



# RECREATING A MEDIEVAL URBAN SCENE WITH VIRTUAL INTELLIGENT CHARACTERS: STEPS TO CREATE THE COMPLETE SCENARIO

## LA RECREACIÓN DE UNA ESCENA URBANA MEDIEVAL CON PERSONAJES INTELIGENTES: PASOS PARA CREAR EL ESCENARIO COMPLETO

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### Abstract:

From historical advice to 3D modeling and programming, the process of reconstructing cultural heritage sites populated with virtual inhabitants is lengthy and expensive, and it requires a large set of skills and tools. These constraints make it increasingly difficult, however not unattainable, for small archaeological sites to build their own simulations. In this article, we describe our attempt to minimize this scenario. We describe a framework that makes use of free tools or campus licenses and integrates the curricular work of students in academia. We present the details of methods and tools used in the pipeline of the construction of the virtual simulation of the medieval village of Mértola in the south of Portugal. We report on: a) the development of a lightweight model of the village, including houses and terrain, and b) its integration in a game engine in order to c) include a virtual population of autonomous inhabitants in a simulation running in real-time.

**Key words:** virtual archaeology, digital archaeology, cyber-archaeology, cultural heritage, 3D reconstruction, 3D data interoperability.

### Resumen:

El proceso de reconstrucción en 3D de lugares históricos poblados con habitantes virtuales es complejo, y requiere de un gran conjunto de habilidades y herramientas. Estos procesos incluyen el asesoramiento histórico, el modelado 3D, o la programación y estas limitaciones hacen que sea muy difícil construir sus propias simulaciones en pequeños equipos arqueológicos. En este artículo, describimos nuestro intento de minimizar este escenario. Se describe cómo integramos el trabajo curricular de los estudiantes en la academia, haciendo uso de herramientas libres o licencias de campus. Se presentan los detalles de los métodos y de las herramientas utilizadas en el proceso de construcción de la simulación virtual del pueblo medieval de Mértola, en el sur de Portugal. Se presenta: a) el desarrollo de los modelos ligeros 3D en el pueblo, incluyendo las habitaciones y el terreno, y b) su integración en un motor de juego con el fin de c) incluir la población virtual de habitantes autónomos, en una simulación que pueda ser ejecutada en tiempo real.

**Palabras clave:** arqueología virtual, arqueología digital, ciber-arqueología, patrimonio cultural, documentación, reconstrucción 3D.

## 1. Introduction

Amongst the challenges of creating a 3D simulation of ancient sites are the costs associated with these types of simulations. One of our goals was to address this issue by building a pipeline of tools and methods available for free in an educational setting or with campus licenses, and basing it on volunteer work. This work resulted from a multidisciplinary team of volunteers, including archeologists from the *Campo Arqueológico de Mértola*, and students and teachers from *Faculdade de Ciências da Universidade de Lisboa* working as part of their curricular activities.

The former group of participants has provided useful insights and historically relevant guidelines about the

architecture and culture of the ancient site of Mértola. This input included information about the civil housing and military structures in the urban landscape, such as the defensive wall and the watchtower. Based on this information, students' activities were then organized by teachers in such a way as to include tasks that would allow the modeling of these features of the urban scene (Figure 1).

Initially, three groups of students used manual modeling to reproduce architectural models of the old village. One group modeled the iconic watchtower on the riverbank of the Guadiana in AutoCAD (AutoCAD, 2016). Another group modeled a sample of houses using AutoCAD and Blender (Blender, 2016) which were later textured using 3ds Max (3ds Max, 2016). Finally, a third group

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(a)



(b)

**Figure 1:** Overview of the village inside the defensive walls: present state (a) and our model (b).

produced an agglomerate of fifteen houses of the Alcáçova (citadel) in 3ds Max.

The following step to generate the combined landscape departed from obtaining a model of Mértola's terrain and placing these architectural models on top of it. This step was performed using CityEngine (CityEngine, 2016). Taking advantage of a CityEngine functionality called CGA (Computer Generated Architecture) shape grammar, the virtual landscape was enriched with streets, vegetation, defensive walls and a new house model that was built combining polygonal modeling with rules.

Finally, the complete model was exported to a format compatible with Unity (Unity, 2016), a software tool used to develop videogames. Then, virtual characters were included in the scenario, the physical appearances of which are faithful to the epoch we intend to recreate. These characters exhibit simple, intelligent behaviors that in the future will be improved upon by algorithms inspired in artificial life (Antunes & Thalmann, 2016a; Antunes & Thalmann, 2016b).

We obtained the models of the characters and their basic animations from specialized software companies like Daz 3D (Daz3d, 2016) and Mixamo Fuse (Mixamo Fuse, 2016). Their spatial movements were accomplished by means of the physics engine and algorithms incorporated in Unity; some scripts were used to tune movements and behaviors (e.g. character following another character; donkey following a man). Our approach explores the interoperability of 3D software tools to combine the models of different

elements of the scenario with animated virtual characters to obtain an interactive application. The main contribution of this paper is the identification of a set of techniques and procedures that can be used to attain the final interactive environment recreating the inhabited ancient village. We intentionally give some detail with the aim of easing the effort of producing a similar result for other case studies, targeting other places and epochs. Figure 2 illustrates an overview of the village of Mértola, populated with some virtual humans.



**Figure 2:** Detail of the model inside the defensive walls populated with virtual characters.

This paper is organized as follows: Section 2 summarizes related work, Section 3 explains the setup of the virtual urban environment and Section 4 describes the integration of virtual intelligent characters in this environment. Finally, Section 5 discusses the results of the work, while Section 6 sums up the main goals achieved.

## 2. Related work

In recent years, there has been widespread use of virtual environments that reproduce ancient civilizations anchored in credible historical information. Without being exhaustive, we refer in the next paragraphs some valuable works in this area. The first group of references concerns approaches that recreate ancient virtual architectural scenarios. Then, we direct attention to works that include intelligent virtual humans. Finally, we look at some other examples that incorporate intelligent crowds.

The methods adopted to recreate ancient virtual scenarios from the architectural point of view may be similar to the general approaches for urban generation (see Musialski *et al.*, 2013, for a thorough survey). Concerning virtual recreation of historical places considerably damaged or that no longer exist, the processes used are predominantly based on manual or procedural modeling.

For instance, in the recreation of "La Venta", the major regional center of Olmec culture during the period 800-400 BC in present-day Mexico, Gillespie & Volk (2014) used manual modeling starting with plans mainly produced from the archaeological excavations. Also resorting to archaeological excavations that had been

made in Zaragoza, Spain, [Basterra & Pintado \(2015\)](#) produced a virtual model of the "Forum Renscens", the ancient public square of the Roman town, a place which is still in process of research. The recreated 3D model was produced by manual modeling and constitutes, as the authors emphasize, a working piece for the team of researchers that studies the historical place and that includes architects, archeologists and historians.

Manual modeling can also be used to complete initial drafts. [Carpetudo & Lopes \(2015\)](#) recreated a 16<sup>th</sup> century church in Montemor-o-Novo, Portugal, using photogrammetry with images obtained with a drone. They produced an initial model of the contemporary ruins and then manually completed the church based on its representations in ancient paintings.

In the project "Rome Reborn," ([Frischer et al., 2008](#); [Dylla et al., 2009](#)) both manual and procedural modeling were used to depict the evolution of the city of Rome from the late Bronze era until the 6<sup>th</sup> century AD. Procedural methods are also used by [Rodrigues et al. \(2014\)](#), who propose a grammar for generating virtual heritage traversable house models. They demonstrated their method with the creation of several Roman houses from the heritage site of Conímbriga, Portugal. Another approach consists in the parametric associative geometry design tools used by [Rua & Gil \(2014\)](#) to model the 14 km length of the Lisbon Aqueduct.

[Fita, Besuievsky & Patow \(2017\)](#) present a set of techniques for virtual reconstruction that merge procedural modeling with structural analysis methods. The aim of these techniques is to provide models that are realistic from two perspectives: visual accuracy and structural feasibility. The faithfulness of the model is crucial to understand how structural elements such as bricks, stone blocks or vaults, were combined in the construction of the building; this constitutes valuable information for preservation and maintenance actions. These authors describe, as a case-study, a model of a Romanesque church.

Besides the architectural structures of the sites, some authors explore other facets of the simulations, implementing approaches commonly used in videogames (see [Anderson et al., 2010](#), for a review about serious games for cultural heritage). Three recent examples are provided by [Capurro, Nollet & Pletinckx \(2014\)](#), [Saldaña \(2015\)](#) and [Kennedy et al. \(2013\)](#). [Capurro et al. \(2014\)](#) conceived a virtual model (including architectural decoration and furnishing) of the 13<sup>th</sup> century Saint Saviour abbey in Ename, Belgium, with the objective of releasing an educational game for young visitors of the Provincial Heritage Centre, nearby the archaeological site of the abbey. The players will walk inside the virtual abbey, discover the daily life of monks, while overlooking the real archaeological site. [Saldaña \(2015\)](#) presented a set of procedural rules that generate buildings for modeling Greek and Roman cities. In the work, the observer is represented as an avatar in the virtual environment and is able to navigate and explore the scenario. [Kennedy et al. \(2013\)](#) used OpenSim to recreate St. Andrews Cathedral in Scotland during the 14<sup>th</sup> century. They populated the scenario with virtual characters. Additionally, the user controls the movements of an avatar, which can interact with several elements of the environment.

Some reconstitutions elevate the challenge by including virtual populations with intelligent behaviors. For instance, in the reconstruction of the *agora* of Argos, Greece, [Heigeas et al. \(2003\)](#) created a crowd resorting to a physically-based particle model. Another example is [Ciechomski et al. \(2004\)](#), who created an audience of Intelligent virtual characters (usually called agents in artificial intelligence) in the ancient Roman Odeon of Aphrodisias. With the aim of studying the ergonomics of the Roman Colosseum, [Gutierrez et al. \(2005\)](#), simulated a crowd of virtual agents whose movements are spatially uncertain.

More recently, [Bogdanovych et al. \(2010\)](#) deployed intelligent agents in the online virtual world Second Life ([SecondLife, 2016](#)) in a simulation of Uruk, an ancient Sumerian city.

Building upon this last work, [Trescak et al. \(2014\)](#) presented an approach where objects have annotated emotional responses. The agents in the scene, in the course of their actions, choose actions and objects that better fit their personality parameters. So, depending on the particular configurations, certain aspects of one individual might differ widely from those observed in others, for instance, the level of tolerated proximity or walking speed.

The work we describe in this paper continues this line of research and is part of a larger project called "BIHC - Bio-Inspired Human Crowds" whose partial objectives are the development of a set of tools for the animation of 3D reconstructions of cultural heritage sites<sup>1</sup>. This paper describes a combined effort to work under a low-budget pipeline to make a 3D simulation of an ancient village. Our case study is the medieval village of Mértola in the south of Portugal, and the work involves a multidisciplinary team of volunteers comprising archeologists in Mértola, and students and teachers from *Faculdade de Ciências da Universidade de Lisboa* working as part of their curricular activities.

### 3. Creating the virtual scenario

The creation of the virtual scenario combines several elements in the same environment: terrain, streets, houses, fortifications (the watchtower and the defensive wall) and vegetation. Figure 3 highlights the main components used in the pipeline. We have applied the geographic processing capabilities of the ArcGIS platform (version 10.3.1; ArcGIS, 2016) to import the model of the terrain, and AutoCAD (version 2016), Blender (version 2.73) and 3ds Max (version 2015) to model the architectural features. The resulting models were then exported to CityEngine (version 2014.0), where more elements were added mainly by procedural modeling. Afterwards, the complete virtual environment was exported to Unity (version 5.3.3) in FBX format, and the intelligent virtual characters were integrated in the final simulation.

#### 3.1. Terrain

Three main steps were carried out to obtain the model of the terrain. The first, Input Datasets, was required to acquire the topography of the terrain in the area of

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<sup>1</sup> <http://bihc-fcul.weebly.com/>

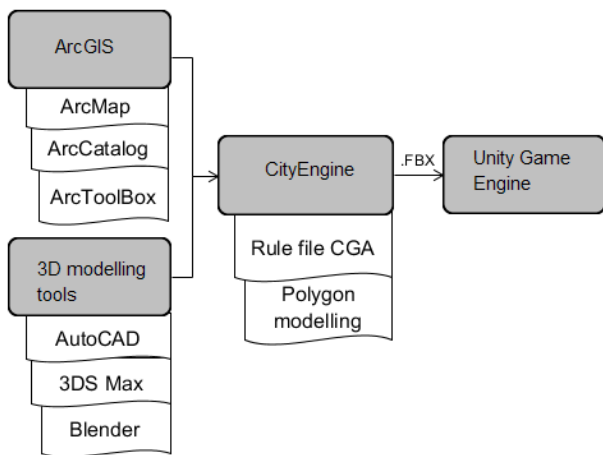


Figure 3: Pipeline overview.

interest that our virtual model reproduces. The second step, Image Generation, was necessary to get a texture for the corresponding area. The third, Data and Image Processing, combined the results of the two previous steps and prepared the files to be transferred to CityEngine. Figure 4 illustrates this sequence, which is detailed next.

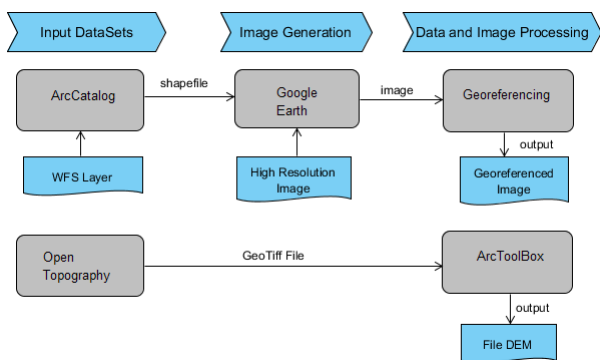


Figure 4: Steps to obtain the textured terrain.

### 3.1.1. Step one - Input datasets

The whole process started with the selection of the geographical region of interest where the 3D scene should be located. In the Google Earth interface, we identified the region consisting of the ancient village of Mértola as an area of 1 km<sup>2</sup>. We then obtained the village's upper and lower limits expressed in terms of longitude and latitude. Next, we used OpenTopography (OpenTopography, 2016), a service that offers raster datasets with different granularities for digital terrain models (DTM). The values of latitude and longitude established the four corners of the region of interest. We then generated a corresponding image in GeoTIFF format containing the information about the elevation of the terrain. This image file was then processed with the ArcGIS platform to be combined with a texture using its tools: ArcMap, ArcCatalog and ArcToolBox.

The ArcCatalog application was used to access information provided by the Portuguese entity *Direção Geral do Território* (DGT). The first step of this process was the configuration of this service following the

guidelines described in a DGT document<sup>2</sup>; namely, selecting Window Catalog/Interoperability Connections, choosing Concelhos<sup>3</sup>\_2015 and finally our target municipality, Mértola, whose limits appear in the interface. A new shapefile, called *points\_of\_control*, was created selecting the feature type (in this case the type point) and the corresponding coordinate system (in our case-study, WGS 1984 UTM Zone 29N). After that, the data was transferred. This shapefile was dragged and dropped into the interface of ArcMap where a new layer was defined. Then we edited it to configure the latitude and longitude of the four corners of the region of interest obtained from OpenTopography services. By the end of this process, the measurement units were converted to meters.

### 3.1.2. Step two – Image generation

With ArcCatalog, the shapefile created in the previous step (*points\_of\_control*) was exported to the KML format. The resulting file was imported into Google Earth Pro to achieve a high resolution image (in JPG format) that involves the region of interest with the four delimiting control points marked with glyphs.

### 3.1.3. Step three - Data and image processing

In ArcMap, we similarly created a new layer to import the image produced in the previous step. Then, using the four coordinates marked in the image and the shapefile points of control generated earlier, we georeferenced the image using the *Georeferencing* tool. This process was repeated for each point. Previously, we disabled the option *Auto Adjust* in *View Link Table*.

Furthermore, we also cropped the image using the coordinates defined by the mentioned four points so that only the inside area remained (*mosaic to new raster* tool). These two operations assured that the image fit as a texture for the area of interest. Next, the previously mentioned GeoTIFF file was imported to ArcMap in order to produce the map of elevation of the terrain (height map). This map was generated using the ArcToolbox functionality *Spatial Analyst Tools*.

Finally, this procedure was completed by importing and combining the produced height map and texture to CityEngine. This was done by creating a new project in CityEngine and then importing the mentioned files under the menu option *Layer/New MapLayer* (Fig. 5).

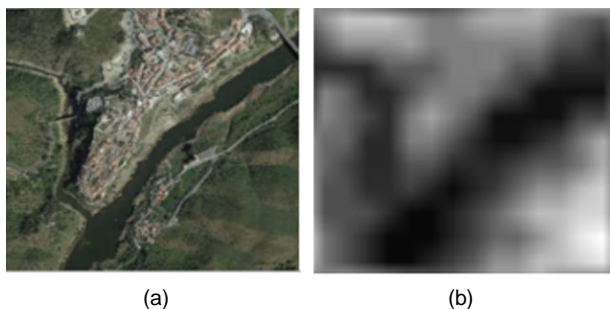
## 3.2. Streets and shapes

The CityEngine feature *Grow Street* was used to generate the streets as well as the blocks in between these streets where the buildings were placed. This feature uses the heightmap file and an obstacle file that in our case study prevents the appearance of streets on the riverbeds.

The obstacle file (Figure 6) was obtained by editing the georeferenced image on the left side of Figure 5. The streets were textured to simulate gravel using rules.

<sup>2</sup>mapas.dgterritorio.pt/Openviewer/cos2007/Guia\_de\_apoio\_utili\_zacao\_WFS\_ArcGIS.pdf

<sup>3</sup> *Concelho* is the Portuguese word for municipality.



**Figure 5:** Terrain: a) Georeferenced image and b) digital elevation model.



**Figure 6:** Image in the obstacle file.

### 3.3. Houses and fortifications

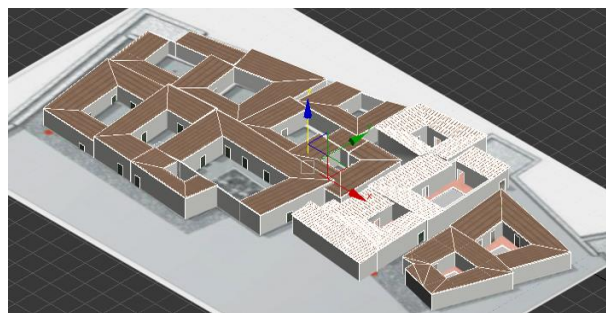
The virtual model of the village comprises houses, the watchtower and the defensive walls with its towers.

#### 3.3.1. Houses and watchtower

We resorted to manual modeling to reproduce three sets of constructions. The first set contains the complete structure of the watchtower; the second set contains three models of characteristic houses of Mértola and, based on guidelines provided by the archeologists, the third set comprises the houses of the Alcáçova.

The watchtower was modeled in AutoCAD. The models of the second set were also created with AutoCAD however, for curricular reasons of the students involved, some of them were also created with Blender. Finally, the houses of the Alcáçova were modeled in 3ds Max. Some of the houses have variations that allow the integration of different levels of detail (LoD): a) a lightweight version with a geometry of a reduced number of polygons, to be visible at a distance; b) a second version, where houses only have the exterior walls but have a higher definition with detailed roofs and doors, to be seen at close range; c) a third version, also in high definition, with the interior walls and props allowing a visit using a first person point of view. Figure 7 gives a combined overview of the three sets of houses side by side, which give no telltale signs of being different in their making.

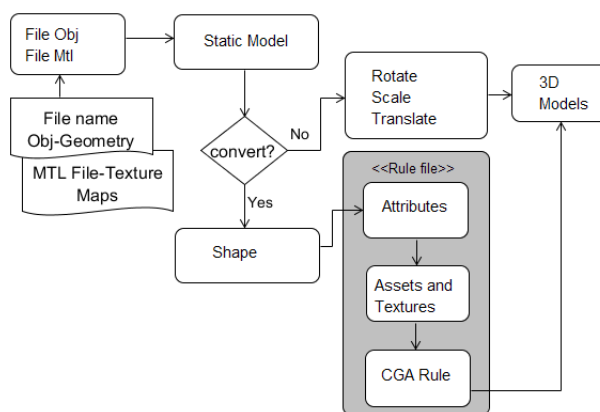
All house models were textured in 3ds Max. Then, when exporting in the OBJ format, two files are created: one with the geometry (extension .OBJ) and another with the texture (extension .MTL). Although it is possible to export files directly from Blender to CityEngine, we also chose to apply the textures in 3ds Max for these models because this software organizes the textures in such a way that eases the import process.



**Figure 7:** Model of the houses in the Alcáçova (3ds Max). The houses highlighted have been modeled with 3 LoD

The models were finally imported into CityEngine as static models and were placed on the terrain using the option *Align static models*.

Afterwards, the watchtower model was converted into shapes to be textured resorting to procedural rules. Figure 8 summarizes the two approaches to use the imported models in the CityEngine context.



**Figure 8:** The pipeline inside CityEngine.

The archaeological remains of the watchtower and the houses of the Alcáçova are still easily identifiable nowadays. As such, we were able to place the corresponding models in their exact locations on the corresponding virtual terrain of Mértola. The models of the Alcáçova houses follow the real plants; the height of the walls and the characteristics of the roofs were provided by the archeologists of *Campo Arqueológico de Mértola*. Concerning the watchtower model, its measures and architectonic details were also provided by the same archeologists.

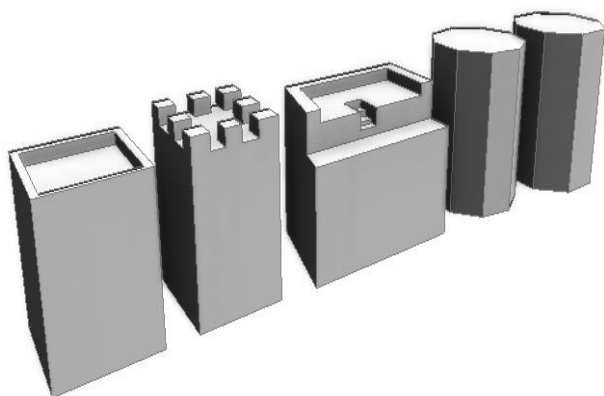
The second set of houses mentioned earlier were used as templates to create house clusters in general areas of the village where we did not have much available information. To cover these unexcavated areas, we also used some house models generated in CityEngine by polygonal modeling combined with procedural rules. We have also created narrow streets similar to the ones in the Alcáçova area.

#### 3.3.2. Defensive wall

The approximate model of the defensive wall was based on information gathered from different sources. The location of the wall on the terrain follows a 2D map

obtained in Martínez *et al.* (2009), while the location and shape of the its towers were inspired by Macias (1996b; 3 towers near the Alcáçova) and on hand drawings made *in situ* by Duarte Darmas in the 16<sup>th</sup> century (this author identified 13 towers around the defensive wall). Although these drawings have been depicted in an epoch that is posterior to the one we want to recreate, we used them as they present many valuable details.

The first step of this process utilized polygonal modeling in CityEngine to produce five different models of defensive towers to form the modular basis of the defensive wall (Figure 9). These models were exported in the .OBJ format to be used as assets by CityEngine in the code rule that generates the final walls.



**Figure 9:** The 5 models of defensive towers produced by polygonal modeling in CityEngine.

The second step to generate the complete defensive wall employed in the *Grow Street* feature, followed by the necessary manual adjustment to approximate the layout of the streets as much as possible to the contour of the defensive wall, as depicted in a) Martínez (2009), b) Macias (1996b) and c) Duarte Darmas (1509), as well as d) the current images obtained by Google Earth. These streets worked as the basis for lifting the wall. A rule was used to split the street in two halves and two distinct rules were applied to each half: on the external half, a rule creates a wall with merlons, and on the inner half another rule generates a lower interior wall where, for instance, the sentinels could stand while watching the surroundings. The towers were inserted in some street intersection nodes. Their models fit the ones depicted in a) Macias (1996b) and b) Duarte Darmas (1509). Figure 10a highlights a street intersection node where a tower



**Figure 10:** Streets used to create the wall with a node on the intersection (a) and the final result with a tower on the node (b).

was positioned, and Figure 10b shows the final result. Figure 11 displays a detail of a tower integrated in the defensive wall. To apply textures to the defensive wall, its towers and to the watchtower we used procedural rules.



**Figure 11:** Detail of a tower inserted in the wall.

### 3.4. Combining the 3D elements

To combine the terrain and the models described in Section 3.3, we have defined layers for: a) the terrain, b) the static models; and c) the shapes. The shape layers include models generated by grammar rules. These include buildings and streets, as well as landscape creation with tree models from a vegetation library<sup>4</sup>. We used alignment features to combine the 3D models with the terrain: *Align graphic to terrain*, *Align terrain to shape* and *Align static model*.

The complete virtual 3D model generated in CityEngine was exported to Unity using the FBX format following the instructions provided<sup>5</sup>. Moreover, we disabled the option *Create Shape Group* to reduce the number of polygons exported, a necessary concern to ensure a lightweight model that supports navigation in real-time. Also considering this constraint, some elements, such as the houses, were modeled with different LoD, as previously mentioned, and set in distinct layers before being exported. This way, the Unity game engine can optimize rendering processes, adjusting the complexity of the mesh according to the distance of the camera. Models that are away from the camera are displayed with fewer polygons while the closer ones are rendered with more polygons to attain a more realistic effect. For all the other models, we also had the concern of keeping the number

<sup>4</sup> [www.arcgis.com/apps/CEWebViewer/viewer.html?3dWebScene=6015f7d48dff4b3084de76bcf22c5bca](http://www.arcgis.com/apps/CEWebViewer/viewer.html?3dWebScene=6015f7d48dff4b3084de76bcf22c5bca)

<sup>5</sup> "How to: Export Textured Models from CityEngine into Unity", <http://support.esri.com/technical-article/000012449>

of polygons low in a way that would not compromise the credibility of the model.

Finally, part of the housing complex in the interior of the walls was reconstructed based on direct evidence from the excavations. However, there was also a large undocumented section of the village for which we had to extrapolate and interpret based on the available material. After the first results, and based on the feedback from the archeologists, these sections that did not follow archeological evidence, had to be redone: a) to narrow the width of the streets, and b) to augment the urban density. The final model, depicted from two different perspectives in Figure 2 and Figure 12, reflects these adjustments.



Figure 12: Overview of the walls, with the village in the background and the watchtower on the right.

#### 4. Inserting the animated characters

The methodology to incorporate animated characters in the virtual environment consisted of two major steps: 1) the acquisition and animation of the models; and 2) integration into the environment. Such integration was expanded providing intelligent behavior to the characters, for instance, making them capable of choosing the shortest path between two points.

The population present in the final scene includes men, women, children and donkeys. Some preparatory work was required to configure the respective models. The initial models of the virtual humans were obtained from Mixamo Fuse (v. 1.0), and later these rigged models were exported to 3ds Max where they were adequately dressed with garments from the recreated epoch. The number of vertices was reduced (*MultiRes* functionality) and they were exported to FBX with the option *Embed Media*. Then, Mixamo was used to automatically adjust skeleton definitions and skinning. This tool was also used to provide a set of basic movement animations (e.g., walk, run, sit on a bench, climb stairs).

Animal characters, such as the donkey, were obtained from Arteria3D (Arteria3D, 2016) already preprocessed and ready to be integrated into Unity.

The basic animations of the characters were combined with scripts included in Unity that implement simple artificial intelligence algorithms, such as the A\* algorithm for choosing the shortest path between two points or “follow target” for making one character follow another. Figure 2 and Figure 13 illustrate situations involving virtual characters moving in the scenario according to these simple algorithms.

To ensure the credibility of the movements exhibited by the characters, two factors are critical: the quality of the initial animations and the reproduction of the laws of physics. Unity's physics engine uses colliders to deal with collisions amongst objects. As such, to guarantee that characters move on the ground and do not exhibit unnatural movements, like trespassing walls, we need to define colliders for every mesh corresponding to elements in the scenario that may be in the way of a moving character, such as characters, houses, walls or trees. Similarly, the terrain also incorporates a collider to ensure the virtual characters will move on its surface, preventing the force of gravity (implemented by the physics engine) from making them fall vertically and disappear from the scene.

#### 5. Discussion

Building a simulation, such as the one described in this paper, raises organizational and implementational questions. In terms of organization, when we compare the present work with others of the kind, such as Pompeii (Maim et al., 2007), the nature of the present work carries inherent risks and increased difficulties since this project is based on construction by volunteers and is built using tools available with free or campus licensing. This has generated a number of extra hurdles to its successful completion. We had to coordinate multiple tasks involving people working on an irregular basis and consequently we all had to be very flexible in our approaches, and to integrate and articulate the progress of the related activities.

One example is the interdependence of a) retrieving the historical information, b) modeling the architecture of a specific building; c) texturing the resulting model; d) validating the historical accuracy of the resulting model; e) creating LoD for the object; f) incorporating the final model into CityEngine and Unity. As these activities had short time slots to be completed – normally part of a semester – and students had no previous experience in such technical tasks, the difficulties increased significantly with a negative impact in the quality and volume of work. Yet, with several adjustments on our part, we are all very pleased with the results achieved since we were able to successfully deliver the simulation with our limited resources. A visualization of a lighter version of the raw 3D models can be accessed at <http://www.arcgis.com/apps/CEWebViewer/viewer.html?3dWebScene=442744f3d8964b6eb921b2e0adef4b8a>. The final simulation is available using Unity Webplayer at the following link: <http://bihc-fcul.weebly.com/myrtula.html>.

A second thread of practical questions relates to the technical complexity of bringing together architecture and vegetation in an urban layout enriched with virtual characters in real-time rendering. The Unity game engine provides an efficient mechanism of occlusion culling, which minimizes part of the problem. Additionally, to reduce the number of simultaneous polygons being rendered per frame, we also had to use LoD for the objects. As the complexity and detail of the models decrease with the distance to the camera, the associated loss of information is negligible, thus preserving the accuracy of the model. Finally, we also maximized the number of shared materials to minimize the number of GPU calls.



(a)



(b)

**Figure 13:** Virtual characters populating the model: a) a group outside the defensive walls and b) two characters interacting with each other.



(a)



(b)

**Figure 14:** a) The architectural features built based on the archaeological evidence: the houses in the Alcáçova and the watchtower (inside the red squares); b) The final composition, where these structures appear combined with our own interpretation of the provided information.

The set of tools that we used support compatible formats for data import and export, which provides data interoperability among them. This fact was crucial to take advantage of specific features of each tool, and to define a pipeline to accomplish the final goal of the project. In particular, terrain generation required the combination of data from different sources. We were able to obtain an accurate georeferenced 3D model of the terrain and,

using the same geographical coordinates, the corresponding aerial image. This image superimposed over the 3D model of the terrain made possible the correct positioning of the models whose ruins are still visible today (Alcáçova and the watching tower).

Despite the arguable merits of the resulting simulation, it is noteworthy to mention that the project is still a work



in progress, and we are still gathering relevant archaeological information necessary for the historical accuracy of the simulation. First and foremost, not all of the iconic buildings of the village appear in the simulation, such as the mosque. This situation might raise incorrect, or rather incomplete, perceptions of the ancient site to the unaware visitor. We plan to mitigate this with further work on the 3D modeling in the following version. Another problematic fact is that we have combined buildings appearing in their exact historical locations next to other ones that were inserted to fill in gaps for the time being (Fig. 14). Besides using different texturing properties to distinguish the former from the later, we also plan to fix this situation in the near future by allowing the visitor to switch the view of these buildings on and off as to distinguish the historically accurate buildings, and we will make adjustments to the simulation as we get further archaeological information from our partners at *Campo Arqueológico de Mértola*.

## 6. Conclusions and future work

We have described the pipeline used in our ongoing work of constructing a simulation of the medieval village of Mértola. Our main contribution is the identification of a set of tools and stages that can be used to obtain the final interactive environment recreating the inhabited ancient village. In this article, we provide a detailed description of the procedures used in creating the terrain, the urban features and the characters used in the simulation.

We began this article by identifying our motivations for using a low-budget process that includes free licensing tools or academic licenses. We have also referred to the requirements of the simulation being accessed by an online audience a) in real-time and b) in immersive mode using the first person point of view, and the consequent need for using lightweight 3D models. Furthermore, we

have identified and discussed the issues that were raised during the process of construction.

We generated an environment that combines 3D models created by both manual and procedural modeling with a realistic model of the terrain. Moreover, this 3D environment scene is inhabited by intelligent virtual characters. The building elements (houses, defensive walls and watchtower) and the appearance of the characters are faithful to the epoch we intend to recreate.

Currently, the virtual model of the medieval village of Mértola is being improved upon. In the previous section, we mentioned the need to improve the current simulation through the inclusion of some of the iconic buildings. Concerning the virtual inhabitants, algorithms inspired in artificial life are also being developed to obtain a generative model for heterogeneity and spontaneity in behavioral animation of small, medium and large gatherings of virtual characters.

Overall, we have set ourselves the challenge of reconstructing the medieval village of Mértola. This is still an ongoing process, but so far our experience with this project provides a useful and practical example of the use of low-budget tools and means to build this type of simulation. This fact is of great help to other small teams similarly constrained by their budgets, but interested in developing this type of educational tool.

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