THE MARRIAGE OF ASTRONOMY AND CULTURE: THEORY AND METHOD IN THE STUDY OF CULTURAL ASTRONOMY

A special issue of *Culture and Cosmos*
Vol. 21 no. 1
Spring/Summer 2017

Published by Culture and Cosmos
& Sophia Centre Press
England

www.cultureandcosmos.org

In association with the
Sophia Centre for the Study of Cosmology in Culture,

University of Wales Trinity Saint David,
Faculty of Humanities and the Performing Arts
Lampeter, Ceredigion, Wales, SA48 7ED, UK

British Library Cataloguing in Publication Data
A catalogue card for this book is available from the British Library

ISSN 1368-6534

Printed in Great Britain by Lightning Source

The Skyscape Planetarium

Georg Zotti, Florian Schaukowitsch and Michael Wimmer[1]

Abstract: Communicating scientific topics in state of the art exhibitions frequently involves the creation of impressive visual installations. In the exhibition 'STONEHENGE. A Hidden Landscape.' in the MAMUZ museum for prehistory in Mistelbach, Lower Austria, LBI ArchPro presents recent research results from the Stonehenge Hidden Landscape Project. A central element of the exhibition which extends over two floors connected with open staircases is an assembly of original-sized replica of several stones of the central trilithon horseshoe which is seen from both floors. In the upper floor, visitors are at eye level with the lintels, and on a huge curved projection screen which extends along the long wall of the hall they can experience the view out over the Sarsen circle into the surrounding landscape. This paper describes the planning and creation of this part of the exhibition, and some first impressions after opening.

Introduction

The classical projection planetarium has over decades been regarded as optimal environment for the communication of fundamental concepts in astronomical phenomenology. With a dedicated opto-mechanical projection system, the entire sky can be projected onto the hemispherical dome which spans over the visitors, providing an immersive experience of being under the starry night sky. The lower limit of the dome representing the mathematical horizon is sometimes decorated with cut-out city skylines, in other planetaria the horizon is decorated with various projected panoramas. However, explanations of architectural alignments with features on the landscape horizon are not correctly possible when part of the view of interest lies on the ground and thus below the mathematical horizon. Therefore systems involving computer graphics solutions seem more useful for the purposes of visualizing horizon alignments.[2]

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[1] Georg Zotti: Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology; Florian Schaukowitsch and Michael Wimmer: Institute of Computer Graphics and Algorithms, TU Wien.

[2] G. Zotti, A. Wilkie, W. Purgathofer, 'Using Virtual Reconstructions in a Planetarium for Demonstrations in Archaeo-Astronomy', in Cecilia Sik Lanyi ed.,

Georg Zotti, Florian Schaukowitsch and Michael Wimmer, 'The Skyscape Planetarium', *The Marriage of Astronomy and Culture,* a special issue of *Culture and Cosmos*, Vol. 21, nos. 1 and 2, 2017, pp. 269–81.
www.CultureAndCosmos.org

In the last decade or so the use of desktop planetarium programs running on conventional computers has become almost commonplace. A few of these programs allow the inclusion of a user-created panorama photograph to be shown in the sky/ground boundary zone, and can also show parts of the visual environment which are located below the mathematical horizon. When the panorama has been properly aligned to a surveyed horizon line, the combined display of horizon panorama and sky simulation can act as proper visual representation of such land-and-sky environments for which the term 'skyscape' has recently been introduced[3] and allow orientation studies almost like on-site, as long as three-dimensional surveys or motions around small objects like stone circles are not required. One of these programs is the well-known open-source program Stellarium,[4] which has grown into one of the favourite simulation applications used by observing amateur and even professional astronomers and also many researchers in cultural astronomy.[5] The freely available source code allows code review and addition of features as required.

Third Central European Multimedia and Virtual Reality Conference (Proc. CEMVRC2006) (Pannonian University Press, 2006), pp. 43–51.

[3] See, for example, Fabio Silva and Nicolas Campion, eds., *Skyscapes: The Role and Importance of the Sky in Archaeology* (Oxford: Oxbow, 2015).

[4] http://stellarium.org [accessed 27 Dec. 2016].

[5] Applications seem almost as numerous as cultural-astronomy research topics. For example, 9 of 70 papers from the SEAC 2015 proceedings published in *Mediterranean Archaeology and Archaeometry* 16, no. 4 and available online at http://www.maajournal.com/Issues2016d.php mention the use of Stellarium, from orientation research to ethno-astronomical studies. Skyscape experience in particular is discussed in that volume by R. Mukundu, W. Ktorides and D. Brown, 'Skyscapes of Clifton', *Mediterranean Archaeology and Archaeometry* 16, no. 4 (2016): pp. 33–39. Applications of Stellarium towards light pollution education include G. Zotti and G. Wuchterl, 'Raising Awareness of Light Pollution by Simulation of Nocturnal Light of Astronomical Cultural Heritage Sites', in Fabio Silva, Kim Malville, Tore Lomsdalen and Frank Ventura, eds., *The Materiality of the Sky: Proceedings of the 22nd Annual SEAC Conference 2014* (Ceredigion, Wales: Sophia Centre Press, 2016): pp. 197–203. Stellarium's hitherto unique 3D mode has been used for orientation research, for example, in B. Frischer, G. Zotti, Z. Mari, G. Capriotti Vittozzi, 'Archaeoastronomical Experiments Supported by Virtual Simulation Environments: Celestial Alignments in the Antinoeion at Hadrian's Villa (Tivoli, Italy)', *Digital Applications in Archaeology and Cultural Heritage* 3 (2016): pp. 55–79.

The Stonehenge exhibition

The Austrian MAMUZ museum of prehistory is located in Asparn/Zaya and Mistelbach, about 50 km north of Vienna. The Mistelbach site has been added a few years ago as location for annually changing exhibitions. For the 2016 season, a team around Wolfgang Neubauer, director of LBI ArchPro, has curated an exhibition[6] around new results of the Stonehenge Hidden Landscape Project (SHLP)[7] in which LBI ArchPro had performed the large-scale motorized geophysical prospection which had detected several hitherto unknown monuments. The high exhibition hall, previously a factory for agriculture machinery, offered a unique opportunity: it provided enough space to set up original-size replica of large parts of the central trilithon horseshoe. A view which included the impression of the outer Sarsen circle should be added with some visual means. The rectangular layout and size of the hall precluded an all-encompassing circular projection, so quite early in the exhibition planning phase the idea came up to have the open side of the replica horseshoe's main axis (north-east) point towards a wall and show the view out of the stones as projection on the upper floor of the hall. The visitor would be surrounded by the trilithons, but at eye level with the lintels, an elevated position which cannot be experienced on site. The view direction obviously invited development of a splendid view of the summer solstice sunrise over the heelstone, which can however only be observed from the ground. So quite early it was clear that we would switch through vistas of several places on the projection wall, and that we should indeed tell a story of Stonehenge also with views of important locations in its vicinity. The projection should fill the visitors' field of view, so the exhibition team decided to develop a 4 m high projection area of 20 m or more width, which can only be achieved by installing several projectors.

Movie or real-time graphics?

The exhibition team was investigating the options for simulating views of Stonehenge and other sites in the area and their development over the course of millennia. These included the production of a pre-rendered movie, or a simulation involving a scriptable panorama viewing program. Given that Stellarium had scripting capability, can show high-resolution

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[6] MAMUZ, *Stonehenge – Verborgene Landschaft. Begleitheft durch die Ausstellung* (Guide brochure through the exhibition), (2016).
[7] C. Gaffney *et al.*, 'The Stonehenge Hidden Landscapes Project', *Archaeological Prospection* 19 (2012): pp.147–55.

panorama views as 'landscapes' and already provided a multitude of projection options including cylindrical or Mercator projections, it seemed better-suited for the wide screen envisioned than most other panorama viewing applications which are mostly limited to a standard perspective projection.

Using Stellarium promised the added benefit of using the projection system for special occasions where pre-produced content is not applicable. Given that Stellarium is first and foremost an astronomical simulation program, it would enable us to demonstrate the astronomical elements in landscape and architecture which have been identified around Stonehenge, and astronomical facts like the slow changes of the ecliptic obliquity.

Fig. 1. Sunrise in Late Neolithic Stonehenge. Panorama by LBI ArchPro's media partner 7reasons based on LBI ArchPro's image-based model. Simulation with Stellarium 0.15.0.

Developing the Skyscape Planetarium

In the year before the exhibition opened (March 2016) we had time to make Stellarium ready for running a show on such a big screen, which brought several useful additions to the program in general. At first we thought about using five synchronized small computers (one per projector), but soon found that a single modern PC equipped with a graphics card that can drive several screens or projectors would be far easier to handle. The raw pixel count of 5x 1920x1200 pixels gives a viewport size of

9600x1200 pixels, which was tested to run sufficiently fast. The 5 projector wall was now redesigned into a partly curved screen which required edge blending, and given the 25x4 m screen area results in a net display area of 100 m² with 7500 (equivalent width) x1200 pixels. The placement of the two rightmost projectors turned out to be challenging: they had to be mounted so that their diverging projection beams avoid one of the trilithon replica and still overlap and seamlessly blend on the screen. Using this additional projector, as seen from the inner area of the trilithon horseshow, the screen extends behind the stones, which adds to the immersive experience of being part of this skyscape, but requires that no important or detailed content is presented in that section of the screen.

We had planned to develop a narrated, media-rich show in the months before the opening on a computer identical to the show PC, but only with regular screens attached. Panorama renderings of several sites in the landscape, based on a terrestrial laser scan taken by LBI ArchPro during the SHLP, from which we had erased all modern constructions like road dams or houses, were prepared by our media partner 7reasons. With this setup we could run a few performance tests and landscape pans, and look for any rendering artefacts which may not be apparent on a single screen.

The best projection usable on the wide screen is the cylindrical equi-rectangular projection, where the mathematical horizon forms a straight horizontal line on the screen. Centring the horizon in the viewport would put it in 2 m height on the wall, and ground and sky would get equal share of screen space. However, depending on narrative context, the horizon should be allowed to shift up (to show more of the ground in aerial views, e.g., of the Cursus stretched out in all its length) or down (to show ground views with the Sarsen circle surrounding the visitor), which required the implementation of such an off-center projection mode that also had been on Stellarium's public feature wishlist for years. When the horizon line is moved to the bottom of the screen, and we zoom out to show 180° of the horizon, the vertical view angle is about 30°. From the viewpoint in the centre of the stone circle, the ring of lintels lies at about 10° altitude, but the horseshoe lintels just extend to about 30°.

Fig. 2. The Skyscape Planetarium, a 25 m wide partly curved screen with 4 m height, providing a view out of Stonehenge from an elevated position within the horseshoe. An automated tour takes the visitor to several sites in the area and explains the landscape development from the Mesolithic to the Bronze Age. The horizon line can move up or down to show more of the foreground or sky, respectively.

The astronomical simulation had to become more accurate than what was available in version 0.13.3 to properly simulate the sky of the Neolithic if not earlier. Stellarium had been developed mostly for contemporary amateur astronomers, with planetary positions from the analytical VSOP87 model which is recommended for use only for years –4000 to +8000, with degraded (undefined) accuracy outside this range. Also, precession had been implemented in a very simple way, and ecliptic obliquity was assumed constant, so that the slight but noticeable changes in solstitial sunrise positions between the time of construction and today could not be demonstrated.[8] The biggest astronomical improvement was therefore the implementation of a recent proper long-time model of precession of the equinoxes and changes in the obliquity of the ecliptic.[9] Also, the long-time

[8] See a discussion about skyscape experiences and about a few well-known limitations of an even older version of Stellarium in D. Brown, ‘Exploring Skyscape in Stellarium’, *Journal of Skyscape Archaeology* 1, no. 1 (2015): pp. 93–111.
[9] J. Vondrák, N. Capitaine and P. Wallace: ‘New Precession Expressions, Valid for Long Time Intervals’, *Astronomy & Astrophysics* 534 (2011): p. A22.

planetary position ephemeris DE431 was made accessible to the program.[10] This can be installed as an optional data file and provides NASA/JPL's results of a numerical simulation of planet positions for the year range –13000…+17000, so that Stellarium should now be able to simulate planetary phenomena even over a Mesolithic landscape.[11] (Note that without an alternative way of computation, we cannot give estimates of total accuracy at the moment and would invite further investigation by other researchers.)

For several years, Stellarium has been able to run pre-programmed scripts, which allows the development of complete astronomy shows. The scenes and narration should also be enriched with image and movie inserts, which necessitated the re-activation and enhancements of Stellarium's multimedia extensions that had been disabled years ago due to changes in the internal software structure.

The RemoteControl plugin

Running the shows in a completely automated manner with occasional manual access required the development of another new extension (plugin): a remote control interface which allows sending commands via network. In addition to triggering the beginning of the next show run, it should also allow the manual control of the application on a separate handheld device, in case a museum guide or lecturer wants to take over the screen and show some specific views without also showing the graphical user interface (GUI) on the projected wall.

A thorough rewiring of Stellarium's internal modules has allowed us to access their properties and settings in a much more consistent manner than before. In addition, the new plugin provides an HTTP network interface which fulfils both purposes: On access with a web browser, a mixed HTML/JavaScript interface which replicates most tabs and buttons of the usual Stellarium GUI is presented to the user. Actions which are commonly performed with mouse and keyboard (e.g., panning or zooming) had to be implemented with a few additional intuitive GUI elements. Accessing the HTTP interface with particular command-line programs allows triggering of single commands or the start of scripts.

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[10] W.M. Folkner, et al., 'The Planetary and Lunar Ephemerides DE430 and DE431', *IPN Progress Report* 42–196 (Feb. 2014), available from URL: https://ipnpr.jpl.nasa.gov/progress_report/42-196/196C.pdf

[11] G. Zotti, 'Open-Source Virtual Archaeoastronomy,' *Mediterranean Archaeology and Archaeometry* 16, no. 4 (2016): pp. 17–23.

To complete the requirements of a fully automated setup which should be easy to operate for the museum staff, our media partner 7reasons developed an operation panel based on a tiny Raspberry Pi single-board computer with touch screen which allows the museum operators to switch on the PC and 5 projectors with a single keypress on the touch display. The Raspberry Pi in addition sends the required script trigger command every 25 minutes during daytimes via cronjob. To start shows after hours, a manual trigger is available on the control panel. If required, an operator in front of the wall can access almost all of Stellarium's controls using a web browser on a handheld tablet computer connected via WLAN.

We have already seen that the web browser based control interface is welcome also in other settings like presentations at amateur astronomers' meetings when operators or presenters want to control the scene displayed on the screen without exposing graphical user interface panels to the audience. Not every functionality of Stellarium was deemed a requirement for this new interface, configuration options, optional downloads or also features of the telescope control or ocular plugins have not been exposed. However, the webpage which comes with the installation can be copied and adapted to other users' requirements by adding or removing functionality, changing screen layouts etc. A more compact layout for a 7 inch tablet which has been developed for use in the museum is provided as example.

The final weeks

With software and the hardware installation at the museum almost ready, we finally received our narrative text, 'The Story of Stonehenge', by the exhibition's co-curator Julian Richards to base the show on.[12] We selected the fitting existing horizon panoramas but found we need a few more created by our partner 7reasons (about twenty in total; creating high-quality renders take many days of computation time, so these should be decided and produced early in the show development), picked additional material to use as inserts from our material collection and found we had to make or find a few more. Less than two weeks before opening the bilingual narration recordings became available, crucial for timing the transitions and pans over the landscapes. Only then a few more issues with automated pans and transitions became apparent which could not be tested before, but which required a few ad-hoc amendments to Stellarium's script capabilities. The opening week approached, and final adjustments could

[12] Based on Julian Richards' *Stonehenge: The Story So Far* (English Heritage, 2007), but with additions resulting from the SHLP.

only be made on-site. While the showcases were filled with exhibits in bright working light conditions, we were desperately trying to calibrate the blending zones in the panorama wall. With work lights switched off later that day, some illuminated showcases were identified which caused severe light spill onto the screen. The worst cases could be fixed before the exhibition opened, but of course exhibition designers should take such light spill on open screens or even glaring show case illumination into account. Finally it was possible to fine-tune the script to the wide screen, a process which lasted literally until minutes before the first pre-opening tour was given to selected guests.

The system has run successfully six days per week during the eight-month exhibition season. A few minor improvements to the show were installed in this time.

Fig. 3. A fisheye view of the exhibition's upper floor. Visitors are sitting on the bench circled by the Horseshoe replica, watching the automated show. The Skyscape Planetarium shows a view into the landscape with several inserts explaining building methods.

Reactions

The exhibition topic 'Stonehenge' is attractive to a wide audience, and the exhibition has been the most successful at the MAMUZ Mistelbach site so far, so that it will stay for the 2017 season. The combination of full-size replica of the horseshoe sarsens with the huge screen makes a big impression to even expert visitors, and reactions have been throughout positive. Visitors can sit on the resting bench and let the narration take them from the Mesolithic hunting site of Blick Mead through the development of long barrows, causewayed enclosures, Cursus monuments, Durrington Walls, Woodhenge and finally Stonehenge in its various phases, ending with the burial mounds in the Bronze Age, recapitulating the main stations of the exhibition which they had seen on the ground floor. Headphones can be used to listen to Julian Richard's English narration instead of the German translation coming from the loudspeakers. Some sites are shown in several phases of use centuries apart. On the other hand, given the ongoing discussion and apparent current inability to identify one stratigraphically correct order of construction and reconstruction phases of Sarsens and Bluestones,[13] we do not show views of Stonehenge 'under construction' but only the finished monument, based on LBI ArchPro's image-based model of the site and reconstruction of obviously missing parts. To connect the visitor to the prospection research done by the LBI ArchPro, the final scene shows our motorized sensor systems rushing through the Bronze Age landscape, detecting hidden monuments.

The mostly archaeological content and rather fast pace of the narration provide only very few moments where Stellarium's astronomical capabilities are exploited. These include a reference to the newly found 'Cursus pits' possibly marking the summer solstice sunrise and sunset seen from the heelstone and just a few seconds of summer solstice sunrise.[14] During the breaks between two shows, the system repeats the famous scene of the majestic summer solstice sun rising and slowly moving over the heelstone (Fig. 1). This silent scene, which runs for about three minutes, was intended to provide enough time for visitors to relax, talk, enjoy the view, experience and make themselves part of this skyscape, or take photographs of themselves with that 'epic' sunrise in their backs. However, just these few minutes of silent, narration-free sunrise, which was also not accompanied by any of the well-known 'sunrise' music pieces from the movie industry or any other soundscape, reportedly caused confusion and made some visitors report to the museum staff that the system was 'stuck'. It appears that in our time of ever-louder media overkill, a few moments of

[13] T. Darvill, P. Marshall, M. Parker Pearson and G. Wainwright, 'Stonehenge remodeled', *Antiquity* 86 (2012): pp. 1021–40.
[14] Gaffney *et al.*, 'The Stonehenge Hidden Landscapes Project'.

silence and just moderate time-lapse come all too unexpected. (A sunrise in natural speed had immediately been considered too slow.) This was finally remedied by adding the Museum's mascot, a little mammoth named Zotti (unrelated to the first author), to the screen, explaining what is seen on display and announcing that the next narrated presentation would play soon.

Night at the Museum

On a few occasions, the museum provides special evening tours for elementary school children. The lights are switched off, and the young visitors can explore the exhibition during a guided tour using flashlights. Eventually they wake up a friendly 'man from the past', an actor explaining some exhibits using an unknown language and acting, and performing some music or dances with the children. In the lower floor, the connection of monuments like timber circles to the course of the sun and seasonal changes, with the solstices as turning points, are introduced to the children. Ascending to the upper floor, the group enters a nightly scene of Stonehenge, with the stars twinkling through the Sarsen circle. Only here the astronomical capabilities of the Skyscape Planetarium simulating a starry sky together with landscape panorama and ground are utilized, but serve to create the nightly ambient only, unfortunately without being part of the didactic narrative. After explanation of the exhibited beaker pottery and bronze artefacts under flashlight conditions, morning twilight sets in (manually controlled using the tablet computer), and the summer solstice sunrise is greeted with a little music and dance performance by the 'man from the past', soon to be joined by the children, close to the end of their excursion into the past.

Fig. 4. For the Flashlight Tours, the Skyscape Planetarium can deliver stunning night ambient settings.

Final thoughts

The huge screen lets visitors almost immerse themselves into the landscape, even though the panorama renderings are only two-dimensional images pre-rendered in a given lighting setting. An interesting observation during the simulation from sunrise to afternoon was an almost three-dimensional appearance of the Sarsens caused by the independent and changing light brightness mixing of sky hues and landscape panorama.

We have not tried Stellarium's Scenery3D mode on the big screen yet, which would really allow a virtual walk through the landscape. The Stonehenge landscape model would have to be simplified (especially cleared from highly detailed vegetation only possible to show in the pre-rendered landscapes) to allow such an interactive mode.

Adding the astronomical simulation quality of Stellarium, such a system appears much better suited than the classical half-domed planetarium for research and demonstration of prominent skyscapes in the sense of combination of landscape, built monuments and the celestial experience,[15] although in the course of this museum installation such further application is currently not exploited. The current exhibition's topics concentrate on the archaeology and do not highlight the various

[15] Silva and Campion, *Skyscapes*.

archaeoastronomical theories around Stonehenge in any detail, and therefore the exhibition show uses mostly its aspect of ‘moving panorama display’, and does not exploit the full astronomical capabilities of Stellarium. A similar setup with more astronomical content should be replicable at other sites, though.

Acknowledgements

The Skyscape Planetarium has been developed as part of the exhibition ‘STONEHENGE. A Hidden Landscape.’ at MAMUZ museum Mistelbach, Austria, which has provided considerable developing time for several new and improved features which have been released in Stellarium version 0.15.0 (released 31 July 2016).

In the weeks before opening, we were supported also by Stellarium maintainer Alexander Wolf (Barnaul, Russia) who even created a new customized installer package with the final changes built overnight just in time for setup at the museum two days before opening.

Florian’s work on the RemoteControl plugin, and the DE431 integration, were supported by the ESA Summer of Code in Space programme 2015.

The Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (http://archpro.lbg.ac.at) is based on an international cooperation of the Ludwig Boltzmann Gesellschaft (A), the University of Vienna (A), the Vienna University of Technology (A), ZAMG-the Austrian Central Institute for Meteorology and Geodynamics (A), the Province of Lower Austria (A), Airborne Technologies (A), 7reasons (A), the Austrian Academy of Sciences (A), the Austrian Archaeological Institute (A), RGZM-the Roman-Germanic Central Museum Mainz (D), the National Historical Museums – Contract Archaeology Service (S), the University of Birmingham (GB), the Vestfold County Council (N) and NIKU-the Norwegian Institute for Cultural Heritage Research (N).

ISSN 1368-6534

CULTURE AND COSMOS

A Journal of the History of Astrology and Cultural Astronomy

The Marriage of Astronomy and Culture: Theory and Method in the Study of Cultural Astronomy

Papers from the 2016 SEAC Conference

Edited by Liz Henty, Bernadette Brady, Darrelyn Gunzburg, Frank Prendergast and Fabio Silva

Volume 21 Number 1 and 2
Spring/Summer and Autumn/Winter 2017