A Virtual Reconstruction Approach for Archaeoastronomical Research

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***Abstract*—Archaeoastronomical research often suffers from lack of data about the three-dimensional situation of prehistorical monuments in their respective landscapes. In our project, we have reconstructed, in virtual models, a series of similar Neolithic monuments with alleged astronomical orientation pattern in their respective landscape. Astronomical extensions to the modelling software and to the models, or the direct inclusion of the models into desktop astronomy software, opens up valuable insights into topics long debated only on flat paper maps.**

Keywords—Archaeoastronomy, desktop planetarium, virtual reconstructions.

I. Introduction

Celestial events and processes are present in our everyday life whenever we talk about simple temporal concepts like days, seasons, or years. Cyclically recurring events in the sky and their impact on everyday life must have evoked the interest of men very early in history, and the connection of celestial events and ancient cosmologies, i.e., systems of beliefs about the nature of the world and the role of humans in it, appears to be evident almost worldwide [1, p.83]. Even today, an irrational association of such events with personal fate appears to gain new popularity, and many ideas about celestial rituals which "the ancestors" may have performed are firmly present in popular culture, much more in fact than can be currently proven scientifically.

Archaeoastronomy is an interdisciplinary science combining archaeological findings with classical astronomy and astronomical phenomenology, i.e. the analysis and description of processes visible in the sky without optical instruments. One topic of archaeoastronomy is the analysis of orientation of prehistorical and historical architectural structures with respect to celestial patterns, like rising or setting points of the sun at the solstices, or similarly extremal lunar standstills (lunistices). Bright stars may also be topic of investigation in cases when the structures are well-dated by archaeology: due to a slow drift (precession) of the Earth's rotational axis, stars change their position on the horizon over centuries. In cases of still existing architecture, like the pyramids and temples of Egypt, a direct survey of the structures in their landscape provides the best and usually clearest results. In order to demonstrate such results, often acquired in remote locations, to a wider audience, virtual reconstruction, physically correct light simulation with computer graphics and demonstration in VR laboratories have gained some popularity. For instance, the orientation of precolumbian temple remains at lake Titicaca was studied in a large-scale VR installation [3]. Also the impact of natural and artificial illumination in an Egyptian temple has been investigated with physically based computer graphics [4]. The ubiquitous availability of affordable powerful graphics hardware has led to an enormous increase of impressive virtual reconstruction projects in the last years, often in form of unfortunately costly collaborations between archaeaologists providing their data and scientific expertise and experts in virtual architecture actually building models of high visual appeal.

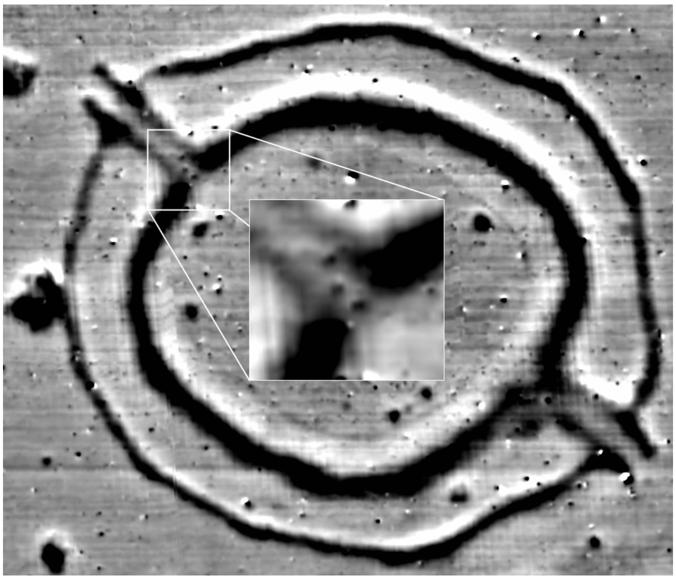

Fig. 1. Geomagnetic prospection of KGA Pranhartsberg 2 [2, Tafel 91], showing typical characteristics of a KGA: two almost circular ditches, and traces of a palisade still visible. Two opposing entrances with radial connecting ditches. The North-eastern entrance (enlarged in the inset) shows two magnetic anomalies which may have been postholes.

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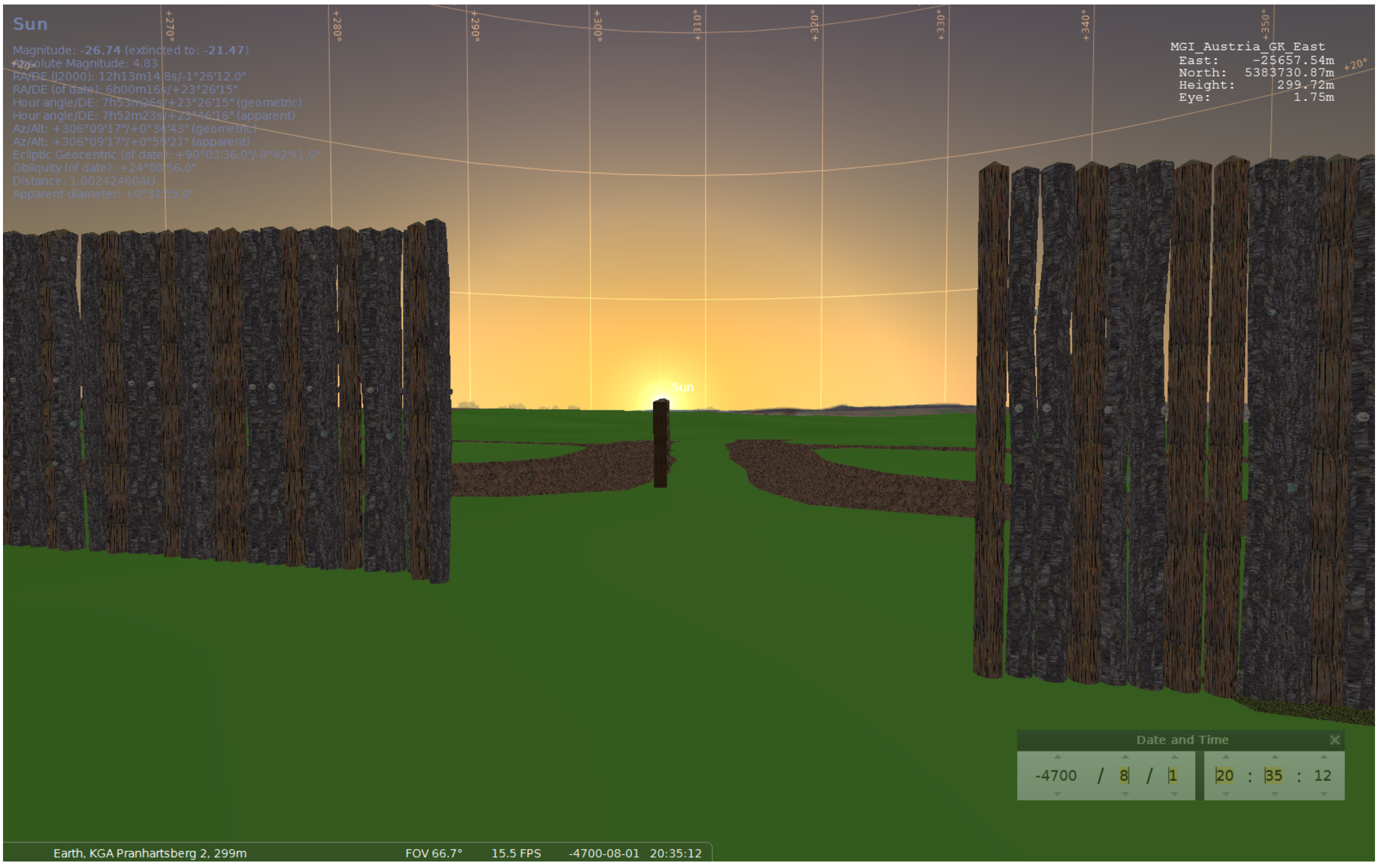

Fig. 2. Simulation of the summer solstice sunset at KGA Pranhartsberg 2, shown in the Scenery3D plugin for Stellarium. The magnetic anomalies visible in the north-western entrance have been interpreted as postholes, and the posts placed in them accurately provide what may have been an indicating device for the setting sun.

However, there existed monuments built in prehistoric times which are nowadays lost for a direct investigation, and only indirect evidence is present indicating their earlier appearance. In such cases, also affordable virtual reconstruction based on archaeological data and investigation in a three-dimensional virtual environment offer new possibilities and insights. For example, a VRML model including static sky snapshots from a desktop planetarium draped over a skydome geometry was used to investigate potential astronomical orientation patterns of the Neolithic triple henge structure of Thornborough [5]. Such projects call however always for multidisciplinarity in that they require knowledge about the archaeological context and existing structures on the one hand, skills to derive accurate georeferenced models, and the astronomical knowledge to apply existing or develop new software, circumventing or correcting possible shortcomings. For instance, while simulation of contemporary daytime conditions including shadows is nowadays a widely available feature of architectural visualisation and city planning software, the slightly different solar positions of prehistoric times, and especially stellar positions, are generally not available in an accuracy required for archaeoastronomical research and simulation. Also, some important effects like atmospheric extinction and refraction are only rarely found in astronomical desktop programs.

Since the 1980s, a large number of a certain class of Neolithic circular enclosures has been discovered by aerial archaeology in a large area of central Europe, involving several archaeological culture groups living in the area of today's Hungary, Austria, Slovakia, the Czech Republic, Germany and Poland. Radiocarbon dating reveals their time of use lying around 4900–4500 B.C. Geomagnetic prospection and partial excavations clarified the characteristic appearance of these so-called *Kreisgrabenanlagen* (KGA) which consisted of 1–3 (normally) circular, V-shaped ditches enclosing up to 3 palisade rings and usually interrupted by 2 or 4 opposing entrances (Figure 1). They cannot be interpreted as fortificatory structures or livestock corrals, but with their large diameters of up to 200m they mark a monumental structure linked to a nearby settlement, and are now interpreted as multifunctional place for rituals [2]. They are thought of having provided a secluded space, separating the inside from the outer environment, with the palisade wall preventing potential external witnesses from knowing what happens inside, and vice versa. Since the 1990s, a possible astronomical orientation of the entrances has been discussed (e.g. [6], [7]). The observer is usually assumed to have been standing in the centre of the respective KGA looking out of an entrance, although no archaeological feature can usually be identified that could have acted as foresight. In

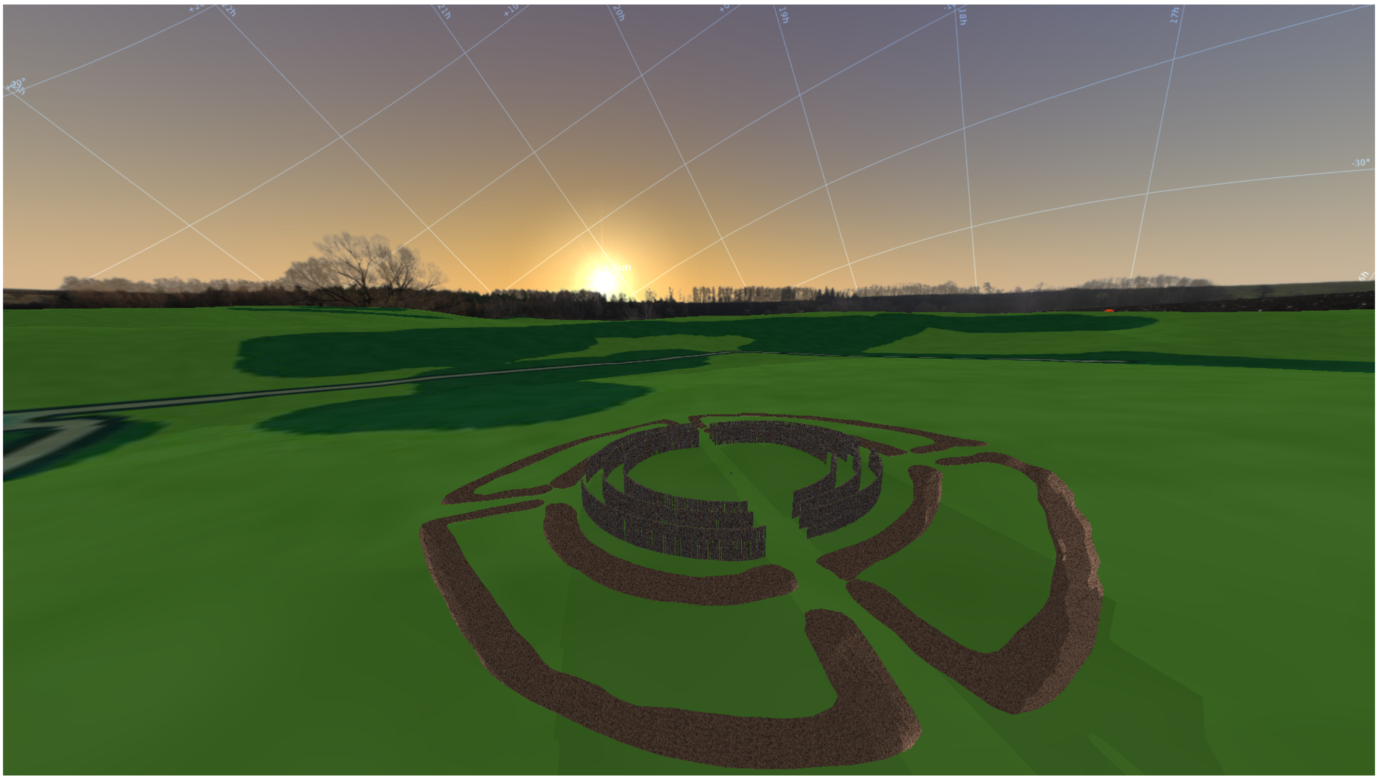

Fig. 3. Simulation of the winter cross-quarter ("candlemas") sunrise at KGA Pranhartsberg 1, shown in the Scenery3D plugin for Stellarium combining a current photo horizont with the three-dimensional model which also casts shadows. The viewer is slightly above ground to also show an overview over the whole scenery. The accuracy and deliberateness of this orientation is unclear, because the ridge over which the sun rises may have eroded, and not as many KGA as previously suspected show this orientation pattern.

fact, the inner area is typically empty, or at least all superficial structures have eroded away in the long times since then. Another direction of interest, in cases where radial ditches connect two or more ditch rings at the entrances, is the sight along those or along the earth bridge as seen from the inside. KGAs in Bavaria have been found showing orientation towards the solstices [8], while KGAs in Slovakia have been associated with lunistice directions by connecting opposing entrances [9].

II. Previous work

In 2003/04, 28 ground plans derived from a then ongoing systematic campaign of geomagnetic archaeological prospection of KGAs [2] had been available for a first round of astronomical investigation. From these plans and several artificial horizons derived from GIS-based analysis of a digital elevation model (DEM), a slight pattern of systematic astronomical orientation of entrances and gaps in the palisades also in many Austrian KGAs seemed to emerge. Besides a few solstitial orientations of entrances, there appeared to be a connection, at some places, with the sunrises or -sets at specific dates right in between solstices and equinoxes, the so-called cross-quarter days. These are still prominent in the Irish calendar, and our All-Saints day, Candlemas and Mayday are likewise closely related. In addition, also some orientations towards rising and setting points of a few stars which could then also otherwise be connected by simultaneous rising and setting events which may have played a calendrical role seemed to manifest themselves [10], [11], [12]. Panorama horizons created from two virtual reconstructions were used in a desktop planetarium for animated simulations of these results, and some experiments were also performed in a planetarium in order to exploit the much higher visual and immersive quality of this dedicated sky simulation environment for public presentation. On the downside, the lack of contextual visual information, i.e., a simulated view of the foreground, has been identified as a shortcoming in such an environment [13].

From this incomplete data it appeared possible that many KGAs were built with some astronomical elements, however, a final conclusion was not possible at that time because crucial information, especially horizon elevations, were not available for most of the KGAs, and the professional creation of 3D models from which panoramas were created was costly. The effect of an elevated horizon is that it shifts both rising and setting azimuths southward (on the northern hemisphere) and would therefore invalidate results from evaluation on a horizon assumed flat by default. Also, because many KGAs are not exactly circular and no mark is available where a potential observer could have been located, static panoramas created by external contractors are somewhat insatisfactory to investigate potential prehistoric stellar alignments along several options provided by linearly stretched, occasionally slightly non-radial passages of reconstructed prehistoric architecture.

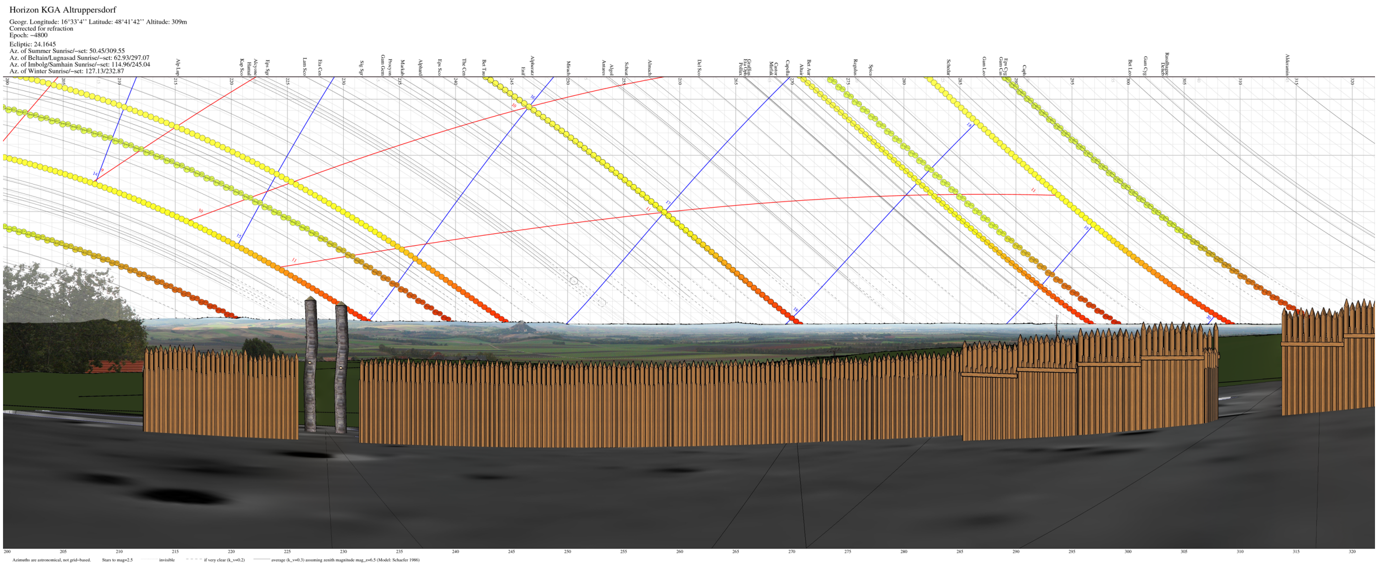

Fig. 4. A partial panorama taken from the centre of KGA Altruppersdorf, enriched with a model snapshot from Sketchup. From the three-dimensional model and the wide view into the landscape we see and experience the effect of the sloped terrain: the observer is not really separated from the rest of the world, but can see over a palisade of average height. A prominent peak left of center almost coincides with sunset on the winter crossquarter days, suggesting calendrical significance to the place, which was however unique to this location. On the right side, the summer solstice sun (chain of solar disks) is setting in the direction of the entrance.

III. Project ASTROSIM

A thorough investigation of the possible astronomical orientation of the Austrian KGAs had to wait for our current project ASTROSIM which is now entering its final phase. In this project we combined the results from the previous geomagnetic archaeological prospections [2] with newly gathered survey data, GIS analysis, virtual reconstructions and a newly-developed three-dimensional walkthrough simulation in an advanced open-source desktop planetarium program. In this paper, we describe the project and then present the main results.

A. Surveys

Aside from unsharp soil and crop marks, nothing remains visible in today’s landscape from these monumental structures, so there are also no physical remains like standing stones which could be analysed for their potential function as target markers against the horizon in a field survey. The only new data that could be acquired in the field were accurate horizon profiles which were recorded with a total station and a digital SLR camera. The first visited site also showed a promising conspicuous peak very close to the direction of a cross-quarter sunset (Figure 4), however the later surveys showed this was the only site with such a prominent landscape feature, so any evidence for an intentional selection of the site motivated by that peak could not be furnished.

B. Data processing

The major part of the work had to take place in virtual space and required the combination of GIS and 3D modelling software and some new developments and extensions of an open-source desktop planetarium program.

1) Horizon panoramas: As background for the measured horizon profile, a diagram with relevant astronomical data (azimuthal grid, declination curves, and solar tracks for solstices, cross-quarter and equinox sun as well as lunar tracks for the 4 lunistice declinations, including effects of topographic parallax) was developed. It also shows diurnal paths for the brighter stars for the epoch, with indications of their extinction altitudes for best and average visibility conditions [14], and accounts for the raising effect of atmospheric refraction which appears to slightly shift all horizon intersections towards the north. The photographic panoramas were stitched with the open-source program Hugin [15] and aligned to the measured horizon line in an iterative process. The sky was then made transparent in an image editor (background of Figure 4).

From this diagram-enhanced panorama, astronomical declinations (the latitude coordinate in the astronomical equatorial coordinate system) and potential celestial targets of horizon intersections can be immediately read off, or, without the diagram, the calibrated panorama can also be used in modern desktop planetarium programs like the open-source program Stellarium [16] to gain a good impression of today’s on-site conditions.

2) 3D Modelling: We use a geographical information system (ArcGIS) to collect, manage and display all georeferenced data related to our monuments. Unfortunately, direct 3D modelling is very cumbersome, inviting data export and the use of dedicated 3D modelling programs. An export plugin working in ArcGIS 9.3 allowed us to export, for each site, parts of a digital elevation model in TIN (triangulated irregular network) format, background maps or aerial images, the georeferenced magnetogram and outlines of the main features (ditches, palisades) of the KGA into Google Sketchup. This modelling

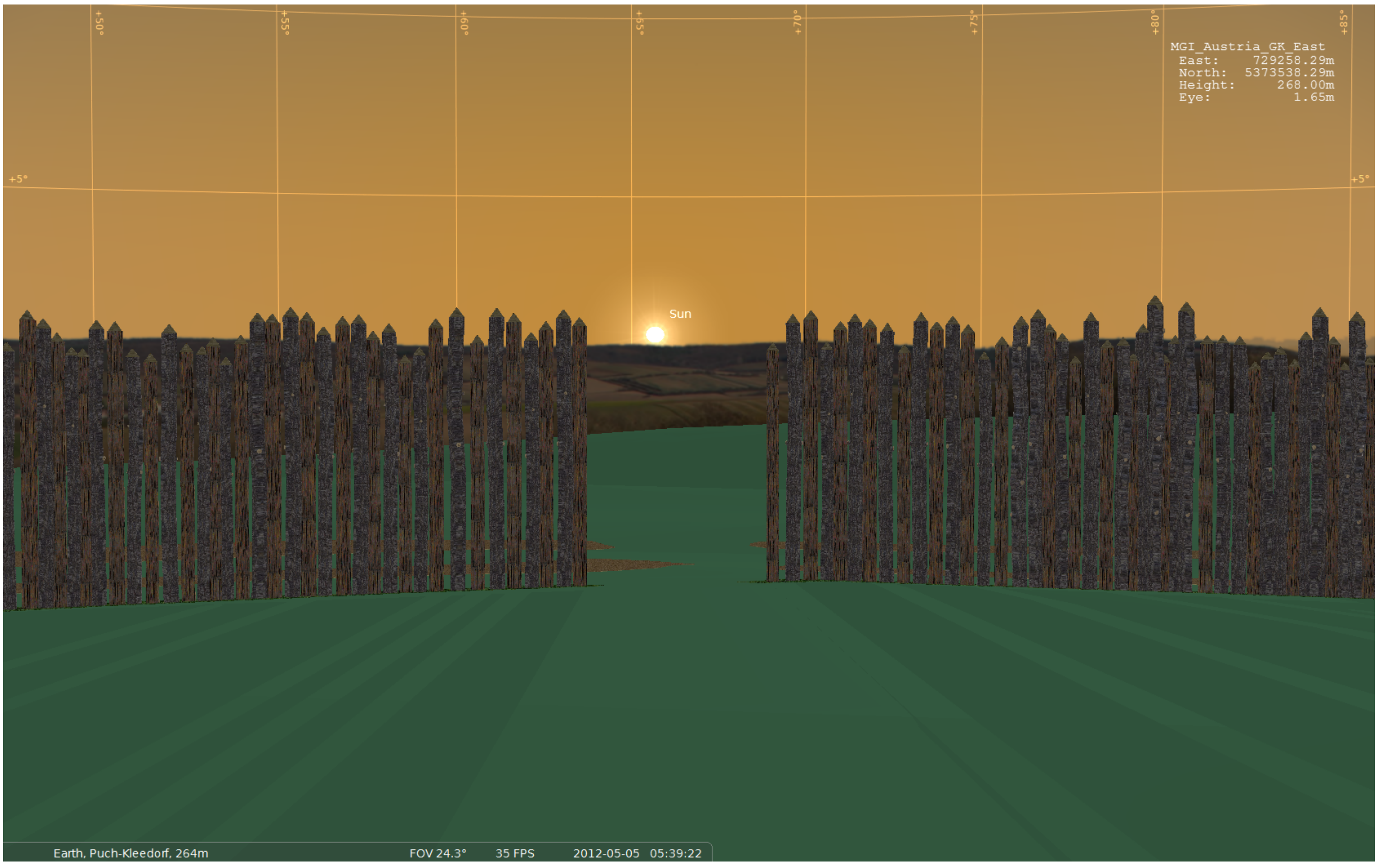

Fig. 5. Simulation of the summer cross-quarter ("Mayday") sunrise at KGA Puch, shown in the Scenery3D plugin for Stellarium. Although the orientation is practically perfect in this unique case, it also follows the local terrain slope downward. Also, the gap in the palisade, constructed based on the traces still visible in the geomagnetic surveys, appears too wide to having singled out the date in question.

program is simple to use also for occasional modelling by non-experts, is available in a cost-free (but not open-source) version, and it is widely used especially to create the 3D buildings in Google Earth. A huge advantage of this program over many others is that models are georeferenced, that is, both geographical position on Earth and orientation are stored in the model file. Another plus is that it is extendable by plugins, in the easiest case in the form of Ruby scripts. Sketchup also allows the proper simulation of (hard) shadows, but only for days starting in 1970, so that for solstices in prehistoric times, where the earth's axis was stronger inclined, some trickery is required to achieve the required larger solstitial morning and evening amplitudes. Unfortunately, support for this export plugin was lost with the current version 10 of ArcGIS, and the Collada models now exported directly are no longer georeferenced.

In Sketchup, the maps, magnetograms and outlines of ditches and palisade trenches were projected onto the TIN, and the ditches cut into the "virtual soil", and, where seen in the magnetograms, palisades were put up to provide an approximate representation of the past structures usable for geometric evaluation. In this phase, achieving a natural or even photorealistic look was not required and, for reasons of development time, not intended. Also, the exact shape and extent (height) of the wooden structures cannot be derived with high fidelity just from the palisade traces, and different possible forms were tested on different sites.

A problem with the photo panorama is that it was taken only on one spot (the KGA centre), while in the 3D simulation we want to walk around on the terrain. If the horizon is sufficiently far away, the photo can however be used to represent a background of infinite distance. A loader plugin was therefore developed for the panorama diagrams. Sketchup has no sky box which could provide a background of infinite distance without parallax shift. The Sketchup requirement of putting it on geometry of limited distance means that this geometry, simply a part of a sphere extending over the landscape, had to be linked to the observer eye to avoid parallax shifts when moving through the virtual scene. Together with the diagram-enhanced panorama, the actual astronomical investigation could now be performed using the models inside Sketchup.

C. Astronomical Simulation

As mentioned above, we use Stellarium as desktop planetarium. It is still under active development, but offers several features interesting also for its applications in the fields of ethno- and archaeoastronomy, like exchangeable artistic constellation figures, or several projection modes which allow

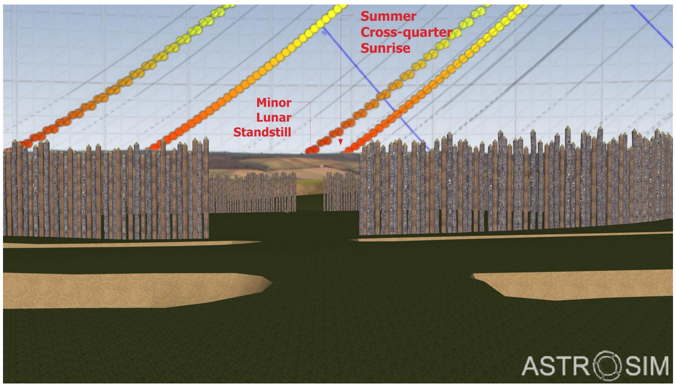

Fig. 6. Potential lunar orientation at KGA Puch, noticed in the direction from south-western towards north-eastern entrance [9] and providing a different astronomy-motivated explanation for the same general direction as the solar cross-quarter orientation shown in figure 5.

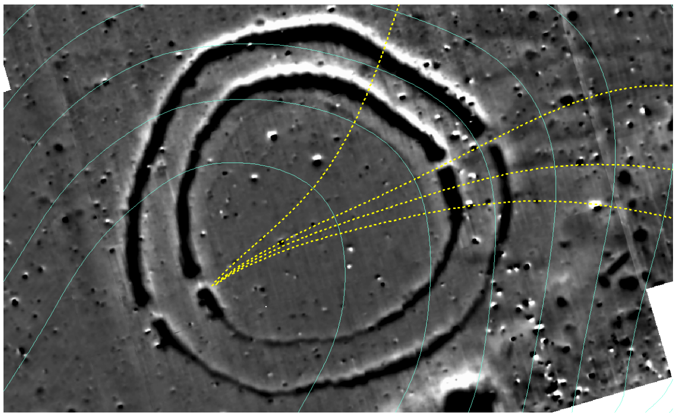

Fig. 7. Slopes at KGA Puch. As seen from centre, the entrances point towards solar cross-quarter events (Figure 5). The direction from south-western towards north-eastern entrance has been described as lunar-oriented [9] (Figure 6). However, all those directions coincide with terrain slope (bright lines going down from the south-western entrance).

super-wide fields of view. However, during the project some shortcomings were observed which must at the moment be circumvented, and should be corrected in future versions in order to create software that not only looks impressive, but also delivers correct, dependable results for its application in research on historical problems. However, being an open-source project, everybody is invited to contribute! Our contributions so far which are important to horizon astronomy and astronomical phenomenology were a correction of the horizon display, and atmospheric refraction and extinction, available since version 0.11.2. The biggest new functionality however is the still ongoing development of a new plugin which is capable of providing a three-dimensional walkable scenery. With this plugin, a georeferenced landscape model with building structures can be explored virtually in combination with the impressive astronomical simulation quality of Stellarium (Figures 2, 3, 5). Models can be exported in Wavefront OBJ format directly from Sketchup with yet another plugin that creates the necessary configuration file from the model metadata, or from other modelling software.

IV. Results

The first KGAs investigated in this detail nicely seemed to confirm several of the preliminary results from the older study. A stellar alignment was confirmed (and in this altitude also atmospheric extinction would not have impeded its visibility), and also several solar-related orientations towards the rising or setting points on the cross-quarter days can indeed be demonstrated (Figures 3, 5), although doubts about their significance arose later, see below.

On the other hand, from the site visits and investigations of first self-made virtual reconstructions on the digital elevation model, it became clear that the mental image of a KGA as an enclosure providing a totally secluded space with the upper edge of the palisade wall forming the visible sky line, must be corrected. KGAs frequently, indeed almost always, have been erected on sloped ground, and so by their large diameter, an observer standing in the central area and looking down the slope will most likely have been able to see over the rim of the palisade and into the valley or counter slope, unless the palisade was unexpectedly high on the downslope side. The elevation difference between the highest and lowest point inside the area enclosed by the ditch (the inner, in case of multi-ditch KGA) is about 3.5m on average and exceeds 6 metres in KGA Friebritz 1. KGA Gauderndorf, with its two entrances outside the solar or lunar declinations, was thus immediately excluded from further astronomical consideration, when any expected stellar target of the south-eastern entrance turned out to be invisible, the entrance pointing right into the valley, and the other direction also failed to meet the proposed bright star setting on the landscape horizon. In KGA Steinabrunn, the entrance which indeed pointed towards rising Deneb likewise was identified as being at the same time the entrance on the top of the slope (Figure 8), while the southern entrance again was looking right into the valley, so that no star could ever have been observed from the KGA centre through this entrance. Also, a few data errors were identified in the digital elevation model which had given cause to a few previous claims relating to horizon features, in one case thus invalidating the previously identified significance of a certain direction.

Further, we had to notice that also the solar cross-quarter orientations, although confirmed with the measured altitudes, typically at least almost coincided with directions that were connected to the aspect (the azimuth in which the surface is oriented) of the terrain, either going up and down the slope, or following the contour of the terrain. A suspicion substantiated that we were on an unfortunate mission, and we should reconsider our classification attempts also with the simple topographic data of surface aspect and slope, data not available in the earlier study. In our 25m digital elevation model originally available for the reconstructions, the slopes read off at the KGA centres average at almost 4 degrees (7%) and reach up to 6.4 degrees (11%). Of course, all the sites have been in agricultural use for centuries if not indeed millennia, and have therefore been under influence of erosive processes and also intentional changes like levelling and in some instances even terracing. In a few KGA magnetograms one half of the ditch is better preserved than the other, suggesting that the terrain has eroded asymmetrically, which can also cause a slight rotation of the aspect. From our DEMs we can of course only read the present value. However, we had now a second concept against which to test our azimuths.

A. Astronomical orientation of the entrances

The classical result of archaeoastronomical orientation studies is usually a conversion from measured azimuths and horizon altitudes into astronomical declination, in the hope to identify a non-uniform distribution that shows a higher sample count in declinations of major significance, e.g., the solstice or lunistice declinations, or, if evidence is convincing and the sites can be dated, declination of stars that may then be interpreted as having been the subject of attention to the builders, for religious, calendrical, or whichever other reasons.

A histogram plot for the incomplete data of the 2004 study had shown a few indicative gatherings of declinations which we had hoped would become conclusive in this detailed study, once all horizon elevations would have been available. In strong contrast, we had to observe now that those gatherings have dissipated entirely and in fact no large groups of similar declinations can be identified, although winter and summer solstice sunrises and sunsets are represented at, in total, about five entrances: Pranhartsberg 2 (both), Altruppersdorf (summer sunset, see Figure 4), Stiefern (winter sunrise over an 11° high horizon) and Oberthern (summer sunset). In the incompletely preserved KGA Altruppersdorf in fact both solstice sunsets can be connected with entrances when observed from slightly different off-centre spots. The highest clustering of declinations not more than 4 KGAs showing entrances towards these — astronomically otherwise apparently insignificant — declinations, involved not more than 4 KGAs showing entrances towards two certain — astronomically otherwise apparently insignificant — declinations, but this seems not enough to propose any significant role for them. We must especially observe that the orientation towards the cross-quarter declinations, although impressively confirmed with shadow simulation in the virtual models for the neighbouring KGAs Puch (Figure 5) and Kleedorf and maybe KGA Pranhartberg 1 (Figure 3; here the sun rises over a nearby breakline which may however have eroded substantially) can only be further shown at 2 other sites when the measured horizon is taken into account. This result represents in fact a severe defeat for any hypothesis on a regular connection of the KGA entrances with an observation-based solar calendar that took note of the cross-quarter days — any such observations, if performed at all, now appear to have been the exception, not the rule, for the KGAs in our study area. Likewise, the number of working stellar alignments turned out too small to further support their significance.

Regarding lunistice declinations, the 2004 study already had turned out negative, and the only working case we could now find for an extremal lunar standstill is for the southern major standstill moon setting in the south-western entrance at KGA Pranhartsberg 1, which however is also its top-most entrance, making its deliberate lunar connection unlikely. (The major standstill events repeat in a 19-year lunar cycle, and the practical difficulties of their observation makes their significance questionable [1, p.67].) The south-eastern entrance at KGA Rosenburg is close enough in line with an observer slightly off-centre to suspect a connection with a major standstill moon rising over the adjacent cliffs, but is likewise entirely explainable by downslope orientation. At KGA Puch, the line connecting the entrances towards east-northeast coincides indeed with the minor standstill moonrise (Figure 6), but at the same time is again practically identical to the direction down the slope (Figure 7). The south-western entrances both of KGA Schletz and Michelstetten point steeply upslope and clearly miss any lunistice direction previously suggested in the literature [9, p.276].

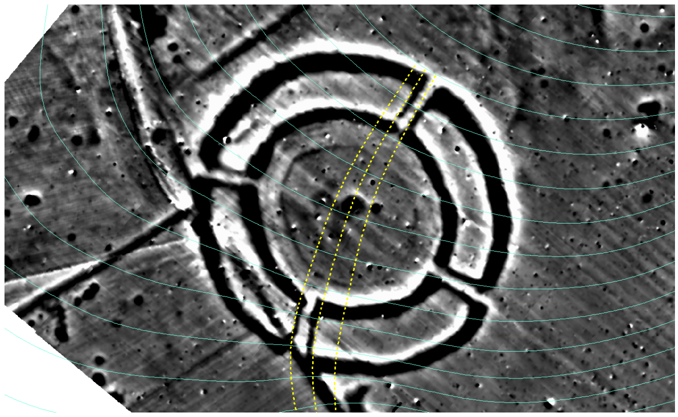

Fig. 8. Evaluation of terrain slope at KGA Steinabrunn based on Lidar measurements. A slope line started from the north-eastern entrance runs almost through the KGA centre and out through the southern entrance, revealing the latter's orientation as slope-motivated.

B. Slope orientation of entrances

Only in late 2011 new Lidar (airborne laser altimetry) data of the KGA sites have been available to us for even more detailed investigation of the now-suspected slope orientation. From Lidar data, highly accurate digital surface and elevation models can be derived, with typically several samples per square metre, which means that the data even had to be smoothed with a low-pass filter or else both aspect and slope orientation are susceptible to the local roughness of plough furrows visible in the terrain data. With such high-resolution data it was possible to measure reliable data of local aspect and slope variations not just in the centre, but at each entrance, which made a significant difference in some cases. In ArcGIS it is possible to create a line following the local slope down into the valley (Figures 7, 8). An interesting example is shown in figure 8 for KGA Steinabrunn: lines released next to the top entrance (north-east) run through the central area and bend right into the direction of the opposing entrance, which on the (flat) map always had appeared to be strangely misaligned as seen from the KGA centre. This means, at least in today's surface, the direction of the lower (southern) entrance path exactly follows its own terrain aspect, and not the line connecting its outer end to the centre of the KGA. Similar slope line results can be seen for many of our sites, and this seems indeed to provide a much better pattern for orientation preference.

V. Conclusion and future work

In this paper we have presented a case where structures of prehistoric monumental buildings only detected by archaeological prospection and documented in a GIS have been virtually reconstructed on a digital elevation model in order to make them accessible for visual analysis and demonstration of their archaeoastronomical potential. The orientation of 87 entrances to 32 of these suspected cultic monuments has been investigated in affordable, self-made virtual models using astronomical diagrams and carefully calibrated panorama photographs added to the models, which helped to identify data errors existing in the DEM and to keep control over the correct geographical orientation and placement of the structures. In addition, a new plugin for astronomical desktop software was developed in order to display the models in the context of a visually convincing sky simulation. The creation and evaluation of three-dimensional models in their three-dimensional landscape significantly helped to clarify some common misconceptions about the purported "look and feel" inside those long-vanished monuments. It turned out however that only in rare cases, and not as regular element, there seems to be a connection between the entrance orientation and astronomical events on the horizon.

Lidar data was finally utilized for an accurate three-dimensional analysis of the slope in today's landscape, which may deviate in some places from the prehistoric slope orientation due to effects of erosion. Still, a topographical orientation pattern, such that the entrances are oriented along slope and contour lines, has emerged and in general provides a much better explanation than any astronomy-related interpretation, although one site shows a perfect solstitial orientation pattern demonstrable in the models and astronomical simulation. The inclusion of the local terrain in addition to the surrounding horizon has been found to be a vital ingredient to the analysis, and clearly shows that many similar studies based on available published archaeological records only are in severe danger of coming to wrong conclusions when 3D topographical data is not available.

A publication of the numerical results and a detailed description of the situation at each KGA are in preparation. Some of the models will be further developed and should become accessible on the project website [17] for public display and explanations. The Scenery3D plugin for Stellarium still undergoes improvements and will be made publicly available for similar research cases involving other times and cultures, whereever architecture may involve systematic orientation in directions of astronomical significance.

Acknowledgment

The Scenery3D plugin for Stellarium has been implemented mostly as student work by Simon Parzer and Peter Neubauer and later improved by Andrei Borza, co-supervised by Michael Wimmer (TU Vienna).

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