. They wanted to express emotions, concepts and engage people but first of all they had to think what did they want to express to ask themselves why did they want to express that and then find the tool that assists them in doing so. It was an approach to how should technology contribute to art ahead of its time, which still prevails nowadays.

The XX century is the one that has seen the birth of the video mapping as we know it. In the second half of it there have been many pioneers in the art of drawing with light. One of them is Bruno Munari. In 1953, he inserted slides containing many materials, such as leaves, burnt plastic or onion peels between two Polaroid Filters, resulting in his *Polarized Projections*. "Rotating the filter fixed before the projector, the polarized light goes through the materials in the frame and decomposes into the colours of the spectrum changing continuously the work." (Hajek 2008: 2)

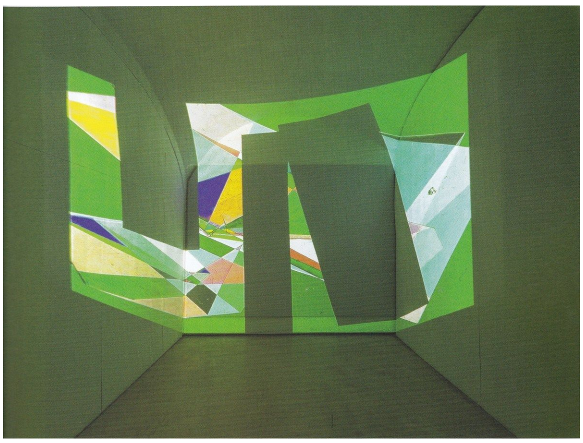

Figure 26 and 27. Bruno Munari 1953. Proiezione a luce polarizzata

However, the first artist to create volume with light was the californian James Turrell with his work Afrum in 1967. His work is undoubtedly one of the major exponents of lighting, using light to create perspective.

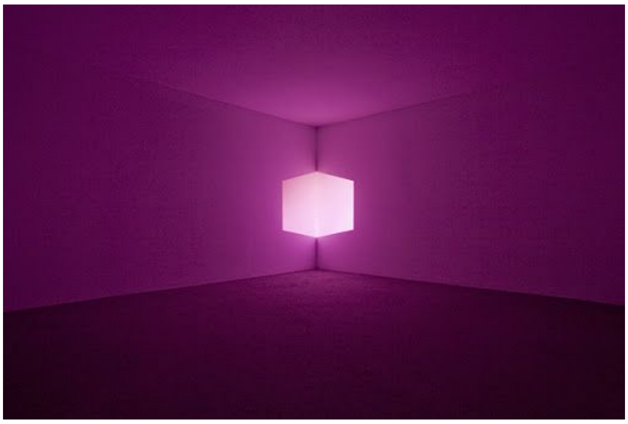

Figure 28. Afrum by James Turrell

In 1969, in the Haunted Mansion of Disneyland there were 6 busts and 16mm recordings of 6 people singing were projected onto them, making it look like they were real people singing, terrorising the spectators. During the decades of the eighties and nineties, the term Virtual Reality (VR) came through, gaining popularity with films such as The Lawnmower Man (1992), a story about a dull gardener whose IQ is raised via VR experiments. Into the nineties, Augmented Reality (AR) also appeared in spectacles such as the one of the Amiens Cathedral in which a recreation of how it was painted in the XIII century gave the building a vivid appearance.

It was done by taking photographic slides of the cathedral's facade and digitally retouching them by removing the shadows and adding color.

Figure 29. Disneyland's haunted Mansion

Figure 30. Amiens Cathedral

One of the most agreed modern influences on video mapping are the video jockeys (VJs). They were most popular between the 1960's and the 1980's. The presenters of MTV that put one music video after another were already called VJs. Music videos experimented their boom in the 60's, with the birth of electronic music along with the underground club and rave scene, in which the band playing disappeared and forced the artists to create a visual experience to offer to the public.

Very often VJing is confused with video mapping. The main difference is the creation of the content. A VJ selects already existing videos and mixes them creatively in real time, which adds complexity to the live performance, while in a video mapping the artist is involved in a more complex process of creating the content. Nowadays, they have both become experimental visual artists that create non conventional narratives by combining music with video.

Video Mapping in the present

The majority of people might associate video mapping to projecting an image on a building's facade, but that is a rather incomplete description to its actual possibilities. It is a technique, a tool to express something. It can also mean projecting over animals, trees, vegetation, bodies, in theater or dance performances, installations or to give experiences such as projecting on high cuisine dishes before eating them. There are many types of mappings nowadays, and they can be classified taking into account three different parameters: its goal, the object and the content.

Goal

Corporate or artistic. Although all mappings have an artistic process to create it, many of them are oriented to promoting a company or a product.

Object

Depending on the object that is being used to project on, a mapping can be classified into the following types.

- Architectonical: historic buildings with suggestive buildings
- Stage: objects shaped in different geometric shapes

Content generation

- On a photography. A video is created on top of a photography done from the location of the projector.
- On a 2D model. The video is created on a vectorial image that represents the surface.
- On a 3D model. The video is created on a 3D representation of the surface.

Glossary

RAM: Random Access Memory.
RAID: Redundant Array of Independent Disks.
VJ: Video Jockey.

DMX512-A: Digital Multiplex 512-A. It is a standard for digital communication networks.

MIDI: Musical Instrument Digital Interface.

DLP: Digital Light Processing.

LCD: Liquid Crystal Display.