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The Church of the Charterhouse of Miraflores in Burgos: Virtual Reconstruction of Artistic Imagery

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This article presents a novel approach to the interpretation of artistic and archaeological heritage, based on the use of current state-of-the-art CAD tools. Firstly, the study defines the collective imagery of an historic-artistic monument. It then goes on to analyze existing virtual reconstruction techniques and selects the most appropriate in order to use virtual recreation in the teaching and dissemination of cultural heritage. CAD tool modelling with extensive use of image textures on low-resolution 3D meshes is demonstrated to be the most appropriate option for these purposes. The methodology is applied to the Church of the Charterhouse of Miraflores in Burgos (Spain). The 3D model will be used for teaching art history through its inclusion in a virtual reality platform.

Keywords: 3D Modelling, Imagery, Cultural Heritage, CAD Tools, Blender

1. Introduction

The development during recent decades of graphic design hardware and software has led to new approaches, being proposed for the interpretation and dissemination of historical and archaeological heritage. The specific context in which this study is situated is the virtual reconstruction of cultural heritage; nowadays a multidisciplinary research field in which historians, archaeologists, 3D designers and educators collaborate with each other.

The aim of this work is to carry out the virtual reconstruction of a historic-artistic monument. However, not as a representation of its appearance today, but as the inhabitants of the city where it is located might imagine it. In other words, the virtual reconstruction seeks to reproduce the characteristics of this monument in correspondence with an artistic imagery or an association of features that convey a particular understanding of the work preserved over time (BODEM, 1988).

The study also analyzes the different 3D modelling techniques that exist, and those techniques based on the optical reconstruction of surfaces, in order to choose the most suitable one for its purposes. The main criteria followed in this reconstruction are: 1) optimization of human resources necessary to carry out the virtual reconstruction, 2) optimization of computing resources necessary to generate real-time rendering and 3) obtaining a virtual reconstruction of sufficient quality for the proposed applications of the 3D model.

This virtual recreation is conceived for two applications. The first one is the teaching of history and art history. The second is the understanding of historic-artistic monuments as living documents that allow us to study the societies responsible for their construction. The use of rendered images is planned for these purposes, as is the integration of the 3D model in the virtual reality platform at the University of Burgos. Geometric accuracy plays a secondary role for these two applications. The main objective in this case is that the viewer clearly understands the main elements of the monument and receives a good visual sensation. High geometrical accuracy in the 3D model is not necessary to achieve a satisfactory visual sensation. Furthermore, the integration of the 3D model into a virtual reality platform that will allow real-time rendering implies limited accuracy.

The chosen historic-artistic monument for the virtual reconstruction is the church of the Charterhouse of Miraflores in Burgos, Spain. There are two reasons for this choice. The first is the importance of this building for the artistic imagery of this city, because of its significance in the history of the kingdom of Castile-Leon. The second is its beauty, the fusion of cultures, and the visual clarity of this monument; which may be used as a benchmark for teaching history of art of Castile-Leon.

The procedural methodology of the study was as follows. Firstly, an interdisciplinary bibliographic review and a photographic study of the Charterhouse of Miraflores were

conducted. Secondly, the collective imagery of the monument was defined. Thirdly, using the defined imagery, its virtual reconstruction was performed using CAD tools and comparing different techniques. Finally, some conclusions were established and future lines of work were identified.

Figure 1: *External image of the Charterhouse.*

Figure 2: *Interior view of the Charterhouse*.

This methodology is replicated in the structure of this article. Section 2 presents the historical contextualization and the main characteristics of the building's artistic imagery. Section 3 describes the virtual reconstruction of the historic-artistic building, comparing the different techniques that are available for the reconstruction and selecting the most suitable one. Section 4 shows the results achieved in the virtual recreation from the point of view of the final applications: teaching and dissemination of heritage. Section 5 contains the conclusions of this work and identifies future lines of work.

2. Historical contextualization of the building and features of the artistic imagery

The Charterhouse of Miraflores is located at a short distance from the city of Burgos. It was built in the late fifteenth century in a culture that, at around the same time, had recently discovered the "New World" and had begun to expand the dominion of the Catholic monarchs throughout much of Latin America. The building belongs to a very significant moment in the history of Western Europe and is characterized by its outstanding artistic quality.

2.1. Historical Aspects

In 1401, King Henry III of Castile and Leon decided to establish a royal hunting lodge near Burgos. He built it on a small hill and enclosed a large plot of land around it (ARIAS DE MIRANDA, 1843).

In 1441, Henry III of Castile was succeeded by John II, who decided to build, under his patronage, a Carthusian monastery on the same spot. In the years that followed, construction of a large church began, in which the king desired to be buried upon his death, surrounded by the prayers of the monks (TARIN and JUANEDA, 1896). King John II of Castile eventually died in 1454 in the city of Valladolid, where he was provisionally buried. However, in fulfilment of his will, the royal corpse was transferred to Burgos in 1455. The city gave him a solemn funeral in the Dominican Convent of St. Paul, from where he was transferred to the monastery "with great pomp on the day of S. John the Baptist ... [and] held in the sacristy until the church was finally built" (FLOREZ, 1772).

During the reign of his son, Henry IV, construction of the church suffered delays due to the historical events that took place in the Kingdom of Castile and Leon. After his death, and once Isabella, his sister, had been crowned, the construction was finally completed at the express desire of the new queen (LISS, 1992), who had ascended to the throne after a fratricidal struggle with her brother's heir, princess Joana. She sought to consolidate herself with her subjects as the rightful successor by underlining her relationship as a dutiful daughter to her father, King John II, acting swiftly to execute his last will and testament (AZCONA, 2002). Thus, she strove to fulfil the old tradition of creating, for political purposes, an image of a ruler whose authority was founded on piety and religious virtue. She therefore appears as a pious daughter who, out of filial love, was moved to fulfil the last wishes of her father (LISS, 2002).

The effort invested by the new queen to build such a complex design is evident in the high artistic quality of its decoration, which involved artists of great prestige, and which once again considerably delayed its completion. In 1524, John II and his wife Isabella of Portugal were laid to rest in the royal tomb that these artists had painstakingly decorated with a host of sculpted works.

The church was completed in 1488. It is a monumental funeral composition that perpetuates the memory of Isabella's parents. The queen was also at pains to ensure that the only references in the work were to the monarchs who were buried there. She therefore, made a clear distinction between their reign over the various Spanish

kingdoms, and her own reign, during which she aspired to unite the Spanish kingdoms (PEREZ, 2002). Over the following centuries, further contributions were added to the church under the care of the Carthusians, mainly for religious rites.

2.2. The creation of the artistic imagery

Historical fact and the exceptional artistic qualities of the Charterhouse of Miraflores result in a mixture of cultures, which define the strong imagery of this building. By imagery, we understand the association of images that transmits an interpretation of our past based on the confluence of politics, art and religion (WILLIAMS, 1980; KOSSLYN, 2000).

The Church of the Charterhouse of Miraflores is considered a magnificent burial mound or funeral ship (LAMPÉREZ *et al*., 1904). The architectural design of the building and its location on the top of a hill enhances this interpretation. The long profile of the church and its high pinnacles in rhythmic succession recall the solemn royal funeral of the king laid to rest amidst a torchlit procession (RICQUOI, 1988).

Such an interpretation is even stronger once inside the church. Thus, the virtual reconstruction focuses on the church´s interior, and includes its most representative elements, such as the royal tomb, stained glass windows, the altarpiece and choir stalls. Other elements have also been incorporated, such as carpets, tapestries and torches, which are documented as characteristic elements of late medieval furnishing (YARZA LUACES, 1993). In contrast, certain modern additions, such as chapels, gates or secondary altarpieces are erased in the virtual recreation. These elements are foreign to the original church and to its interpretation as a funeral ship.

A 3D imaginary tour is planned through the building, walking on comfortable carpets under starry vaults with the emblems of Castile and Leon. This layout is characteristic of the fifteenth century (CHUECA *et al*.,2002) and recalls the heavenly fate that awaited those who inhabited the building. Alongside the walls, the Carthusian monks find the time in their dark stalls to sit in prayer for their deceased monarchs (WETHEY, 1936). As the visitor approaches the altarpiece, its full significance may be understood. The sarcophagus of the kings stands before the visitor, carved on an alabaster eight-pointed star (PORTELA SANDOVAL, 2002). This tomb is the only royal Christian burial configured around the octagonal star, a leading symbol of paradise in the Muslim world. To complete its meaning, the artist developed an iconographic programme at the base of the royal tomb, with a deep Christian significance in relation to the ultimate salvation (PEREDA, 2002).

Finally, the sarcophagus is enhanced by the densely populated altarpiece, symbolic reminiscent of the Muslim *horror vacui*. Its scenes focus on the celebration of the Eucharist andis presided by Christ on the cross; a clear affirmation of his triumph over death (YARZA LUACES, 2001). It is carefully polychromed and overlaid with gold leaf, casting a golden hue over the royal tomb made of white alabaster.

This tour takes place within a multicoloured environment created by the light falling through the stained glass windows brought from Flanders at the express desire of Queen Isabella (DAMME, 2007).

3. Virtual Reconstruction Process

Having defined the artistic imagery of the Charterhouse of Miraflores, we proceeded with its virtual recreation on the basis of two fundamental criteria. The first was the minimization of 3D modelling and rendering time. The second was to obtain a final rendering with sufficient quality for teaching and interpretation of the artistic imagery of the building.

Over the last decade, different approaches to 3D reconstruction of cultural heritage have been proposed. A first approach is a reconstruction that uses high-resolution image acquisition equipment. Related to this approach is the use of high-resolution photo-realistic texture mapping onto 3D models generated from range images (BERALDIN *et al*., 1998; ROUSSOU *et al*., 2003), combinations of near-range photogrammetry and terrestrial laser scanning (ZEHETNER, 2005; BESORA *et al*.,2008, TORRES, 2009) or high-resolution satellite imagery (GRUEN *et al*., 2005). The other approach involves the use of CAD tools (CABRAL *et al*., 2007). There are also some examples of hybrid technologies that combine both approaches (GUIDI *et al*., 2005). In our case, the final applications of the virtual reconstruction do not require high-level detail. In particular a high-degree of detail would make it impossible to visualize the 3D recreation in a Virtual Reality Platform. For these reasons we chose CAD tools and images of mid-high quality for the virtual reconstruction.

A computer with an Intel Core 2 Duo T8100 2.1 GHz processor, 3Gb RAM and a 9300m Nvidia Ge-force graphics card was used for the virtual reconstruction. The digital camera used for the image acquisition of the building was a Canon EOS D40 with a 15-55 mm zoom lens and a digital resolution of 10.1 MP.

The steps followed in the virtual reconstruction were as follows: 1) 3D modelling of the meshes included in the imagery, 2) shading, and 3) lighting definition. During this process three computer programs were used: Photoshop© to retouch photos and create the image textures; Crazy Bump©, to create normal maps for textures and Blender for modelling, animation and rendering. Blender is a 3D modelling and animation software developed as open source software and distributed under GNU GPLicense (www.blender.org).

3.1. 3D Modelling

The artistic imagery of the Charterhouse of Miraflores is composed of the following structural elements: walls,

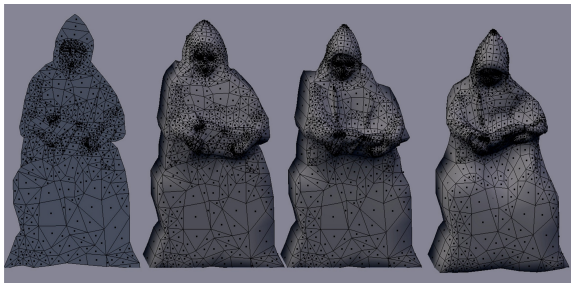


Figure 3: *Sculpt mode 3D CAD Tool for the modelling of complex elements.*

altarpiece, and vaults. In addition to these structural elements, the imagery of this building is comprised of several unique elements, among which is included the royal tomb of John II of Castile and Isabella of Portugal and the altarpiece. The artistic imagery of the building also includes the choir stalls, lecterns and various grilles. Figure 2 shows their arrangement inside the Charterhouse of Miraflores where these elements can be seen today.

Most of the main structural elements of the building have been modelled using well-established 3D CAD techniques.

The 3D modelling of the volume of the building was done from an extrusion of a 2D drawing of the building plant, using the information extracted from photographs for the Z-Axis. Different meshes were then integrated into these walls, such as doors, stained glass windows and the rose window, all of which were also completed by extrusion from simple polygons.

The ribbed vaults were recreated by extrusion along a Bezier curve (*Extrude along path*). Only a quarter of the vault was modelled and the rest was completed using the symmetry operator. The crowns of the vaults were not modelled. The recreation technique used for these elements is described in Section 4.2.

The choir stalls were modelled by extruding their 2D lateral view created using Bezier curves. Revolution operators -*spin* and *spindup*- were used for the grids and the lectern. The modelling of the drapery covering the choir stalls was made from a simple plane. The density of the plane mesh was increased using the *subdivide* operator and then local deformations were applied by hand to different mesh faces with the *proportional* operator activated. In this way, the 3D sensation of the plane mesh is achieved.

However, standard 3D CAD Techniques were not considered appropriate for modelling highly complex elements such as the royal tomb or the altarpiece. A specific 3-step technique was therefore defined for these elements: 1) generation of a single geometric element, 2) application of an *Image Texture* to this element, and 3) modification by hand of the geometric element mesh using *sculpt mode* to adapt it to the *Image Texture*. Figure 3 shows the use of *sculpt mode* for the modelling of a Carthusian prayer sculpture included at the base of the sarcophagus of John II and Isabella of Portugal. This 3-step technique provides a medium quality result with a very limited number of polygons. It also drastically reduces the time required for the realization of complex meshes.

1 2 3

Figure 4: *Carthusian prayer group included in the basement of the Royal Tomb of Juan II. Comparison of mesh generating systems: original sculpture (1), mesh generated with the technique described above (2) and mesh obtained with digital scanning (3).*

Figure 4 shows a comparison of the mesh generated by this technique and produced by 3D laser scanning, using a laser scanner Minolta Vivid 910 for a small sculpture of praying Carthusians that form part of the lower surround of the royal tomb. This scan is not part of this project and is only included here as a standard for comparison. Table 1 shows the total number of polygons in both meshes.

Accurate model with procedural texture	**Model 3D scanning**
44,427 polygons	4,000,000 polygons

Table 1: *Comparison of number of polygons using the proposed CAD technique and 3D Laser Scanning*

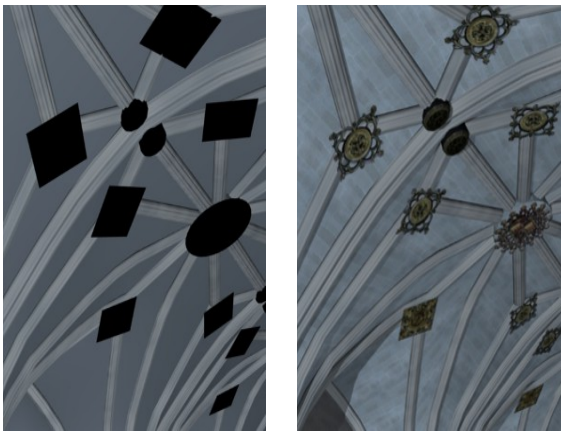
It may be concluded that the CAD Technique gene-rates a 3D model with a small number of polygons. This allows real-time rendering in Virtual Reality platforms. It also creates sufficient visual quality for the applications already presented in Section 1.

3.2. Shading

Three different techniques were used for shading. The first is used for large homogeneous surfaces, the second for complex and unique 3D surfaces, and the third for secondary complex surfaces.

For large surfaces, such as the stone surfaces of walls and vaults, shading is defined using three layers and extensive use of procedural textures. The first layer defines the general diffuse and specular surface colour. The second layer generates colour irregularities using a procedural texture or a low-quality image. The third layer produces irregularities in the surface using a procedural texture for Normal Mapping.

The second technique has been applied to complex elements that need high realism, such as the sarcophagus and the altarpiece. In this case, a first *image texture* is applied. This texture reproduces an image of the object with medium resolution and provides the mesh with its colours. Then the same *image texture* is applied as



1 2

Figure 5: *Shields without image texture (1) and shields with image textures with alpha channels (2).*

greyscale for Normal Mapping. This texture improves the three-dimensionality of the object. Both textures are adapted to the mesh using UV Mapping. Texture quality differs depending on the role of the element to which it belongs. For example, high-quality image textures are required for the stained glass. However, in others, such as the royal tomb, the quality is not high. This is because these elements play a very different role in communicating and understanding the artistic imagery of the Church of the Charterhouse of Miraflores. This same principle has been used in previous studies by other authors (BESORA *et al*., 2008; TORRES *et al*., 2009).

The third technique was applied to objects that require medium level detail because their 3D modelling is not essential, such as the shields in the vaults. These objects were not modelled. A plane replaced their meshes to which an image texture was applied, which is a real image of the object to be built. In this real image a transparency or alpha channel was added which defines the highly complex shape of the object. Figure 5 shows an example of this technique and its application to the shields in the vaults. It reduces both modelling time and rendering time, and gives a medium visual quality, which is sufficient for these secondary elements.

There are elements of the building where it is possible to apply the first two techniques described above: procedural and image texturing. A comparison of visual quality, texturing and rendering time was conducted for both techniques in relation to these elements. Figures 6-7 and Table 2 show this study for the case of the ribbed vaults. From these figures, it may be concluded that applying procedural textures implies a significantly lower application time (around 40%) and a slightly shorter rendering time (around 12%), but it also reduces the visual quality of the rendering, Figure 6.

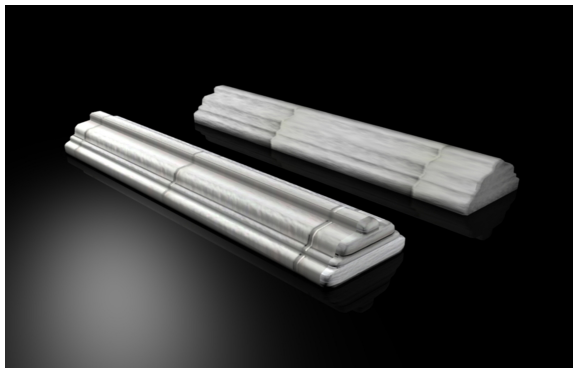


Figure 6: *Texture of the ribs in the vaults: image texture (left) and procedural texture (right).*

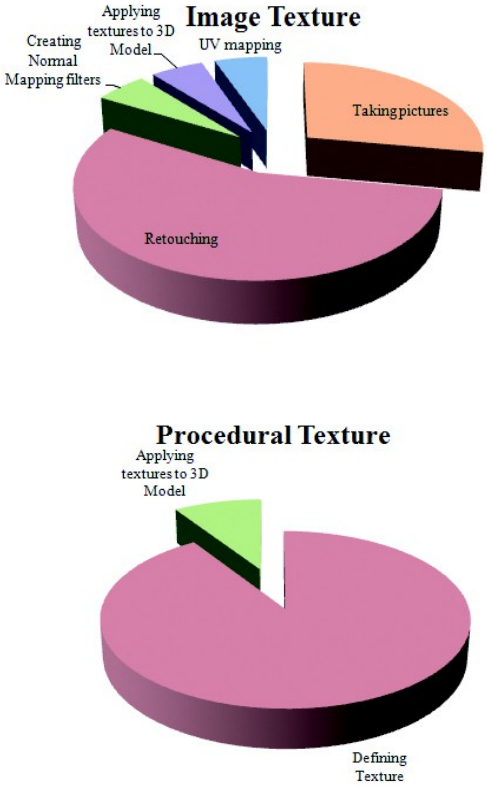


Figure 7: *Comparison of application time of procedural and image texture to the ribbed vaults.*

Rendering time	
Procedural texture	**Image texture**
29 seconds	33 seconds

Table 2: *Comparison of rendering time for the ribbed vaults using two shading techniques*

It is also important to note that the use of image texturing requires specific knowledge of image processing and its application to complex 3D models, mainly by UV mapping. Procedural texturing is faster and can be applied directly by Blender with almost no human interaction. On the other hand, UV mapping is a technique that provides good control of the application of textures to difficult and complex parts of the mesh, thus providing a better final result although it is quite time-consuming.

Thus, for secondary elements with medium mesh complexity, such as the ribbed vaults, the application of procedural textures was selected. However, for more unique and highly complex objects, image texturing was chosen as the best option because of its higher final rendering quality.

3.3. Lighting

Lighting is one of the key steps in the virtual reconstruction of a building. It plays an essential role in highlighting each element and their interrelation in an artistic monument. In our case, lighting has been defined with two types of light. On the one hand, torches are placed around the Royal Tomb. On the other, coloured light simulates the daylight entering through the church windows.

The torches were created using a *lamp* light with a procedural texture that emulates fire. The intensity of these lamps is set relatively low. This way, an atmosphere of quiet meditation around the Royal Tomb is created in this way, as the light from the windows barely reaches this area of the church.

To recreate the light coming through the stained glass, *area* lights were allocated beside each window. The orientation of these lights was changed during animations to simulate changes in daylight from mid-morning through to sunset. An *image texture* was applied to these lights to reproduce the light of the stained glass. Thus, these lights are projected onto the opposite wall, creating a multicoloured effect (Figure 8). In addition, a *halo* effect of low intensity was applied. This effect is intended to enhance the sense of quiet meditation in the imaginary church.

4. Results

Once the lighting step was ready, different renderings were calculated for each main view of the church. This section contains some of these renderings. Each one is an attempt to show some of the fundamental values of the artistic imagery of the building that should be transmitted to students and the public.

Figure 8: *Projection of the daylight from the windows on the opposite wall.*

Figure 9 shows a central view of the nave of the church as a "burial ship". The colourful lighting provided by the Flemish stained glass can be observed on the higher parts of the walls. The vaults are also strongly illuminated by the windows, although the choir stalls, at ground level, remain darker. The interplay of light –up- and shadow –down- may be perceived, reflecting the two steps of life for Christians: dark life and the light of salvation after death. The rendering is in harmony with the daylight in the morning.

Figure 9:*Recreation of the Church of the Charterhouse of Miraflores. Central view.*

Figure 10 shows a side view of the Royal Tomb with night lighting. This rendering shows the recreation of torches, the play of light and shadow cast by the torches, the reflection from the golden altarpiece and the quiet meditative spirit that is generated.

Figure 11 shows an aerial view of the Royal Tomb at late afternoon. This rendering illustrates the fusion of cultures for the students found in this church: an altarpiece that symbolizes the *horror vacui* in Muslim art and the Christian tradition of salvation, and the Christian Royal Tomb on the 8-pointed star that symbolizes paradise in the Muslim world. The strong diffused reflection of the alabaster stone of the sarcophagus highlights the tomb against its limestone pedestal base.

To conclude this work, a study of time allocation for the completion of this virtual recreation was conducted. The whole virtual recreation described in Section 4 took 300 hours of work. Figure 12 shows the distribution of this effort among the different activities. From this figure, it may be concluded that the selected CAD tools require intense image pre-processing, which proves very time-consuming.

Figure 10: *Virtual recreation of the altarpiece and Royal Tomb of the church of the Charterhouse of Miraflores.*

Figure 11:*Virtual recreation of the tomb of Isabella of Portugal and John II. Aerial view.*

Conclusions

This article has presented an approach to the interpretation of artistic and archaeological heritage, and in particular the artistic imagery of a late medieval royal tomb in Castile-Leon, Spain.

The work shows that current state-of-the-art graphic design technologies can generate a virtual recreation of archaeological or historic-artistic monuments that are useful for the teaching, dissemination and interpretation of cultural heritage. A modelling methodology based on simplified 3D models and a multilayer texture application has been described that allows a real-time virtual recreation of the selected monument. The virtual recreation obtained in this way can be easily integrated in Virtual Reality Platforms. The image texture preparation is one of the core elements of this methodology and is also a highly time-consuming activity. The methodology has been applied to the Church of the Charterhouse of Miraflores in Burgos, Spain for the use of the 3D model in the teaching of Art History. A visit to the real church followed by a virtual visit to the 3D recreation is planned for student immersion programmes, followed by a final discussion of both visits.

Further research will be conducted on the integration of the model into the Virtual Reality Platform at the University of Burgos, and the integration of interactive multimedia content in the virtual tour depending on the visitor's location. Also, the use of 3D optical scanning equipment could be tested on some unique and complex elements to obtain high quality meshes of them and, therefore, to broaden the final applications of the virtual recreation.

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Figure 12: *Time distribution of the virtual recreation of the Church of the Charterhouse of Miraflores.*

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