







# INTERACTIVE VIRTUAL REPRESENTATION OF THE DISAPPEARED CONVENT OF EL CARMEN (LOGROÑO) GENERATED FROM A PAPER CRAFT MODEL

## REPRESENTACIÓN VIRTUAL INTERACTIVA DEL DESAPARECIDO CONVENTO DEL CARMEN (LOGROÑO) GENERADA A PARTIR DE UNA MAQUETA DE PAPEL

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### Highlights:

- A significant part of the architectural heritage is represented by mock-ups of different materials (paper, wood, metal and so on).
- Virtual modelling and augmented reality (AR) can be appropriate tools for materializing, recovering and disseminating scale models to the public.
- Techniques for geometric documentation and visual representation need to be adapted in order to tackle the peculiar features of these elements (size, materials, fragility, etc.).

### Abstract:

The concept of mock-up, which share with the drawing the expressive synthesis for the analysis of the architectural form and evolution, is an invaluable asset for the preservation of the heritage. To mark the 175<sup>th</sup> anniversary of the Práxedes Mateo Sagasta's secondary school of Logroño (Spain), an exhibition about the history of the institution was organized at the premises of La Rioja Library. The current school building became operational in 1900 and was built on the former site of a Carmelite convent. In fact, the convent rooms were the first location for the school, after the expropriations of religious communities during the mid-19<sup>th</sup> century. For the benefit of the aforementioned exhibition, it was considered interesting to generate a three-dimensional (3D) virtual reconstruction of the convent buildings to show how it would have looked. However, the lack of sufficient contemporary graphic information was a challenge, so it was decided that an efficient solution would be to generate the virtual reconstruction from a paper craft model, which had been created by the librarian of the secondary school as a result of his research on this matter. This text describes the 3D modelling of that cut-out element by means of monoscopic photogrammetry (perspective drawing) and the use of non-realistic rendering based on the appearance of the paper mock-up (and not trying to recreate the real image of the buildings) so as to provide a suggestive view of the convent and create interactive exhibition items. Moreover, the text deals with the long-term preservation and the improvement of the re-use of the 3D models. The former by resorting to institutional repositories —from which users can download the full detailed versions— and the latter employing versions able to be visualized in 3D warehouses (such as Sketchfab) and augmented reality (AR) applications.

**Keywords:** paper mock-up; perspective rectification; non-realistic rendering; photogrammetry; virtual reconstruction; augmented reality (AR)

### Resumen:

La maqueta, que comparte con el dibujo la síntesis expresiva para el análisis de la forma y evolución arquitectónica, resulta de un valor incalculable para la preservación del patrimonio. Con motivo del 175 aniversario del Instituto de Enseñanza Secundaria Práxedes Mateo Sagasta de Logroño (España) se organizó una exposición sobre su historia en la Biblioteca de La Rioja. El edificio, que actualmente acoge el instituto, fue inaugurado en el año 1900 y se construyó sobre el mismo terreno en el que, previamente, había estado un convento de Carmelitas. De hecho, la primera sede del instituto estuvo situada en las dependencias de este mismo convento, tras la desamortización de los edificios eclesíasticos que tuvo lugar a mediados del siglo XIX. Como parte de la muestra, se consideró interesante generar una reconstrucción virtual tridimensional (3D) de los edificios del convento con el fin de mostrar cómo debieron haber sido. La dificultad, sin embargo, residía en la escasez de fuentes gráficas de la época que permitieran conocer su forma y apariencia; por este motivo, se decidió utilizar como base para la recreación virtual una maqueta en papel que había sido realizada por el bibliotecario del instituto como resultado de sus investigaciones a lo largo de los años. El presente texto describe el proceso de modelado 3D a partir de esta maqueta de papel utilizando técnicas de fotogrametría monoscópica (dibujo perspectivo) y el empleo de renderizados no realistas basados en el aspecto de la maqueta de

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papel (y no en el que debieron tener los edificios) con el fin de generar vistas evocadoras del convento y crear contenidos útiles para la mencionada exposición. Asimismo, el texto trata la preservación a largo plazo de los modelos 3D y el incremento de su reutilización. En el primer caso, mediante el empleo de los repositorios institucionales —desde donde los usuarios pueden descargarse las versiones más detalladas— y, para el segundo fin, mediante la creación de versiones para su uso a través de almacenes de modelos 3D (como Sketchfab) y aplicaciones de realidad aumentada (RA).

**Palabras clave:** maqueta de papel; rectificación perspectiva; renderizado no realista; fotogrametría; reconstrucción virtual; realidad aumentada (RA)

## 1. Introduction

Práxedes Mateo Sagasta's secondary school celebrated its 175<sup>th</sup> anniversary in 2018. Because of that, an exhibition about the history of the institution was presented in La Rioja Library during that year's months of April and May.

The school building that is nowadays in use opened in the year 1900. It was erected on the location where a former convent or Carmelites was situated and the existing rooms of the convent were the first premises of the school during the second half of the 19<sup>th</sup> century, until its demolition in 1895.

In order to give the visitors an image of how the aspect of the convent would have appeared, to generate a three-dimensional (3D) virtual model was planned, from which multiple views, movies and other interactive products could be obtained. The first difficulty encountered was that the contemporary graphic information about the convent (photographs, drawings...) was scant. For that reason, it was decided to take as a reference a paper craft model created by the librarian of the school (Mr. Fernando R. Blanco), as a result of his research on this matter for over 25 years.

This paper explains the methodology used for the generation of this virtual model, the features of the result, the use during the exhibition and its potential re-use in the future.

Within this particular case study, the article gives a brief look at the history of building miniatures and their interest in the study of construction engineering. Moreover, the relevance of these pieces as part of our heritage is emphasised and, consequently, the importance of knowing and documenting them is noted. Furthermore, the choice of techniques for the geometric documentation of scale models is marked by many specific features such as the size and fragility of the pieces, the visibility of the different parts, the limitations for handling or touching each component, as it was pointed out in the description of the documentation works of the Langweil's model of Prague (Buriánek, 2011); therefore, this kind of projects are well suited to explore the selection and quantification of variables for the design and development of geometric documentation works.

## 2. Description of the problem

When it came to deciding how to generate the virtual model of the convent, several issues concerning different aspects arose: from the choice of the most suitable techniques for the geometric documentation of this element (taking into account its size, materials, etc.) up to the degree of closeness that was desired between the mock-up and the virtual model, or the way to present the resulting 3D model in an evocative environment.

The cut-out paper model of the convent of Carmelites is a small element, no bigger than 50 x 30 x 20 cm, its different parts can be mounted and disassembled, the approximate scale is 1:200 and remains unfinished in one of the corners (Figure 1). This small piece of craftsmanship is the result of several years of meticulous research about the history of the institution in scattered textual and graphic sources; additionally, it possesses an undeniable attractiveness for the public, which is why it became one of the main pieces of the exhibition, together with a rich set of informative panels showing the development of the school through the decades, old scholar artefacts (ancient school books and materials, students' cards...) and some of the most relevant books of the library (which contains works from the 16<sup>th</sup> century to the present time).



**Figure 1:** Miniature in paper showing the hypothetical appearance of the convent by the middle of the 19<sup>th</sup> century.

As regards the 3D recording of the mock-up, several topics should be mentioned:

- To begin with, the size of the element will require close-range techniques (photographs or scanning devices).
- Secondly, the surfaces are problematic because of the material used (paper). Indeed, only a limited number of volumes can be easily created with this material, mostly, prismatic ones; on the other hand, the paper is not rigid but forms warped surfaces.
- Finally, the textures on this mock-up are too poor for the common image-based algorithms (e.g. Structure from Motion) that are used by the software for 3D reconstruction.

Considering all these circumstances, for the 3D reconstruction, it was decided to make use of techniques of monoscopic photogrammetry and exploit the possibilities based on the perspective analysis.

Besides this, it must also be considered that, in general, a virtual representation is part of an account about a piece of history, so it needs more than just the

3D geometry of the object. An adequate environment, the possibility of interaction or a complete explanation of what the user is seeing are also essential parts of the final product.

### 3. State of the art

There is a huge variety of scale models (nativity scenes, dioramas, military miniatures, airplane/railway/ship models, etc.) for multiple purposes: worshipping, exhibition, gaming, entertainment and so on. Amongst all these, the focus of this paper will be on building models, especially, the ones aimed at architectural and historical studies.

Many ancient civilizations created building scale models: there are huts from Central Europe and sanctuaries from the Balkans which go back up to 8000 years ago, as well as examples from Mesopotamia, Egypt, Minoan, Greek and Roman civilizations. In the Americas, Aztecs, Maya and Incas produced scaled representations as they did in ancient China, Japan and Korea (Azara & Esparza, 2006; Herrero, 2014).

Scale models made of different kinds of materials—such as cardboard, wood or plastic—have been used from ancient times as tools for projecting buildings and structures in 3D, guiding the construction process and for the reconstruction of hypothetical appearances of disappeared constructions, cities, etc.

Many mock-ups have been lost over the years, sometimes because they were created for short-lived purposes, built with more or less flimsy materials or due to disasters. Nevertheless, some other models have survived, they are several decades and even centuries old and consequently, have become elements of heritage by their antiquity; in other cases, their interest is due to the craftsmanship, the aesthetic quality, the documentary value, the author or because of the image/building that they represent. Of course, many examples combine several of the said qualities and have come to be considered as reference items in numerous museums and exhibitions.

The use of scale models for the illustration of proposals and technical guides for the construction of buildings has relevant examples from the Italian Renaissance and has become commonplace until present times (Quirós, 1994; Vela, 2014). Constructing mock-ups not only complements drawings and plans, but it also provides very expressive objects that have always fascinated the public (Rodríguez, 2010; de la Torre, 2014). Apart from single buildings or specific parts of these, from the 16<sup>th</sup> century and during all the Modern Era, many European states developed collections of plans in relief of complete walled cities in order to study the performance of their defences and take decisions regarding military strategy (Granado, Barrera, & Aguilar-Camacho, 2016).

Moving to the geometric recording and 3D modelling of scale models, it can be said that there are two different kinds of projects of virtual modelling according to the purpose. Sometimes (e.g. Smutný, Prášek, Pajdla, & Palatka, 2007), the objective is creating a virtual replica of the object that can be used for the conservation of the mock-up itself as a heritage item, in such a case, the result has to be a close image of the scale model as it is, even if the image that it represents is deemed incorrect at present. In other cases (e.g. Lecocq, 2004; Hervy,

Billen, Laroche, Carré, Servières, Van Ruymbeke, Tourre, Delfosse, & Kerouanton, 2012; Demetrescu, Ferdani, Dell'Unto, Touatti, & Lindgren, 2016), however, the scale model is just another source for a virtual reconstruction of a place in a particular moment and, consequently, changes in the virtual version will be allowed, as well as the addition of new elements such as human characters, atmospheric effects and so on.

The techniques generally used for the 3D documentation of the models are close-range photogrammetry (Sedlacek, Burianek, & Zara, 2013; Chevrier, 2015), laser or structured light scanning (Guidi, Frischer, De Simone, Cioci, Spinetti, Carosso, Micoli, Russo, & Grasso, 2005; Zhu, Ma, Mu, & Shi, 2009; Kersten, Keller, Saenger, & Schiewe, 2012) or a combination of both (Chevrier, Jacquot, & Perrin, 2010), often with the help of additional documentary sources in order to fill gaps in knowledge and complete missing parts.

It must be said that, in the present days, the relationship between virtual models and mock-ups goes mostly in the opposite direction, that is to say, thanks to the development of the 3D printing and additive manufacturing technologies, the commonest situation is to start modelling in the virtual space and then prototyping the physical models (Grellert, 2016).

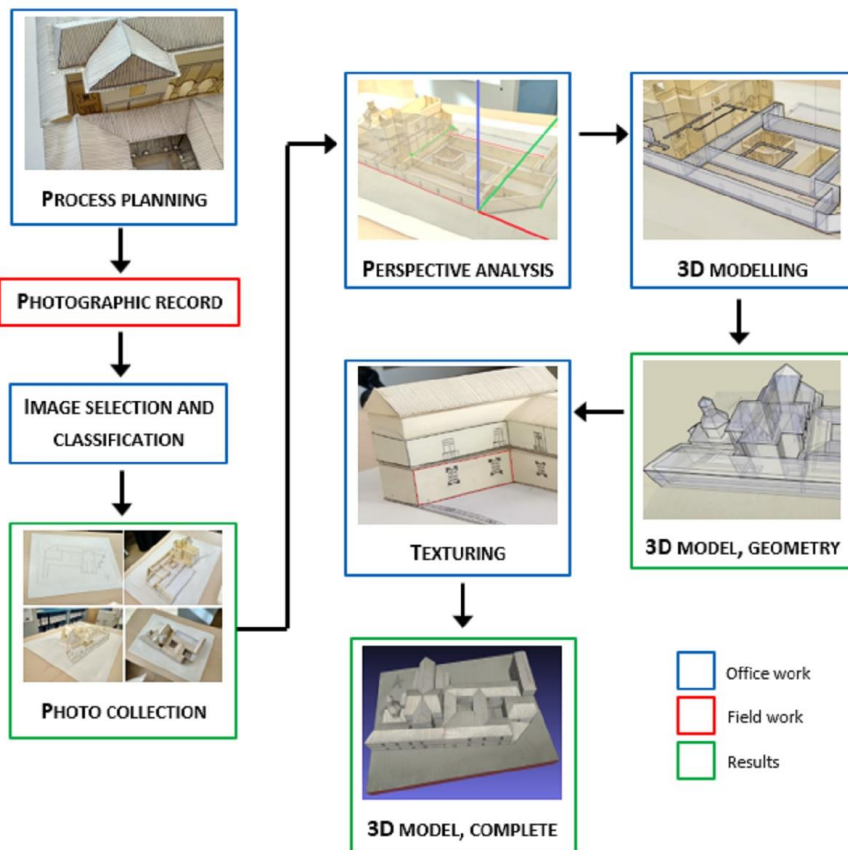
Summing up, scale models are pieces of the cultural heritage that can be profitably used for research and outreach activities, both directly or through virtual versions. In the latter case, several options for the geometric documentation and virtual modelling are available, from which the most suitable ones according to the characteristics of the model and purpose of the products can be used.

### 4. Methodology

In the case of the aforesaid paper model, we resorted to two techniques that are suitable for virtual modelling from scarce sources. Especially, the 3D geometry was reconstructed from perspective analysis using individual photographs, (in particular, using the software *SketchUp®*) and, whilst additionally, textures were extracted monoscopically by means of individual orientation and rectification of each façade (Rodríguez & Valle, 2017). The workflow is summarized in Figure 2.

The base material for this kind of modelling is a complete collection of photographs from different points of view. Contrarily to the pictures taken for structure from motion algorithms where multiple overlapping and convergence of the views are main features to obtain, modelling through perspective relies on monoscopic views showing clear sets of perpendicular directions which converge to well-defined vanishing points. Modelling is based on parallelism and perpendicularity, therefore, this technique is particularly suitable for prismatic volumes (Williamson & Brill, 1990).

In our case, we started with a set of photographs all around the mock-up with only the first floor of the scale model assembled, then, the second floor was mounted and further photographs were there taken. Subsequently the roofs were placed and, finally, another set of photographs was taken. Pictures were taken with a mobile phone (*Xiaomi Redmi 4*, 13 megapixels and focal length of 3.7 mm) within around two hours. Figure 3 shows several steps in the modelling process. The virtual model is always the same but the pictures



**Figure 2:** Workflow for the virtual modelling of the mock-up.

in the background are changed all the time in order to have good views of the different parts of the mock-up. Once a particular photograph has been selected, it is properly located with reference to the virtual model by adjusting the vanishing points and matching the parts already modelled, then the virtual model could be completed with parts that are visible in that photograph. In this particular case, each floor required between four to six different points of view for a complete definition; therefore, a selection of 15 pictures was employed for the whole mock-up.

Albeit the metric exploitation of this model is not a priority issue, it must be worthwhile to say a few words about its geometric accuracy. Firstly, the perspective analysis considers that the image is as a perfect perspective, of which the graphic method computes the values of the different parameters (among them the focal length). This assumption is not strictly true with photographs unless they are previously “idealized” (i.e., lens distortion is removed beforehand); nevertheless, in this case, it was considered that this correction did not add much in terms of accuracy.

- On the one hand, because photographs are used as background references over which the model is generated. The drawing method that is used for 3D modelling forces the lines to remain straight, as well as the preservation of parallelism, same heights, definite distances and so on. These geometric constraints prevail over the position on the picture; therefore, the geometric influence of small displacements of the pixel positions (such as the ones originated by lens distortion) are somehow mitigated.

- On the other hand, the biggest problems with the position where the boundaries of the surfaces appear on the photographs are not due to lens distortion but to the fact that paper surfaces are warped, as well as to the misalignment of the different blocks that compose the mock-up. We were not interested in portraying these deformations in the virtual model; therefore, the modeler had some leeway in selecting the positions on the pictures (e.g. the pixel which defines the corner of a wall) so as to maintain the geometric constraints mentioned above.

Summing up, in this case, the most important factor regarding the geometry of the virtual model is not the accuracy but the coherence. For instance, it is not a serious problem if the height of a wall is measured with an error of a few millimetres; on the contrary, it would be unacceptable that this wall was not fully vertical.

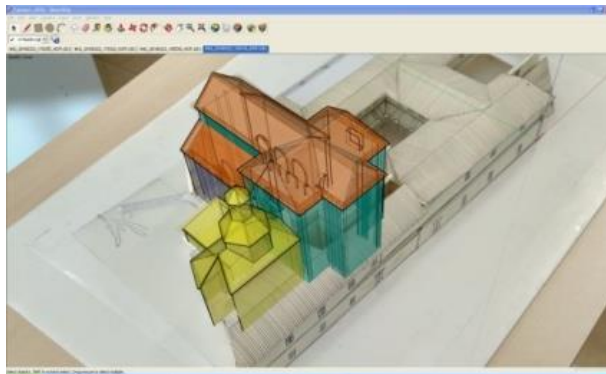
A justification for this course of action lies in the fact that the dimensions of the mock-up are only approximate (the real size of the disappeared buildings is unknown). Consequently, small changes do not significantly modify the image that is intended to convey with the model.

At any rate, the degree of closeness between the original element and the digital version is a subject of continuous concern. Fortunately, during the process of virtual modelling, we had the chance to discuss the validity of the virtual replica with the creator of the mock-up and check with him different alternatives until a satisfying result was obtained.

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(a)



(b)



(c)

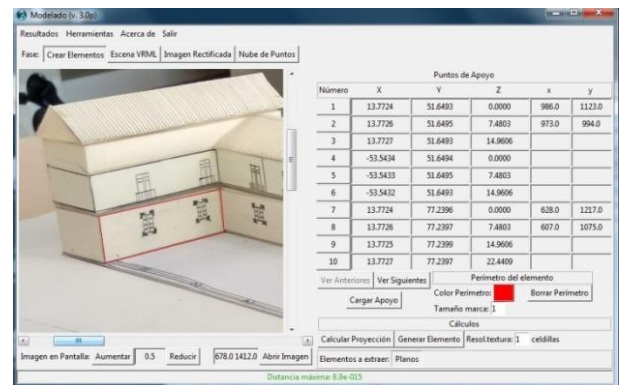


(d)

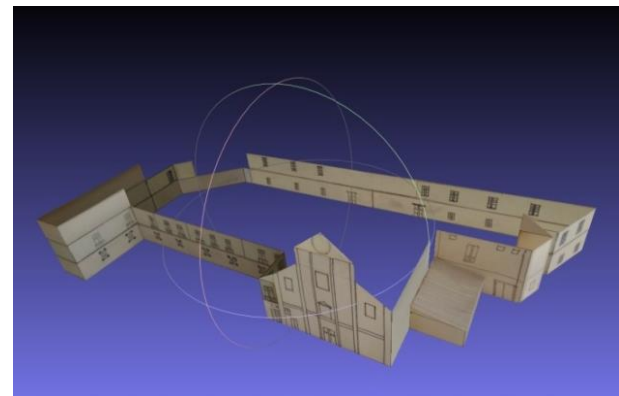
**Figure 3:** Three views of the 3D model during the modelling process -(a), (b), (c)- and complete model (d).

Concerning the visual appearance of the model, it was decided to wrap the surfaces with the textures of the paper model. On this occasion, we also worked monoscopically, extracting the different parts of the textures from individual photographs with software developed in our laboratory (Figure 4). The software

receives a list of 3D coordinates of the different corners and definitory points of the virtual model and, besides, shows a picture over which the user can draw boundaries and identify 3D coordinates with pixels of the image. For the extraction of the textures the user draws a boundary on the picture defined with four points that, in the virtual model, are coplanar and assigns 3D coordinates to each corner, then the software generates a 3D entity with the geometry—the portion of a plane defined by the points—and the texture from the photograph (corrected by means of a perspective projection).



(a)



(b)

**Figure 4:** (a) Screenshot of the software used for extracting and rectifying the textures from photographs; and (b) partial view of the texturized model.

Orthorectification through the perspective transformation is a classical method used in photogrammetry, which is especially suitable for flat surfaces. Moreover, it works without previous knowledge about the camera parameters (in particular the focal length and the position of the principal point), that is why it has been largely used both with metric and non-metric cameras, including the ones for mobile phones. This technique proved to be very successful for architectural documentation from the seventies with analogue photogrammetry (Georgopoulos, 2019) and gained new impetus with the development of digital photography at the beginning of the 2000s (Grussenmeyer, Hanke, & Streilein, 2002). Nowadays, however, it is clearly surpassed by other digital techniques (such as the aforementioned structure from motion), which are far more flexible concerning the geometry of the surface to be documented, availability of photographs or the workflow fully automated. Although this does not imply that orthorectification has no further use; on the contrary,

there are many current examples (e.g. Soycan & Soycan, 2019), especially when—as in the case of the mock-up—the structure from motion algorithms fail to provide good results.

Besides that, when selecting a part of one photograph to obtain the texture of a wall, the perspective transformation is particularly useful for controlling which directions will coincide with the vertical and the horizontal lines. This feature prevents misrepresentations such as skewed windows or doors; therefore, the position and the size of the elements in the textures may vary slightly but their appearance will be always correct. Considering that the original purpose of the 3D model was to be part of a video, the visual features took precedence over the metric ones; thus, this methodology was considered adequate.

Likewise with this idea of producing a visually appealing model, the individual textures of each wall and roof (120 elements) were equalized by matching the means and the standard deviations of the three chromatic channels (red, green, blue) with a reference texture (Rodríguez, Valle, & Lopetegi, 2007).

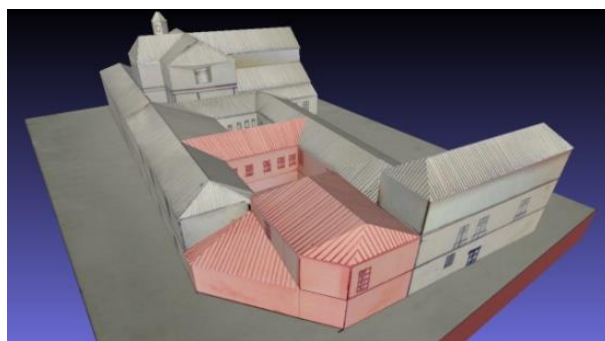
As to the matter of whether the 3D model is a faithful copy of the mock-up or, on the contrary, the mock-up is used just as a source of information that can be used, ignored or modified during the 3D modelling process, it must be said that, in this case, the model aims to be as close a representation as possible to the physical model, both as far as the geometry is concerned and regarding the visual appearance (textures). Nevertheless, some changes were deemed necessary, in particular:

- The original walls (in paper) are not rigid and so remain bent, in addition, the mock-up is composed of several blocks that can be slightly misaligned once mounted. For the virtual model, that was considered unnatural; therefore, in the virtual model, the geometry of the walls, roofs and so forth consists of perfectly straight lines and planes.
- As mentioned earlier, the paper model is unfinished, there is a small missing part. In order to provide a full view of the building, this section was completed virtually (see below about the method of showing the level of certainty regarding the image shown of the different parts of the model).
- Finally, we have modified some of the roofs in order to give a coherent drainage system (Figure 5).



**Figure 5:** During the modelling, some of the solutions for the roofs of the mock-up were considered unrealistic and, hence, it was decided to modify them.

As stated before, the necessity to show complete models creates the challenge of depicting the different levels of likelihood of each part of the reconstructed scene (Favre-Brun, 2015; Apollonio, 2016; Gellert & Haas, 2016; Statham, 2019). There are many options for this: on the one hand, resorting to textual documentation, either that which can be displayed over the model—something that is becoming increasingly easier now that the systems for including annotations on 3D models or the generation of models connected to databases are more common—or the one accessible in attached documents (such as the report of the intervention work); on the other hand, visual resources such as changes in colour, thickness, transparency, level of detail of the geometries, the overlay with the remaining parts of the building, etc. can be also employed (Figure 6).



**Figure 6:** Likelihood of the model shown by means of changes in the tone of the textures. In particular, areas in pink depict the rooms under study, the arrangement of which is still uncertain.

Differences in the level of likelihood corresponding to each part of the buildings do not invalidate the model, neither necessarily imply lack of information nor are they impediments for new researches. On the contrary, this information can be used for identifying the areas that require further efforts in collecting sources or contrasting hypotheses (Lengyel & Toulouse, 2016).

## 5. Results

The model with textures taken from the paper is an example of non-photorealistic rendering (NPR). As such, it is very suitable for being used in expressive and unconventional environments such as over a contemporary city map. In this case, the Coello's plan of the city<sup>1</sup> (issued in 1851) was used as the base to show the virtual model. As can be seen (Figure 7), the virtual model and the city map work very well together visually and, apart from an engaging aesthetic, provide the opportunity of seeing the building in the urban context, i.e. its relationships with the city wall, the squares, streets and so on.

In order to obtain an approximate scale and placement of the result, Coello's plan was georeferenced to the current map using several common points (churches, remains of the city walls, bridges...). As for the precision of this procedure: Coello's plan has a nominal scale of 1:10000, at best, it cannot be expected to obtain

<sup>1</sup> Obtained from the digital catalogue of maps of the Instituto Geográfico Nacional: <https://www.ign.es/web/catalogo-cartoteca/resources/html/001713.html> [access: July 2020].

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(a)



(b)

**Figure 7:** (a) The city of Logroño around the middle of the 19<sup>th</sup> century (Coello's plan) ; and (b) interactive visualization of the model of the convent over (a).

coordinates with a precision better than 0.02% (i.e. 2 m); however, bearing in mind that the picture used was a digitized copy of a printed old map it might be advisable to consider that the errors can easily be twice that value. For the scale of the 3D model, a base distance of the building floor on the map was used, considering the joint errors at both endpoints (say around 5.6 m) and that the longer distance of the building floor that can be selected to adjust the scale is around 112 m long<sup>2</sup>, an estimation

of the error regarding the distances measured on the model is around 5%.

Keep in mind that this bound of error only relates to the change of scale from the mock-up to the real size of the buildings, it does not apply to the faithfulness of the mock-up to the appearance and size of the convent (which will depend on the availability and proper interpretation of the historic sources).

<sup>2</sup> According to the floor plan, the building was approximately 100 m long from east to west and 50 m south to north. Applying

this scale to the 3D model, the maximum height above ground of the roofs was around 25 m.

After the exhibition, the mock-up returned to the library of the secondary school, but the virtual model was deposited in the university repository from which it can be freely downloaded and reused (Figure 8), which provides continuity to the exhibition and visibility to the research carried out about the convent.



**Figure 8:** Record of the project in the university repository from where the 3D model can be downloaded, together with the report of the work, some photographs, an application of augmented reality and a video (<http://hdl.handle.net/10810/41133>).

Institutional repositories are databases open to the public that ensure the preservation of the information over time. Besides, they are well prepared to be easily accessed by the users because they are indexed by many scientific and cultural aggregators. Likewise, the information is described in detail by means of a wide-ranging set of metadata (both in English and Spanish).

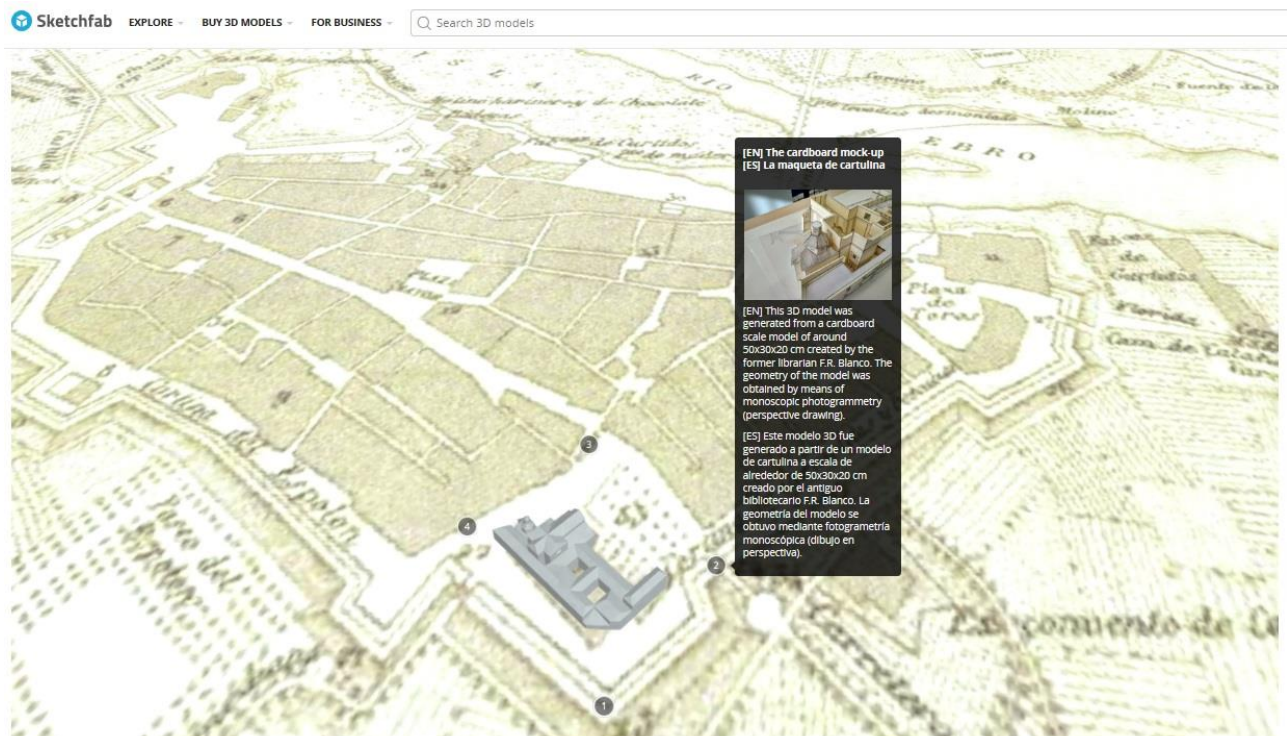
For the particular case of the convent, apart from the 3D model in a standard file format (PLY) packed with all the textures, the record includes the report with a complete explanation of the context and the works carried out for the generation of the virtual model, a set of descriptive photographs, an application of augmented reality (that will be explained below) and a short video (four and a half minutes) presenting the mock-up and the virtual modelling. All the data is provided under a Creative Commons (cc-by) licence; therefore, it can be freely downloaded and re-used.

To increase the outreach and re-use of the 3D model, two additional results were generated: firstly, a model to be visualized in Sketchfab® and, secondly, an application of augmented reality (AR).

Previously to the obtention of these new results, the model was further processed in Blender® since direct import from the original 3D model was not possible. On the other hand, for the AR, the original 3D geometry consisting of surfaces was transformed into solid volumes.

Let us see some specific features of these two means of exploring the 3D model:

- Sketcthab® provides an attractive platform for storage and interactive visualization of 3D contents (both on mobile devices and in desktop browsers), which works fine as a display window for teaching activities and with an almost instantly dissemination effect. In addition, it gives the possibility to include narratives employing numbered information points, in which annotations, photographs and external links can be provided (Figure 9).



Convent of Carmen (Logroño, Spain), year 1851.  
3D Model

**Figure 9:** 3D model in Sketchfab. <https://skfb.ly/6TMEo> [access: July 2020].



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In this case, a simplified version of the 3D model (without textures) is available through this website, the information points tell the user some key pieces of information about the building, the school, the exhibition and the mock-up. Moreover, a link to the record in the university repository is also provided for those users who wish to obtain further information and download the detailed 3D model.

- The AR uses Coello's plan as the marker for placing the 3D model. Therefore, after downloading and printing the plan (as said before, this plan is downloadable from the map catalogue of the Instituto Geográfico Nacional of Spain), the users only need to run the application in their mobile devices and point at the area where the convent was to see on the screen the buildings in 3D superimposed on the plan (Figure 10).

The application was generated with Vuforia® and Unity 3D®. The first step was to select the part of the plan that would be used as a reference for the location of the virtual model and uploading it to Vuforia's online platform. In this platform, the marker needs to be validated (i.e. check that the contrast and variability of the image are good enough to be recognized by the AR engine) and, after that, exported for being used in Unity 3D®.

In this latter software, both the marker and the 3D model were firstly imported and then placed in their relative position. Once the scene was correctly arranged, the result was exported as an application (.apk) for Android® devices, which is stored and downloadable from the university repository, together with the rest of the information about this project.



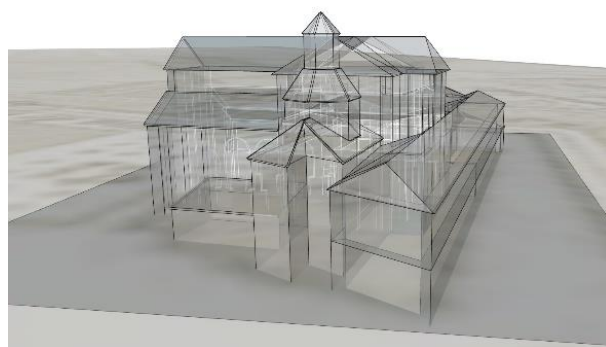
**Figure 10:** By means of the augmented reality, users can see the buildings over a printed plan in their mobile devices.

### 6. Discussion

Supported by digital technologies, efficient products to enhance exhibition experiences for visitors can be generated. This is also a reality for mock-ups (Rizvic, Pletinckx, & Okanović, 2015).

In this text, a case has been presented where, thanks to the combination of photogrammetric techniques based on perspective analysis for the 3D geometric reconstruction, texturing and expressive rendering (Figure 11), an attractive and interactive product for dissemination and support of an exhibition was

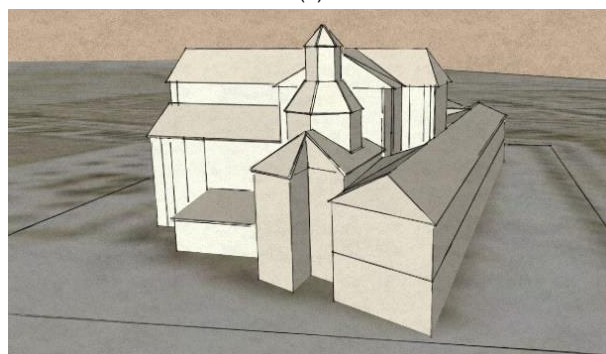
generated. Additionally, the use of visual variables (such as the changes in the tone of the textures) allowed us to add information about the likely appearance of the different parts of the 3D model.



(a)



(b)



(c)



(d)

**Figure 11:** Two different views of the 3D model. The images (a) and (b) show the geometry with semi-transparent surfaces. The images (c) and (d) use expressive (non-photorealistic) rendering in order to improve the attractiveness of the image for illustrative purposes.

The importance of the urban context for the correct understanding of the building has been stressed. In this particular case, we have worked with a single element (the convent) located on a city plan from a particular moment in time and just for generating images for the exhibition, but this approach can be extended to more buildings and landscape, different epochs and for multiple purposes (Kersten *et al.*, 2012; Spanò, Chiabrandò, Dezzani, & Prencipe, 2016; Maiwald, Brusckke, Lehmann, & Niebling, 2019; Walmsley & Kersten, 2019).

However, the extension will require the adoption of several standards, such as the ones published by the Open Geospatial Consortium regarding the geometric definition of architectures and geographic interoperability (Noardo, 2018).

Mock-ups might not be complete, indeed, many of them were created to display cross-sections of the building and to demonstrate at the same time both the inside and outside appearance. Nevertheless, virtual reconstruction can deal with these kinds of elements and even complete them when it is considered appropriate.

Moreover, many scale models were conceived to be assembled and dismantled. Tactility is consubstantial to some of them, such as the collections of 3D models for haptic use by blind people (Moreno, 2014), even for the old and historic ones that, nowadays, the public is not allowed to touch. The virtual environment can recreate these interactions with the users and, hence, recover for the mock-ups part of their original functionality. However, the interactivity that can be provided through the virtual models goes far beyond the constructive assembling but it also encompasses the visualization in meaningful environments, the representation of the people participating in the activities that were developed in these places and so forth.

Concerning the metric quality of the products, differentiation should be made between the use of the 3D virtual model so as to obtain measurements relating to the mock-up itself or to the disappeared buildings that are represented:

- As for the closeness of the virtual model and the mock-up, in this case, the visual appearance took precedence over the geometry. For this reason, the procedure for virtual modelling gave special attention to generate flat surfaces (avoiding the deformation of the paper) and undistorted (i.e. non-twisted) textures; however, the exact location and size of these surfaces and textures were considered less important.
- Regarding the disappeared buildings, it should be taken into account that the paper mock-up is an evocative view of how they may have been, which does not claim to be accurate as their geometry and content are concerned; as a matter of fact, many of the features of the paper model —such as the arrangement of the windows, the heights of the floors, the shape of the roofs, etc.— are the product of the intuition of the creator. In any case, an approximate estimation of the accuracy of the overall dimensions was obtained when the 3D model was adjusted to the building floor in Coello's map. Furthermore, the historical use of the model must be done with the assistance of the documentary sources about the convent to check

the level of knowledge associated with each represented part.

Our last remark regards the use of the repositories for the preservation and the dissemination of the information. Regardless of the initial aim of the virtual recreation (in this case, a temporal exhibition), the generated products have a huge potential for subsequent re-use. If the availability of these products is maintained after the original activity has concluded we will not only create a pool of information for developing new studies, but also we will be working according to more sustainable criteria.

It is true that, nowadays, there are possibilities of visualizing 3D content directly on-line, both thanks to commercial or open-source platforms (e.g. Sketchfab® and 3DHOP, respectively) (Scopigno, Callieri, Dellepiane, Ponchio, & Potenzi, 2017). Although we acknowledge the effectiveness of these interactive tools for the dissemination of light versions of the 3D models, we still believe that the users should be allowed to get access to well documented detailed versions through direct links to institutional repositories, where 3D models are stored and preserved for scientific purposes together with the rest of the context information.

In this way, the webs with interactive 3D contents will be used as a sort of complementary platform which provides a flexible viewer and search engine, as well as some "social network" capabilities, but the main manner of preservation and dissemination will be in the institutional repositories (Rodríguez, Korro, & Valle, 2020).

## 7. Conclusions

A significant part of the architectural heritage is contained in sketches and mock-ups of already disappeared buildings or concerning structures that were never built. Virtual modelling is an appropriate tool for materializing, recovering and disseminating these elements to the public, both for technical analyses and for educational or historical purposes.

Many techniques can be used for 3D documentation and virtual modelling of models, the selection of which will depend on the specific characteristics of the model and the purpose of the results. Geometric accuracy is always an essential factor, but it is not the only one and, sometimes, it may not be preponderant over other aspects such as the visual aspect (in particular for exhibitions).

In any case, inside or outside the exhibition, the products have to be attractive to users; therefore, the generation of multiple versions of the contents for different platforms and with multiple functionalities should also be considered as a complement and incentive for the information preserved in the repository. These allow the exploration of 3D content outside the limitations of dates and exhibition rooms. Institutional repositories can play an important role in this regard since the preservation and reuse of virtual models (e.g. with AR apps) increase their usefulness and scientific performance.

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INTERACTIVE VIRTUAL REPRESENTATION OF THE DISAPPEARED CONVENT OF EL CARMEN (LOGROÑO)  
GENERATED FROM A PAPER CRAFT MODEL

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