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BEYOND 3D MODELS: SIMULATION OF TEMPORALLY EVOLVING MODELS IN STELLARIUM

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ABSTRACT

In recent years the open-source desktop planetarium Stellarium has gained high popularity for simulation in archaeoastronomy, and we have improved recent versions to also become accurate enough for such applications. A dedicated plugin which we introduced a few years ago can be used to visualize loadable scenes of 3D reconstructions of past or present monuments in their landscape. However, while Stellarium can simulate the view of the sky and positions of celestial objects and their respective motions over several millennia in sufficient accuracy for most historical applications, the 3D plugin until recently could only show one static version of a landscape. However, landscapes and monuments may have changed, temples may have been rebuilt and rededicated in part to reflect changes in the sky caused by precession, changes in ecliptic obliquity or stellar proper motion. Our latest developments in Stellarium now enable the simulation of phased or temporally evolving three-dimensional sceneries under Stellarium's sky by configuring parts of the 3D model with material properties that can be used to hide parts of the monument when they don't fit the epoch of the currently simulated sky.

KEYWORDS: Virtual Archaeology, 3D Computer Graphics, Archaeoastronomical Simulation

1. INTRODUCTION

In recent years, the interactive visual exploration and demonstration of three-dimensional virtual models of buildings or natural structures of archaeo-astronomical interest under a simulated sky has become available for users of the open-source desktop planetarium program Stellarium (Stellarium 2018; Zotti and Neubauer 2012; Zotti 2015, 2016, Zotti et al., 2017). Users can load an architectural model with a segment of surrounding landscape (virtual 3D model) in the well-known Wavefront OBJ format and walk around in the model and observe the sky simulation for any dates of interest to explore sight lines or light-and-shadow interaction in present and past times (Frischer et al., 2016).

A virtual 3D model (in this context) is a depiction of an archaeologically plausible reconstruction of a monument as it may have looked like at some point in time.

2. STELLARIUM AS A "TIME MACHINE" FOR SKYSCAPES

Astronomical desktop planetarium simulation programs such as Stellarium nowadays allow the simulation of celestial motions over several millennia, limited by the applicability of the mathematical models they are based on. Stellarium's ability (since version 0.15) to read ephemeris data from NASA/JPL's DE431 (Folkner et al., 2014) means we should be able to simulate the sky over even the earliest human-made stone monuments like Göbekli Tepe (10th–9th millennium BC; see Schmidt (2006)) with sufficient accuracy to evaluate orientation patterns possibly connected to systematic astronomical observations. The only systematic deficit of knowledge concerns the irregularly decreasing rate of Earth's rotation, causing massive uncertainty in the value ΔT which is required for an accurate simulation of Earth's axial rotation. This is most apparent when it comes to simulation of ancient or even prehistoric Solar eclipses, which do not have sufficient observational records before the 1st millennium BC to reliably simulate them much further back than that date (Stephenson 2016). Apart from that, most regular astronomical phenomena, but of course no unrecorded transient phenomena in prehistoric times like supernovae, comets, bright meteors/meteorite falls, aurorae or atmospheric phenomena such as those caused by volcanic activity, can nowadays be reliably simulated, in effect providing a "time machine" for celestial simulation. Any researcher can recreate at least the visual components of the past skyscape by creating a 3D model or at least a panorama rendering of the landscape with all uncertainties concerning buildings, vegetation, shorelines, etc., following best practice like the London Charter (Beacham et al., 2006). These panoramas, and with Stellarium also the 3D model itself (Zotti 2016), can be visualized in the astronomical simulation to re-create the previous appearance of the skyscape.

Many past and present monuments have evolved over time. They may have been re-dedicated or modified to serve new purposes or follow trends in architectural style, and some changes may have to do with astronomical orientation which may have been relevant to one culture and correct in its era but not in the next. If we want to track the appearance of such monuments over centuries of use, this usually requires the creation of several models, each one showing the monument as a snapshot in its respective time.

When visualizing what may be the most famous archaeological complex and landscape with archaeo-astronomical alignment properties, the Stonehenge landscape, we detected small deficiencies in the way a scientist would interact with a 3D model of an evolving archaeological land- and skyscape inside Stellarium. For example, consider a landscape model showing the Aubrey holes with 56 timbers and a stone-free Stonehenge enclosure as it may have appeared in the early 3rd millennium BC. For the purpose of this paper, let us assume the Aubrey holes held timber posts and not bluestones as proposed by Hawley. Bluestones had been rejected in favour of wooden posts by later research but have been discussed again recently after new excavations (Darvill et al., 2012). Advancing the date to the late 3rd millennium changed the sky, but not the Aubrey timber circle, which still showed the wooden posts. Those posts should however have vanished, and the Bluestone and Sarsen circles should have appeared during those few hundred years. To experience the changed appearance of the site, it was necessary to load a new model, which required some interaction with the program's user interface and which also caused a reset of the current viewer location. We have now developed a remedy to overcome these distracting nuisances.

3. CONFIGURING MULTI-PHASE MODELS IN STELLARIUM

Configuring a 3D model for Stellarium with elements that should only be displayed in certain times requires a bit of understanding of the model format and files involved. The widespread classical 3D file format "Wavefront OBJ" can be created by many 3D editing programs, however, it is not fully standardized, and in some cases manual editing is inevitable.

An OBJ model strictly only requires one human-readable text file, but in most cases comes in two such files: one with the file ending OBJ is the actual geometrical description, consisting of lines which list vertices (corner point coordinates), vertex normals (optional, but needed for correct illumination), texture coordinates (optional, but required for higher details) and a description of the actual model parts consisting of a group or object name, (optionally) the name of a *material*, and triangle lists (lines which refer to three indices of the previously specified coordinates each) which describe the tessellated geometric surface. The model geometry is static, which means it is not possible to describe any movable parts like machines with joints or living objects with animations. If a *material* is specified, this refers to one record in a secondary file with ending MTL, which contains the description of various optical properties of model parts: the *materials*. These may be described with ambient, diffuse and specular colours (properties which influence how incoming light is being modulated and reflected), emissive colours (which can be used to simulate luminous faces like illuminated billboards or screens, but not light illuminating other parts of the model), and special properties like transparency or even refractive indices. Optionally it can also refer to "texture map" files, often photo-based image files which are used to show fine details inside the triangular faces. Texture coordinates are only required in the OBJ file when such textures are used. Some 3D rendering programs can make use of other parameters which shall be simply ignored by others.

To allow temporally changing scene parts, we have added two optional parameters to the *material* description in the MTL file, which are only understood by the Stellarium renderer and which modulate the transparency of a *material*. These describe when a *material* starts to become visible and becomes then fully opaque, and when a *material* starts to become semi-transparent and is then fully transparent, respectively (Figure 1).

To prepare a temporally variable model for use in Stellarium, models for all temporal phases which may have been prepared with other means have to be collated into one model file. If a basic modelling program like Sketchup has been used to model different phases in single projects, importing and assembling simple hand-made models should pose no problems, however this program has been found to be too limited to import models created from modern survey methods (like LiDAR-based DTMs, laser scans of buildings or image-based modelling) and consisting of millions of triangles. Users unfamiliar with other editing programs should take note that tools like the free and open-source 3D editor Blender (2018) are capable of such assembly. The Stellarium renderer has been tested to render a model with over 14 million triangles sufficiently fast for interactive use on a middle-class notebook PC with NVidia Geforce 960M graphics, which should be enough to allow the virtual exploration of reasonably complex landscapes. Care should be taken to identify the temporally changing parts of the model and to assign their materials clearly identifiable names.

After exporting the complete model and configuring it for display in Stellarium (Zotti and Wolf, 2017), we can edit the MTL file with any plaintext editor.

```
newmtl heelstone_upright
 Kd 0.5880 0.5880 0.5880
 map_Kd stone_texture01.jpg
 map_bump stone_texture01_bump.jpg
 # We assume it has been
 # deliberately put upright
 # around -3100/3000
 vis_fadeIn 588783.5 625308.5
 # Fade away between 500AD/700AD
 # as inclined version appears.
 vis_fadeOut 1903682.5 1976732.5
```

Figure 1: Material block inside MTL file for temporally changing material in Stellarium.

Each *material* is described in a block of text as shown in Figure 1. The `newmtl` parameter specifies the *material* name which has been given in the 3D modelling program and which is referenced in the OBJ file. It is recommended to assign a clear name for easy identification. `Kd` and other `K`… values define diffuse, ambient, specular and emissive colour components (RGB triplets), while the `map`… parameters indicate the external image files to be used as texture maps, which are modulated by multiplication with the respective `K` value. Hash marks allow comment lines for a human editor who may want to annotate some values for later traceability of his or her decisions. The new parameters introduced in this paper are `vis_fadeIn` and `vis_fadeOut`, and are to be followed by two numbers. These are dates specified as Julian Day numbers JD, the number of days counted from 4713 BC, to make them independent of any calendar. JD is used internally by most astronomical programs and also displayed in Stellarium, so configuration of these lines is quite simple by just setting a calendar date and reading JD from the screen. Giving two points in time allows for modelling uncertainties in the archaeological dating, i.e., for `vis_FadeIn` the first number represents the first possible date of existence (where the object is displayed still transparently), the second represents the date of certain existence of an archaeological structure (object is rendered opaquely). Likewise, for `vis_fadeOut`, the first number represents the last certain time of existence (full opacity), the second number the date of certain invisibility (full transparency). In the intervals between, the object is displayed with gradual transparency to indicate uncertain existence. If one or both lines are missing, the respective *material* is considered visible from `vis_fadeIn` to infinity or from earliest times until `vis_fadeOut`, or at all times, respectively.

Referring to the example given above, views of the Stonehenge landscape shown in Figures 2–5 have been created with Stellarium Version 0.16.1.

Before the earliest phase of building at Stonehenge, the Heelstone is shown to be in-situ, but lying prone (Figure 2). The stone then is put upright, probably around 3100…3000 BC (MacKie 2012), and the Aubrey timber circle erected as shown in Figure 3. Other authors discuss various other dates for the Heelstone and other stones. Difficulties around the date of this stone and its possible companions and various rearrangements of other stones are discussed e.g. by Darvill et al. (2012) who prefer to put up the Heelstone about 500 years later than that and even present two sequences of events allowed by the stratigraphy. However, the creator of a temporally changing landscape model has to decide on one sequence of events. Figure 5 finally shows the Heelstone sunken to its current position. The time of the latter transition is actually unknown, but in the model this transition has been set to lie between antiquity and the modern age. Likewise, most events of decay or collapse before the modern age cannot be dated. The combined OBJ model requires thus three models of a Heelstone for these three phases, and usually only one, at most two models (during transition phases) are rendered visible at a time. Each *material* can have its own time definition, allowing fine-grained transitions when these details are known.

4. DISCUSSION

The advantages of this new feature should be clear from the example presented in Figures 2–5, which were made from a single viewpoint and with just one 3D scenery loaded.

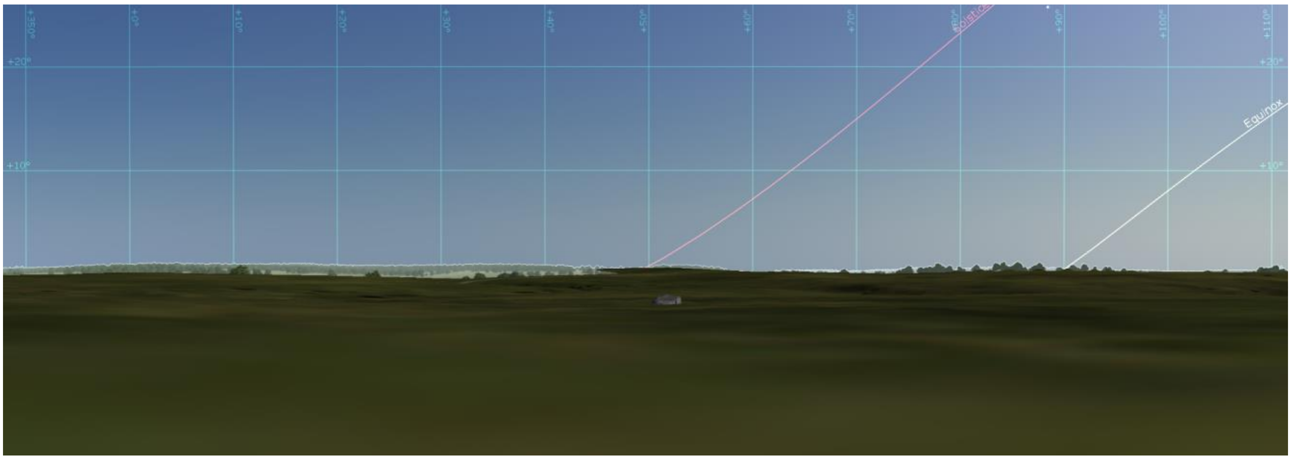

Figure 2: Stonehenge site before recorded human activity, about 3200 BC. A solitary Sarsen is shown lying prone in the landscape.

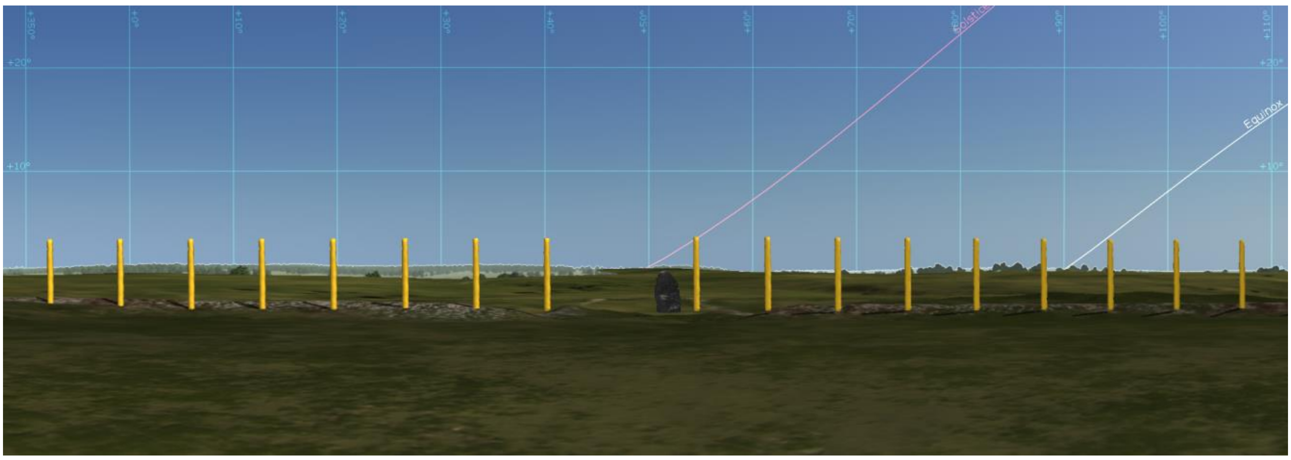

Figure 3: Stonehenge during the early 3rd. millennium BC, showing the "Aubrey Timber Circle" of 56 posts. The solitary Sarsen, known as the Heelstone, is now shown upright.

Figure 4: Stonehenge around 2200BC, after completion of the Sarsen Circle. Several other Sarsen stones stand next to the Heelstone. The date of the simulation is set to show Summer Solstice Sunrise framed by the Heelstone and its adjacent stone. Compared to Figure 5, some bluestones may be slightly off their correct positions in this model.

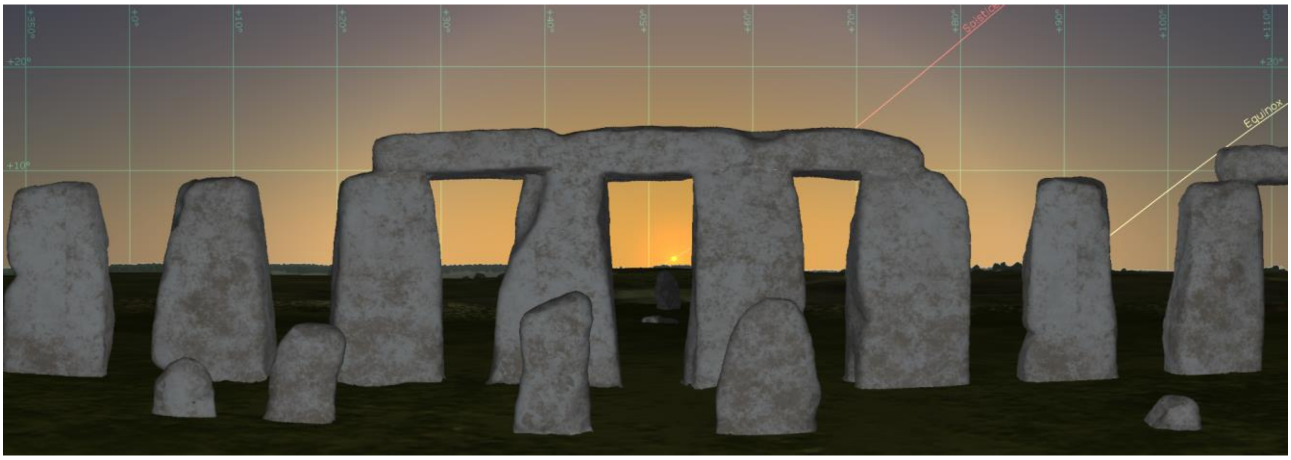

Figure 5: Stonehenge today, created by image-based modelling. Many lintels have fallen, and the stones near the Heelstone have vanished again. Note the slight shift in the red solstice solar declination line.

The scenery is shown always on the day of summer solstice. Regardless of calendar date in the proleptic Julian calendar which is commonly used also in prehistory, summer solstice is observed when solar longitude on the ecliptic is 90°. The only changes applied to Stellarium between the scenes were just changes in date and time of day.
With this new functionality of Stellarium, an observer can remain in a certain location in the virtual model and let the land- and skyscape change over decades or centuries, without the need to leave his or her concentration to load new models for other times. This allows the simulation and observation of construction and reconstruction phases of a site of interest while still always keeping particularly interesting viewpoints unchanged, and will always show the matching sky for the most appropriate reconstruction phase of the model.

On many sites it may however be very difficult or even impossible to find the one and only possible sequence of construction. Structural parts of a monument like windows, roofs or balconies which never have been anchored to leave their footprints in the ground may have vanished without trace, or the stratigraphic analysis of excavations without datable material may only allow relative, but no absolute dating. Even after decades of excavations around Stonehenge, there seems to be currently no clear and definite solution for dating all components of the site (Darvill et al., 2012), which requires making reasonable assumptions in the appearance or vanishing dates of model elements in the 3D model, or assumptions about the purpose and temporal sequence of monument components like the Station Stones in relation to the Sarsen circle and horseshoe.

5. CONCLUSIONS AND FURTHER WORK

This paper has introduced a new option to help researchers simulate and demonstrate temporally evolving 3D models under the sky simulation of Stellarium. The Scenery3D plugin of Stellarium is, however, not intended to become a complete game engine, and replicating the infrastructure found in such game engines – for example to interactively move game objects, or load small sub-components like standing stones and place them at arbitrary coordinates – seemed excessively demanding. The OBJ model format does not support moving parts, and an alternative solution of specifying translation matrices for temporally moving parts may have intimidated the intended target user group, which is expected to consist of casual modellers and archaeologists with a bit of experience with 3D computer applications. The solution introduced here is remarkably simple and should be easily adoptable for the casual model-making researcher.

Some application scenarios may however require more interaction with scene objects. The application of computer game technology for non-recreational simulation is often called “serious gaming” (Zotti, 2014). These additional demands may include more realistic environments with plants moved by the wind, sound, or reflections in moving water surfaces. For experiments in such application fields, we are currently also investigating possibilities to interface Stellarium with one of the popular game engines.

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