Development of Archaeological Astronomy Simulation Software “arcAstro-VR”

Angkor Wat night view / Cambodia
Photography by Kuropiso

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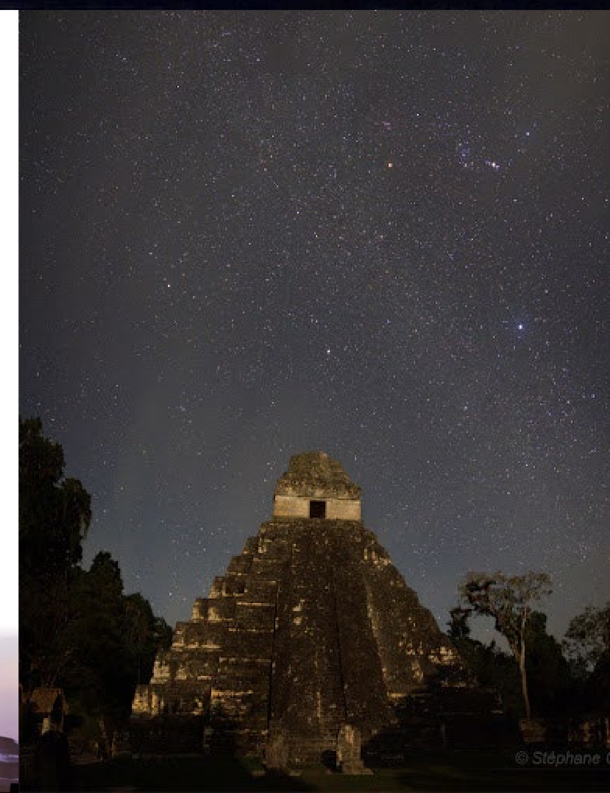
Contents：

I will report on the outline of the newly developed "archaeological astronomy simulation software arcAstro-VR" and the data processing method for accurately expressing and constructing topographical data and architectural data such as ruins/remains of archaeological sites.

Also, as an example of using arcAstro-VR, I will introduce a virtual reproduction model of the Yoshinogari ruins in Saga Prefecture.



Archaeoastronomy

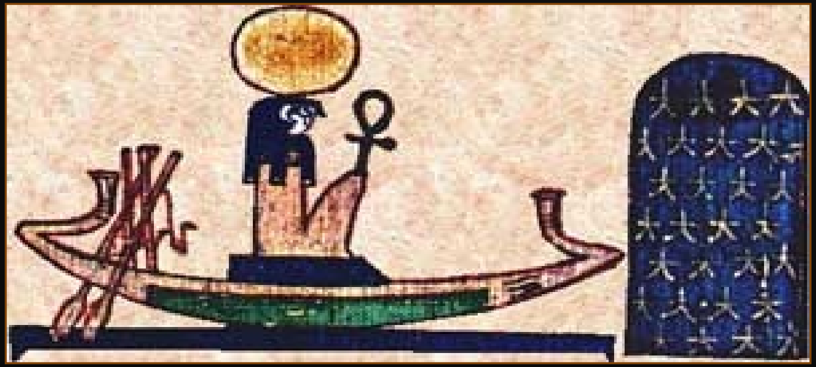
Archaeoastronomy examines astronomical phenomena found in archaeological materials and the azimuth, sunrise/sunset, moonrise/settlement, planetary and stellar positions, spatial patterns of stars, and even the sun and moon on archaeological artifacts. Furthermore, it investigates the correlation between the light and shadows cast.

Astronomical chart drawn on the ceiling of the Kitora Tumulus

Stonehenge

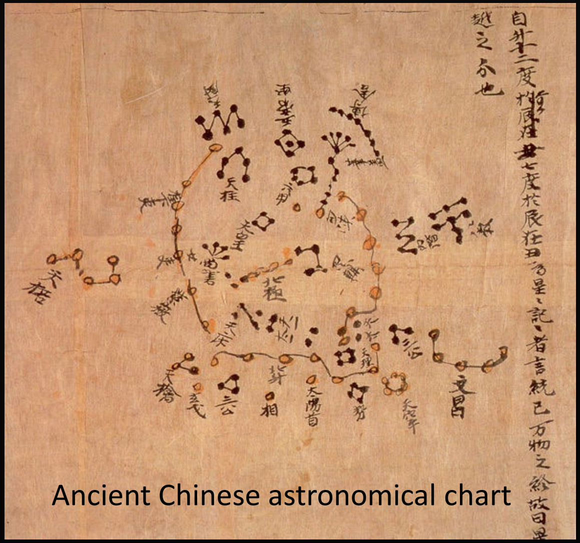
Archaeoastronomy

Egyptian Sun god “Ra”



In ancient societies, the celestial phenomena seen in the sky were part of everyday life. Our ancestors recognized them in connection with concepts about the relationship between nature and humans, especially the concepts of time and seasons.

Therefore, if we can visualize the positional relationship between astronomical phenomena and archaeological structures, we will know how the people of the ancient civilizations that built such structures perceived the celestial bodies, i.e., the concept of the universe and the world.



Ancient Chinese astronomical chart

Positional relationship between celestial bodies and structures on the ground

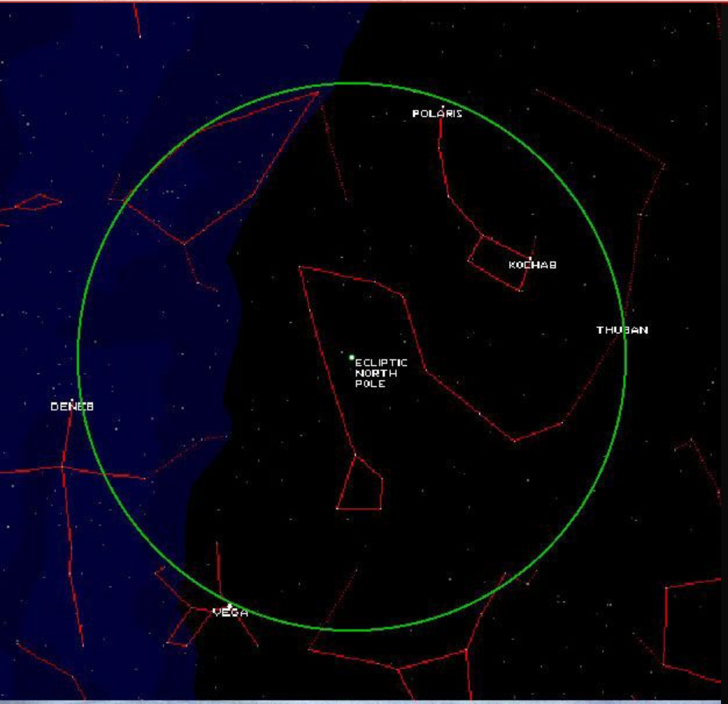
Evidence has been shown to correlate the positions and orientations of celestial bodies at specific dates and times, such as solstices, with archaeological structures. [*1, *2, *3]
Analyzing the placement and orientation of prehistoric monuments allows us to interpret the spatial perceptions of the people who built those monuments.

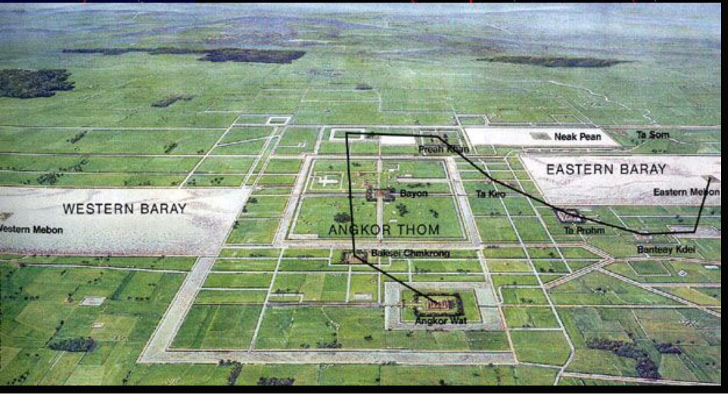
[*1] Belmonte, J. A. (2015). Solar Alignments - Identification and Analysis. In *Handbook of Archaeoastronomy and Ethnoastronomy* (pp. 483-492). https://doi.org/10.1007/978-1-4614-6141-8_36
[*2] González-García, A. C. (2015). Lunar Alignments - Identification and Analysis. In *Handbook of Archaeoastronomy and Ethnoastronomy* (pp. 493-506). https://doi.org/10.1007/978-1-4614-6141-8_37
[*3] Ruggles, C. L. N. (2015). Stellar Alignments - Identification and Analysis. In *Handbook of Archaeoastronomy and Ethnoastronomy* (pp. 517-530). https://doi.org/10.1007/978-1-4614-6141-8_39

The solar alignment of the equinox at Angkor Wat

The sunrise on Angkor Wat during the equinox is such that someone standing in front of the western entrance can see the sun rising directly over the central lotus tower.

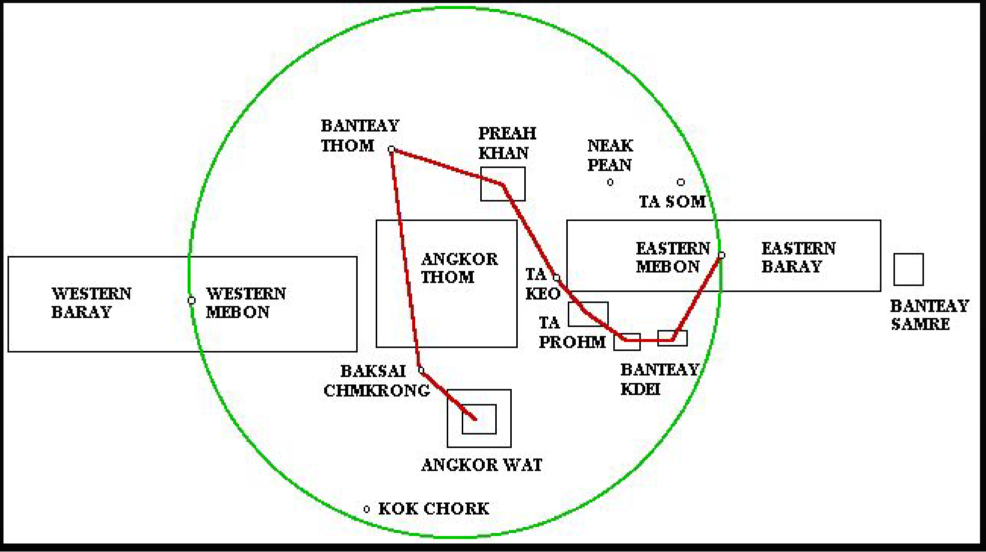
Angkor Wat and Draco



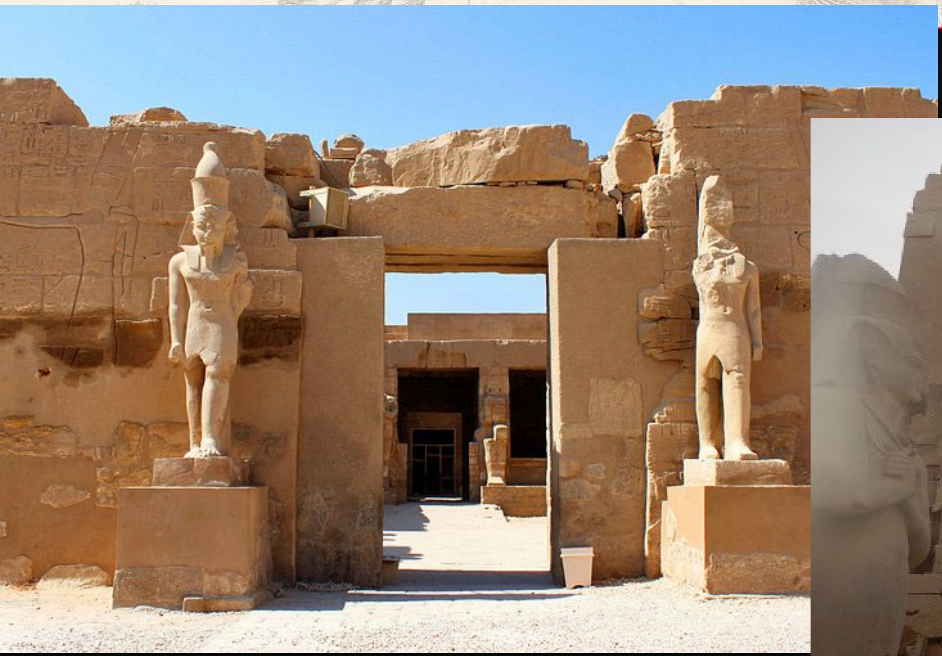


Someone once said: that Angkor Wat is a replica of the Draco constellation. It connects the stars of the Draco constellation in a line. The lines are too similar when connecting at least 15 main pyramids of Angkor.

If it is a fluke, it would be too impressive.



Positional relationship between celestial bodies and structures on the ground

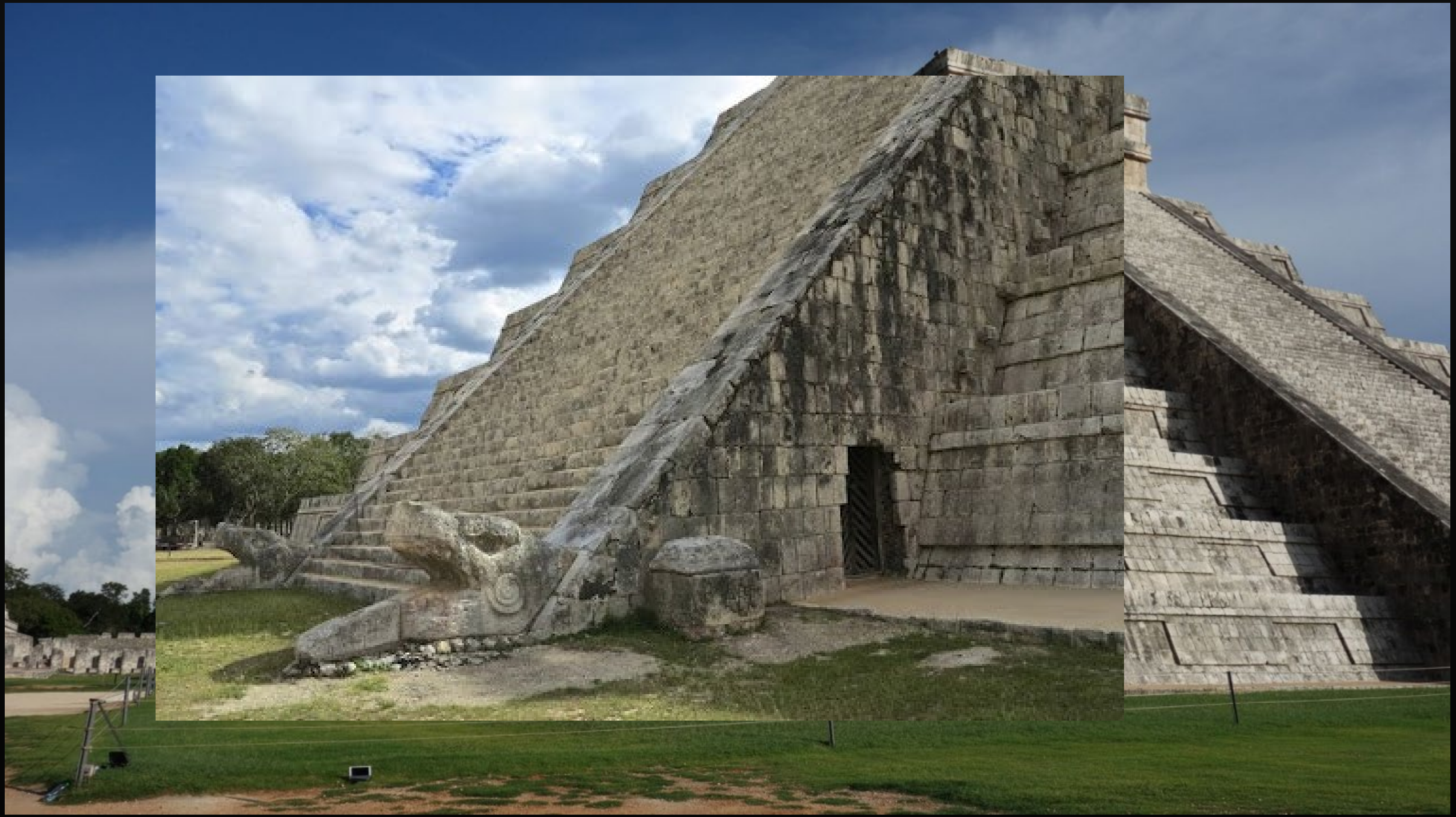


Egyptian Karnak temple

Karnak's Amun Temple has passageways lit only by the rising sun in midwinter.

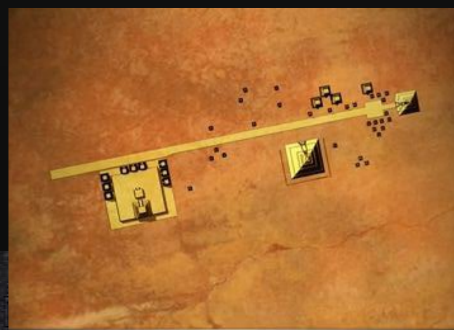
Positional relationship between celestial bodies
and
structures on the ground

Kukulkan's Pyramid casts a snake-like shadow twice a year.

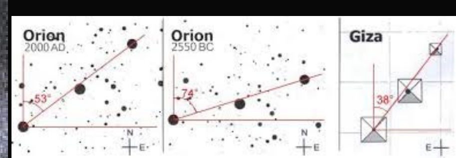


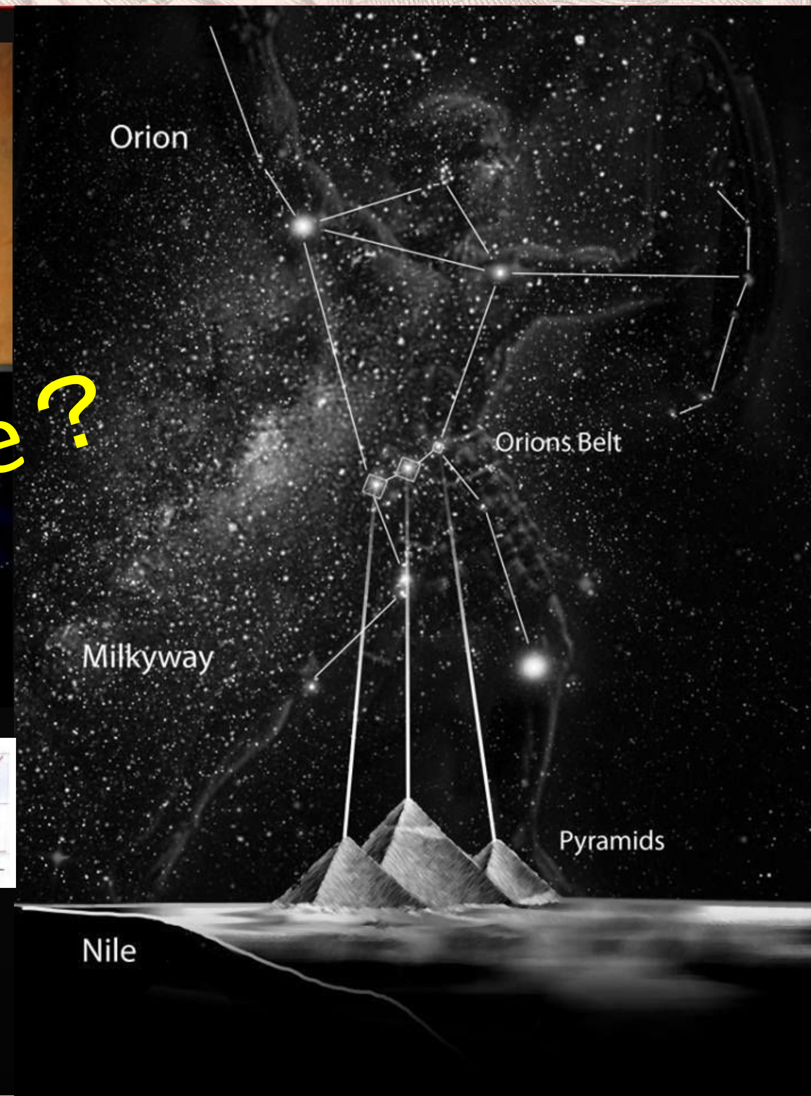
It happens when the length of day and night is the same.

Positional relationship between celestial bodies and structures on the ground



Are these true ?





Great Pyramids of Giza, Egypt

Be aware of Platonicity!

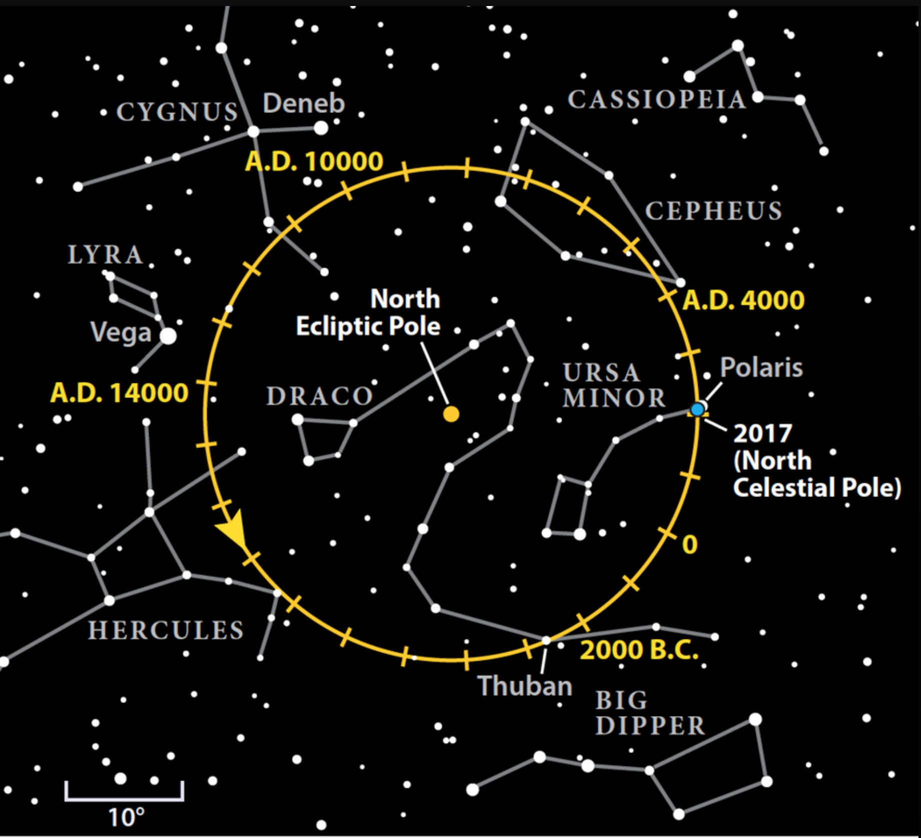
(or the desire for order)

"The purpose of science is to get to the truth, not to get you a feeling of the organization or make you feel better."

(from "Black Swan," Nassim Nicholas Taleb)

Necessity of astronomical simulation

Due to the precession of the earth, the positions of the celestial bodies that we see today are not the same as the positions of the celestial bodies that ancient people saw.



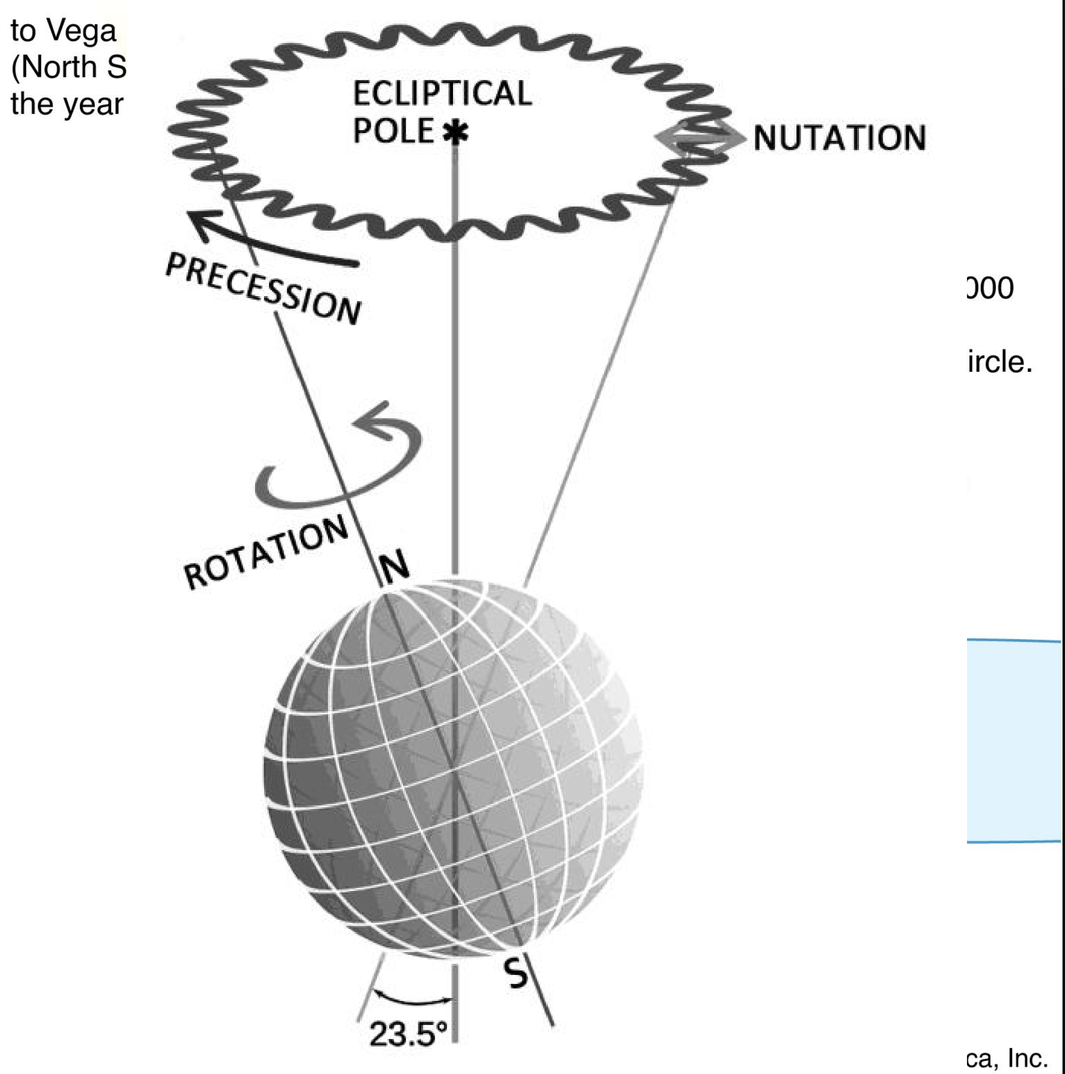
・The characteristic patterns of constellations have mostly stayed the same since the early prehistoric period. The physical motion between stars is negligible to the naked eye, even on timescales of tens of thousands of years.

・However, on timescales of decades to centuries, the entire array of stars moves across the celestial sphere due to equiaxed precession.

・Over timescales of decades and centuries, precession shifts the declination of any star and, thus, its elevation position.

・A circumpolar star may cease to be a circumpolar star, or vice versa, while others may disappear below the horizon or appear for the first time.

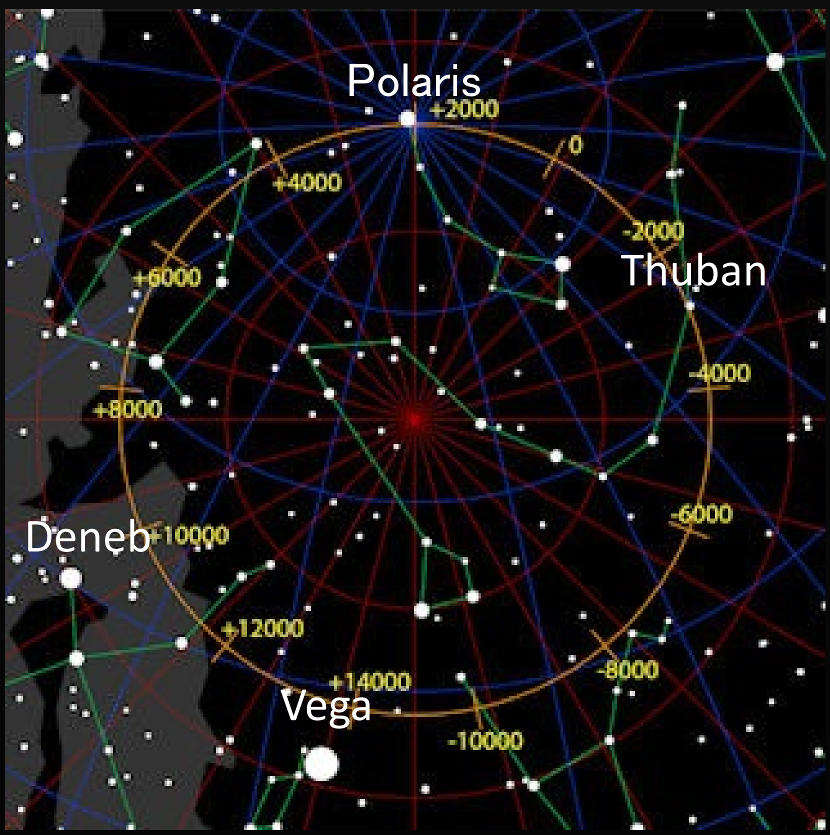
Precession/Nutation and Changes in the Earth's Orientation



The Earth also rotates on its axis once a day as it progresses through its annual orbit around the Sun. This keeps the same orientation in space. Precession occurs when the direction of the Earth's axis with respect to distant stars (unrelated to the fact that the Earth orbits the Sun) gradually rotates like a top over a period of 25,800 years.

Precession/Nutation
and
Changes in the Earth's Orientation

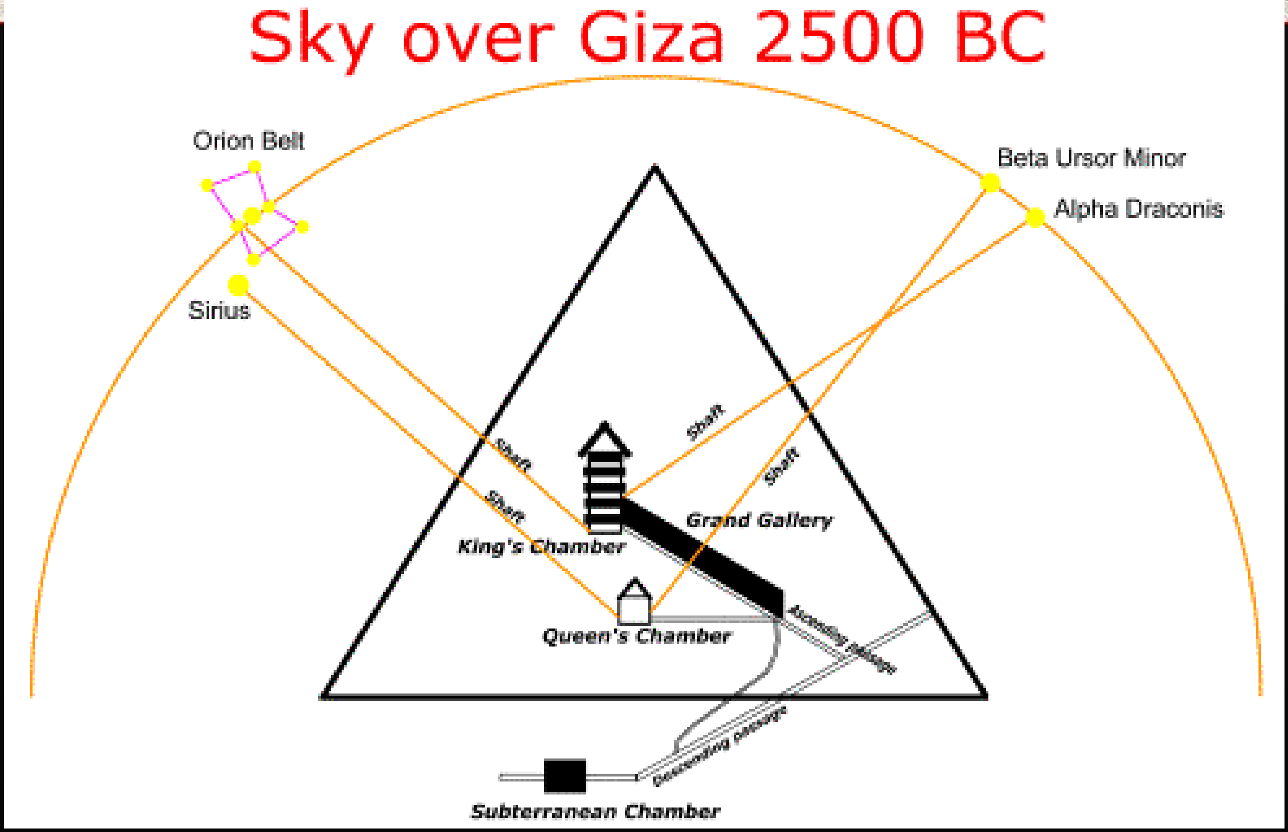
The apparent positions of celestial bodies in the past change due to factors such as precession.



・Polaris, within 1 degree of the celestial North Pole today, was about 3 degrees away from the North Pole in 1600 AD. (As far back as 1000 AD, Polaris was 6 degrees away from the poles, so when was it recognized as the "North Star"?)

・On the other hand, Alpha Draco (Thuban) is 25 degrees away from the pole today but was within 1 degree around 2800 B.C.

Precession/Nutation and Changes in the Earth's Orientation

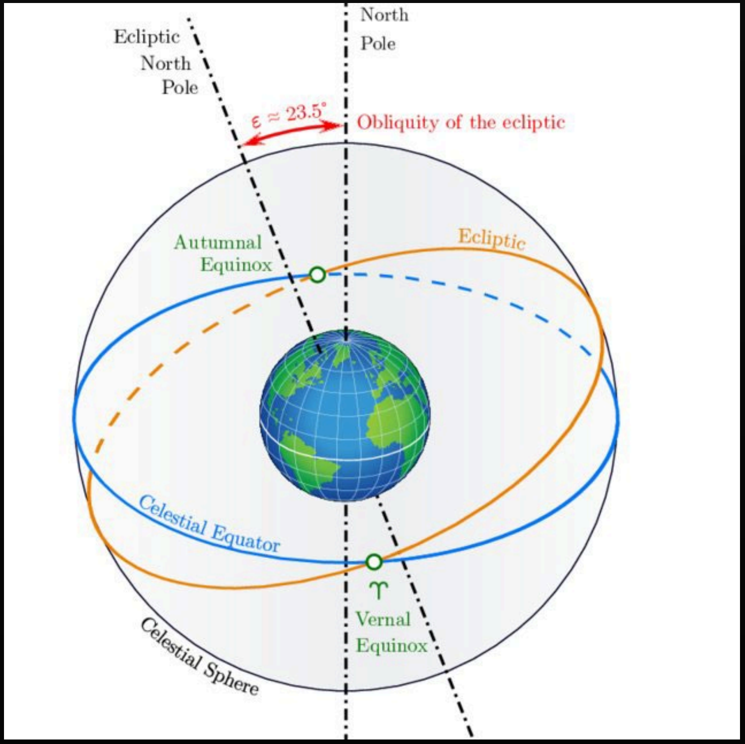


It has been pointed out that one of the shafts in the Great Pyramid of Khufu at Giza may have been intentionally oriented in that direction.

Ecliptic tilt change

The ascent and subsidence positions of the Sun, Moon, and planets are unaffected by precession but change slightly over time as the ecliptic tilt changes slowly over time.

Over the past few thousand years, it has slowly decreased from about 24.15 degrees in 5000 BC to 23.45 degrees today, but over longer timescales (about 41,000 years), it falls between limits of about 24.4 and 22.2 degrees. (It reaches a maximum of around 6,000 BC and a minimum of around 14,000 AD.)



Recreate and visualize past skies and landscapes

In addition to changes in the apparent position of celestial bodies in the past, the state of preservation of the remains itself is not necessarily good.

Angkor Wat

Unrestored East Angkor Wat Beng Mealea

Palmyra ruins

Recreate and visualize past skies and landscapes

It may also be necessary to investigate places that are not easily accessible or where historic structures have been destroyed by natural disasters such as earthquakes or deliberate human actions.

Constructed Solar Panels

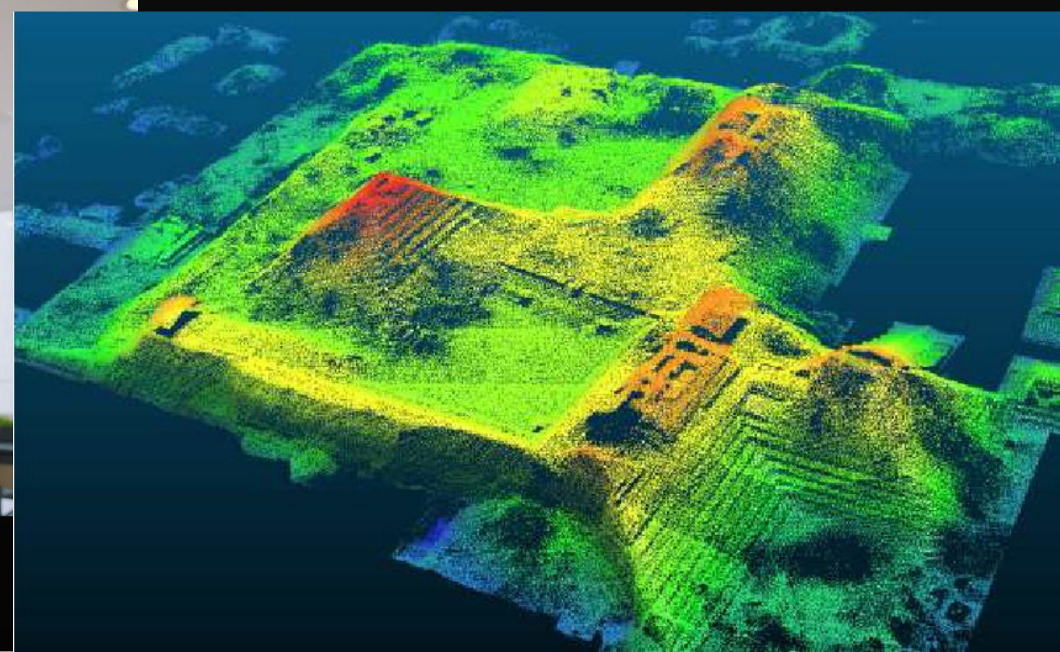
Confirmed that part of the kiln has been shaved. Also, find pottery shards.

Seto City, Aichi Prefecture "Ohira Kiln Ruins"

Ancient ruins submerged in a dam (Portugal)

Recreate and visualize past skies and landscapes

Furthermore, it is difficult to observe over months or years, requiring investigations at specific dates such as the solstice. Therefore, it is desirable to develop a computer system that can reconstruct interesting remains from actual measurements and records and experience the effects of past astronomical phenomena simulations in a virtual 3D space.



"arcAstro-VR" development goals

- Astronomically correct sky simulation, applicable to prehistoric studies.
- Present daylight skies, realistic simulations of twilight, or decorate the horizon with panoramic photos.
- A panorama can be created from on-site photographs or renderings of 3D models from each viewpoint to study the architectural line of sight along the axis of the building (or, similarly, a row of upright stones, etc.).
- When a known point or structure needs to be investigated in virtual space. Can load or extend to load 3D landscapes.

“arcAstro-VR” development goals

• Accurately georeferenced 3D models can be loaded into virtual space, and the ability to identify and observe the line of sight combined with past sky reproductions and simulations to reconstruct archaeological structures and accurately reproduce virtual 3D models. It can be loaded into a computer system at any time.

• Can clearly explain and demonstrate these phenomena to a large audience.

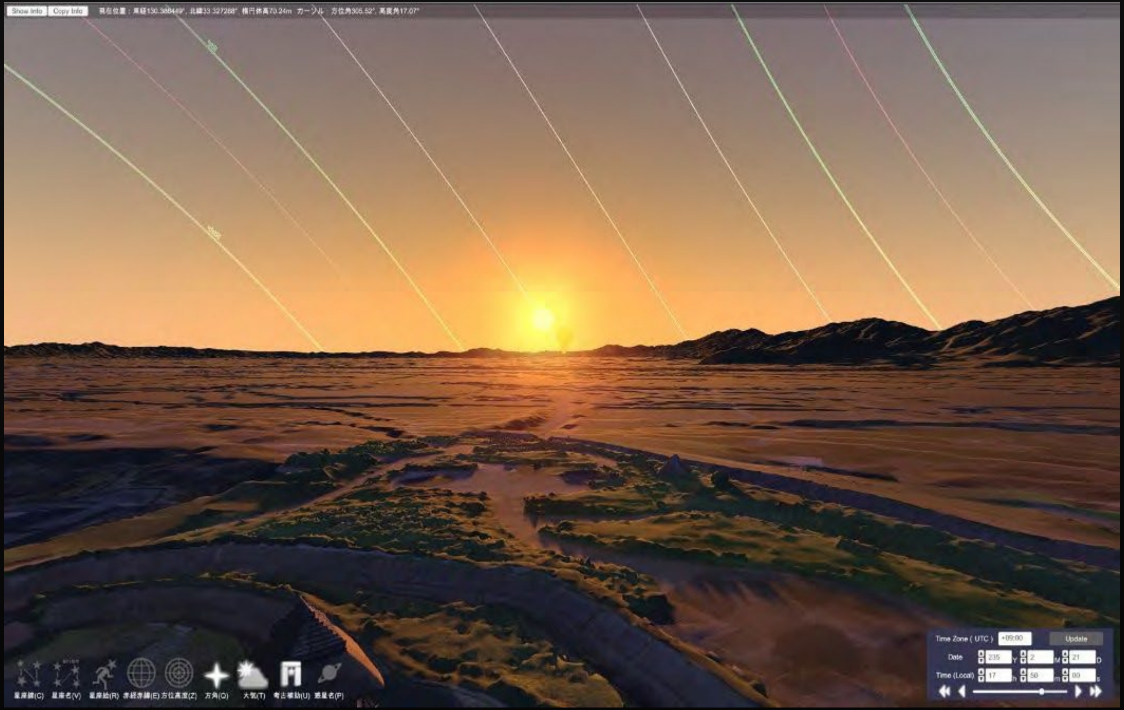
• A virtual reconstruction allows you to recreate the site's appearance as it might have been in the past rather than in today's degraded state.

• A real-time simulation where not only single buildings but also large assemblies such as towns are reconstructed, and users can move around freely, giving a better understanding of the spatial relationships between buildings.

What is arcAstro-VR?

Introducing arcAstro-VR

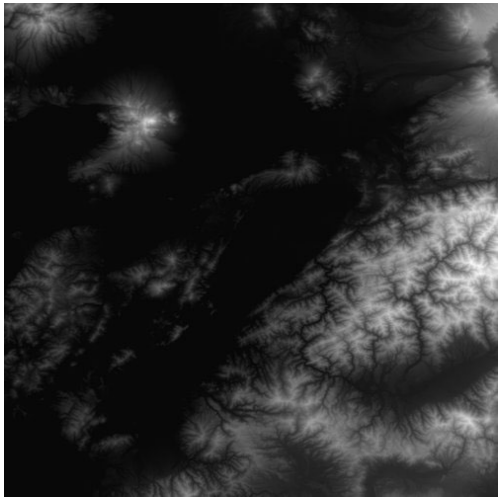
- An application that reproduces topography, 3D data, and astronomical phenomena on a PC in VR.
- Data surveyed by LiDAR and photogrammetry can be visualized in 3D.
- You can move freely in the VR space and change the settings to perform various verifications.



PC monitor display example of arcAstro-VR

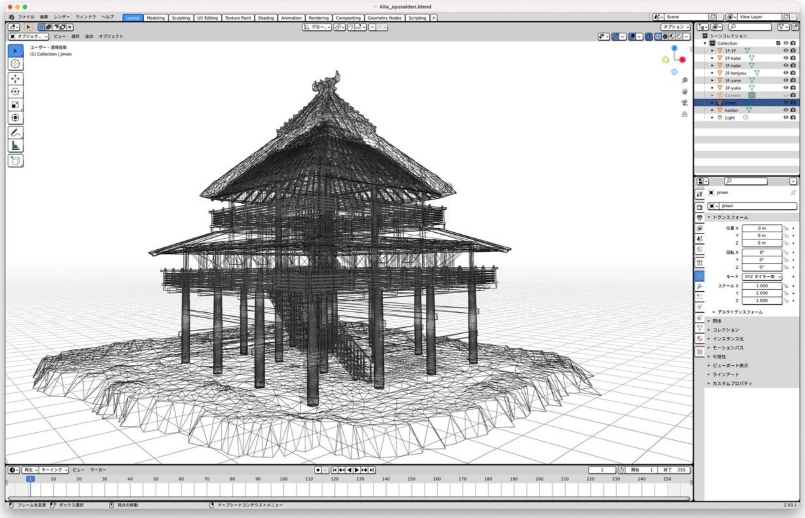
Data formats of terrain and buildings that can be read

Terrain data: GeoTIFF file format



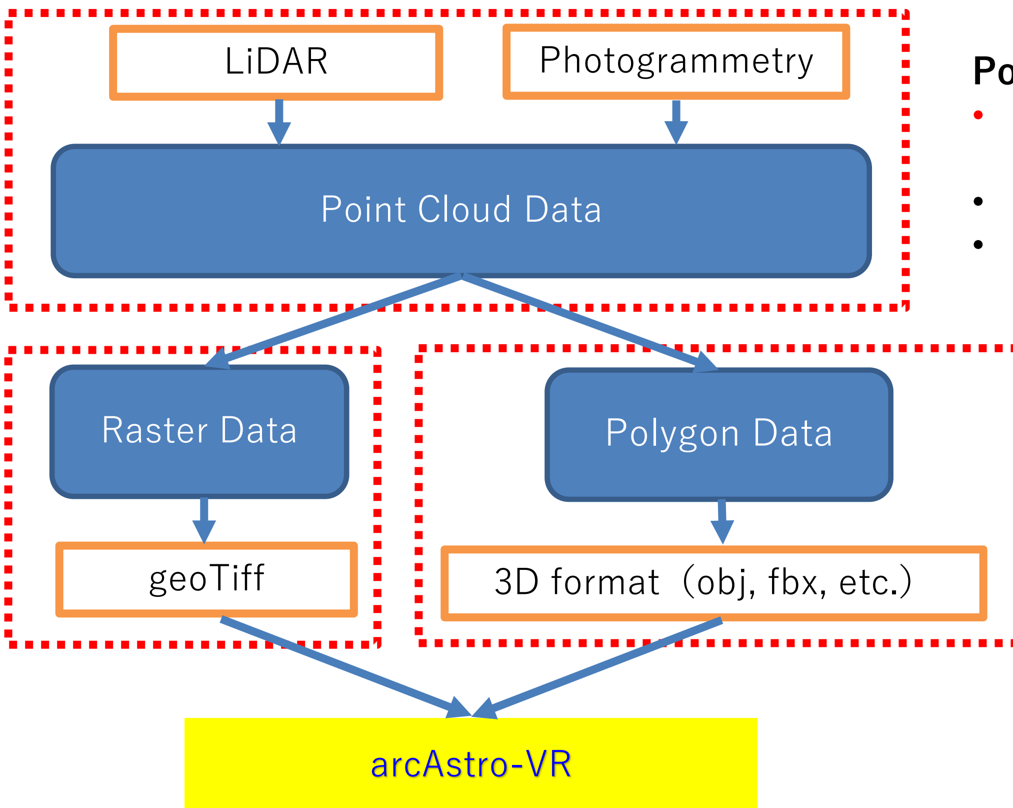
GeoTIFF: Planar image data with elevation in grayscale

Building data: 3D file format (obj, fbx, ply, etc.)



3D file: Three-dimensional space data in which points, lines, and planes are arranged with xyz coordinates

The flow of data creation from various survey measurements



Point cloud data processing
- MetaShape (old Photoscan)
- ScanSurvey Z
- etc…

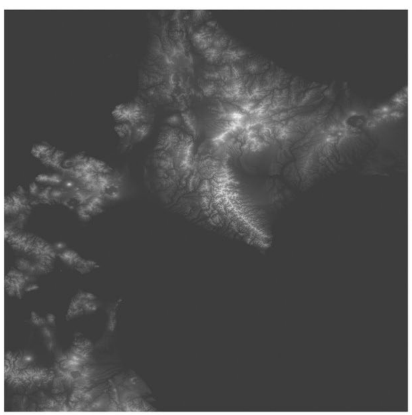
Terrain data processing
- QGIS(free)

dedicated plug-in （Create specially modified terrain with “terrain maker for arcAstroVR”)

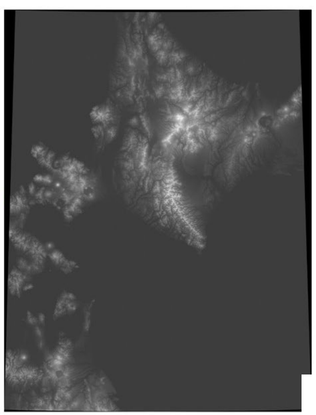
3D data processing for buildings, etc.
- Blender(free)
- Maya
- AutoCAD
- FreeCAD(free)
- etc…

Terrain correction in the QGIS plugin

- orthorectification (orthographic projection)
- spherical shape correction
- Introducing the Geoid model
- Optical correction (Equivalent Earth Radius Correction)

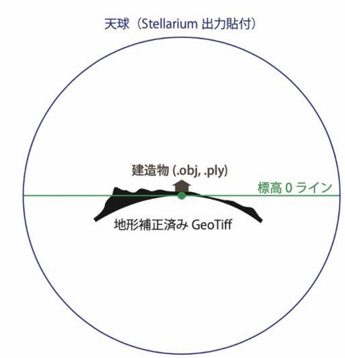


Equal latitude/longitude projection



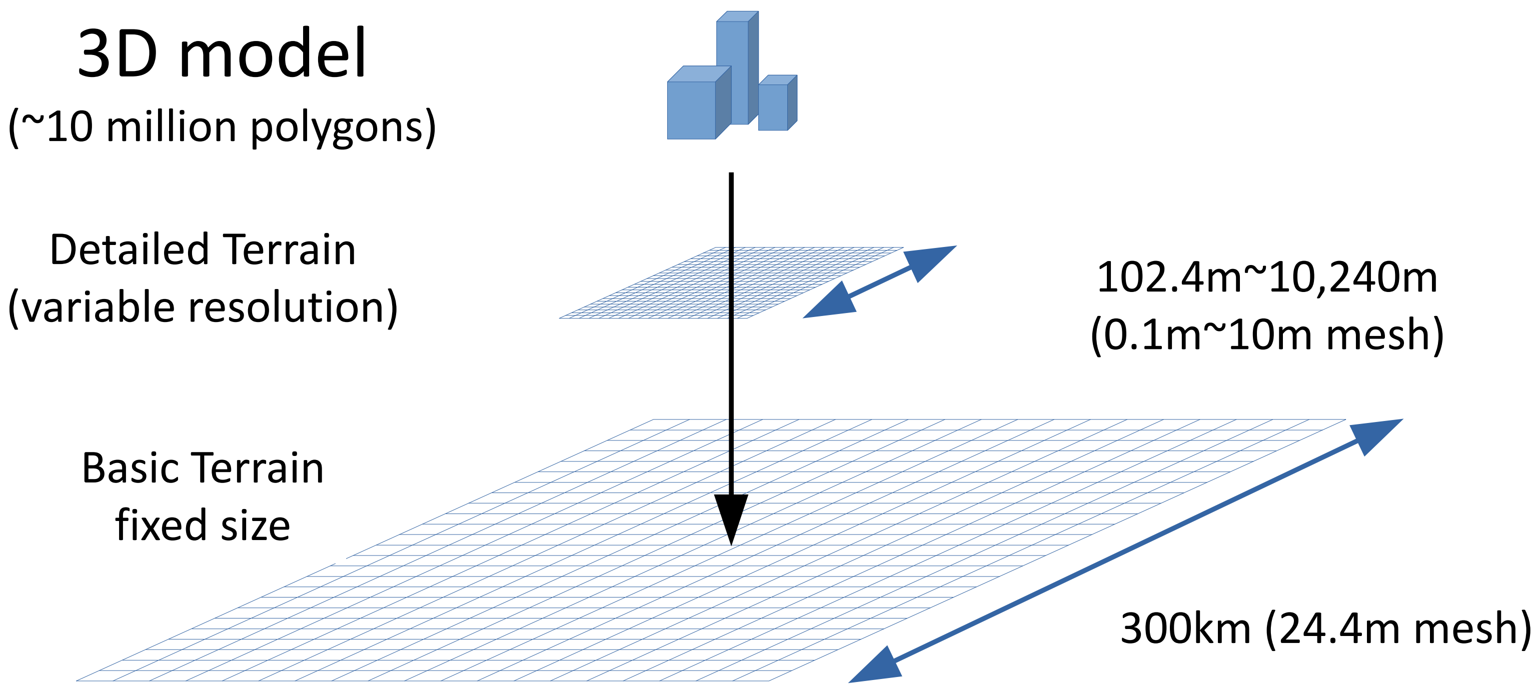
orthographic projection

Terrain Correction
(GRS80 Ellipsoid + Equivalent Earth Rad



Topography, Buildings, and Celestial
Sphere placement in Unity space

Terrain reproduction in arcAstro-VR



Sky reproduction with arcAstro-VR

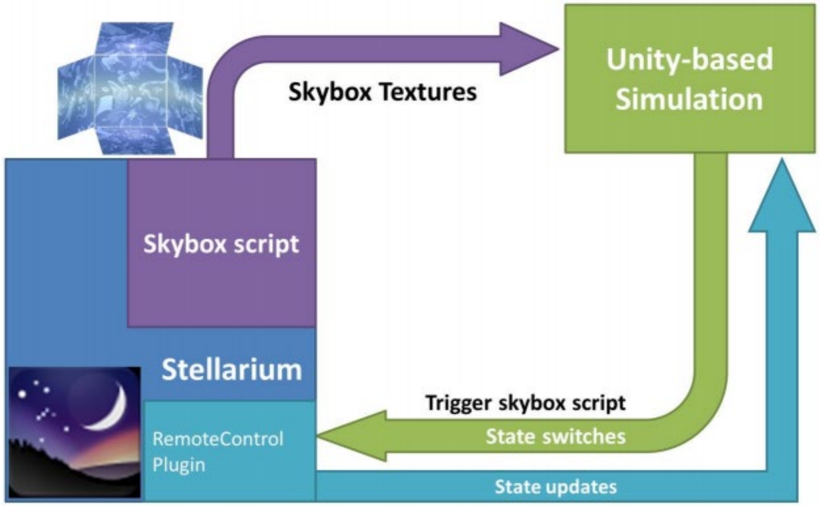
Reproduce the starry sky in cooperation with the astronomical simulator “Stellarium” (http://stellarium.org)

*Free software (Windows/Mac/Linux version)

*Compatible with VSOP87 (-2000 to 6000 yr) as standard

* Expanded support for DE430 (detailed calculation: 1550 AD to 2650 AD) and DE431 (wide range calculation: -13,200 BC to 17,191 AD)

Use Stellarium's Remote Control (Plugin) and Skybox Tiles (Script) functions to transfer Stellarium sky images to arcAstro-VR and display them.



Linkage diagram of arcAstro-VR (Unity program) and Stellarium

What you can do with arcAstro-VR

- Importing 3D model data prepared by yourself
- Display/hide and move 3D models, set markers, set auxiliary lines
- Free movement in VR space (mouse, keyboard, game controller, etc.)
- -2,000 B.C. to 6,000 A.D. Highly accurate reproduction of astronomical phenomena
- Verification of sunlight, shadows, and water surface reflections using the sun and moon as light sources
- For details, please refer to https://arcastrovr.org/en/.

Compass Map Feature

- A compass map centered on the marker that will be the starting point of the extension line
- (Ortho map directly above with direction added)

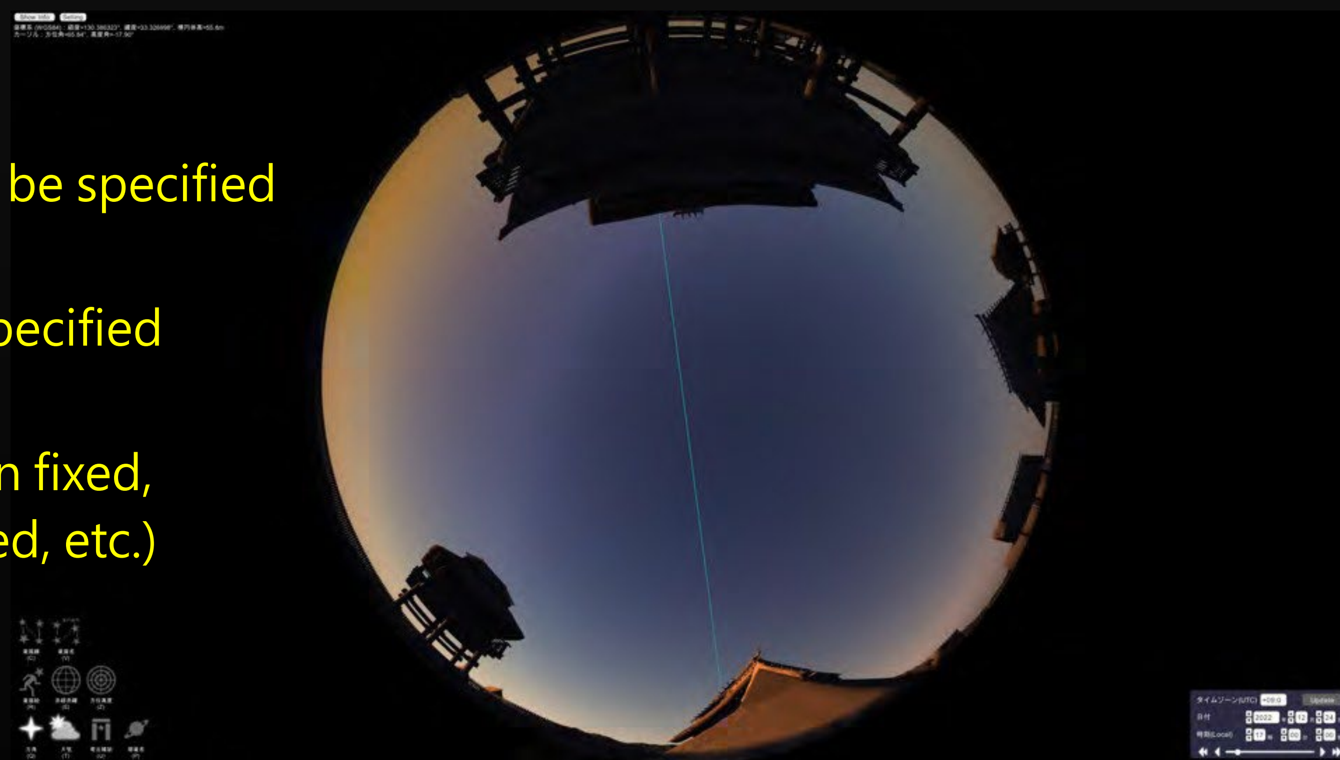
Dome master output support

- 360-degree projection is possible on the dome with a fisheye lens (dome master format)

- Angle of view can be specified

- Azimuth can be specified

- (Advance direction fixed, azimuth angle fixed, etc.)

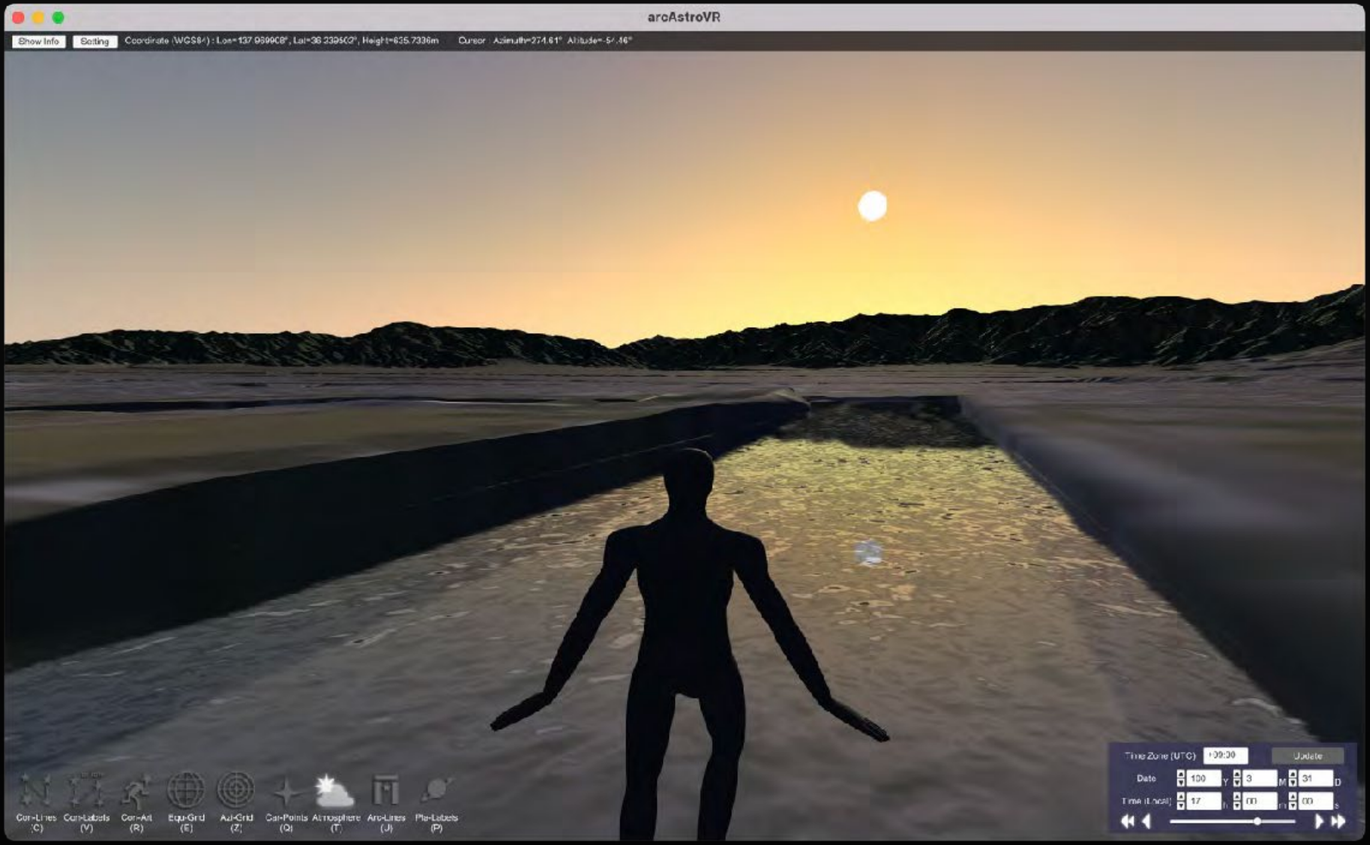


HMD support

- Compatible with Meta Quest (Oculus Quest), You can experience VR space through HMD by connecting to PC with MetaLink.
- *Windows only

Water representation

- Installation on the water surface is possible at any location



- Simulate reflections on water

3D modeling of the "Yoshinogari" ruins

About 3D model creation

From 2021 to 2022, we will carry out a 3D survey of the Yoshinogari ruins, 3D modeling was done.

1) Create a point cloud from survey data

2) Classify point clouds into terrain, trees, buildings, etc., and process noise.

3) Automatically generate a low-polygon model of the terrain based on the classified point cloud.

4) Manually create a low-polygon building model regarding the classified point cloud.

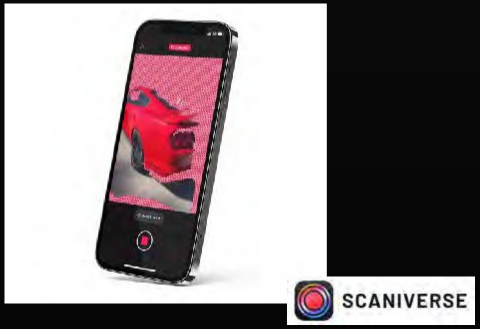
5) Create a normal map and create a detailed model for the low polygon model

6) Create texture maps for low poly models

7) Output 3D model

Survey method of the "Yoshinogari" ruins

- 3D conversion by photogrammetry from aerial photography by drone
- 3D conversion with photogrammetry from video shooting with a 360-degree camera
- 3D conversion from the survey by LiDAR scanner equipped with iPhone/iPad



Aerial survey of the Yoshinogari Ruins

- The drone used was DJI Phantom 3, the mounted camera was FC300C, and the shooting altitude was about 30m
- Create point cloud by photogrammetry processing from aerial photography by drone
- Agisoft's Metashape is used for point cloud formation by photogrammetry. Since the area is vast, the survey is divided into three parts: the north area, the center area, and the south area
- Last year, the north area was photographed (Professor Shunichi Miyahara, Kyoto University), and the north inner wall was converted to 3D. village in 3D

Aerial survey of the “Yoshinogari” ruins: North area

Number of photos taken: 775

Number of generated point clouds: 1,588,823,836 points

Aerial survey of the “Yoshinogari” ruins: Center area

Number of photos taken: 660

Number of generated point clouds: 2,100,216,098 points

Aerial survey of the “Yoshinogari” Ruins: South Area

Number of photos taken: 1131

Number of generated point clouds: 2,645,988,574 points

Problems of aerial survey

- If it can be linked with the GPS information of the drone, the accuracy of photo position identification is high, and the terrain can be reproduced with high precision. (This time, the point cloud interval is several mm to 1 cm)

- On the other hand, since aerial photography is taken from the air looking downwards, obtaining data on the shadowed parts of the building is challenging, and it tends to be only the roof. For buildings, another method of surveying is required.

Processing aerial survey data

- Separation of point cloud into terrain and buildings by Agisoft Metashape
- For terrain point clouds, Metashape's polygonization function outputs both the highest precision (for normal map creation) and 100,000 polygons specified custom precision (for actual polygons to be used).
- For building point clouds, output only polygons with the highest accuracy (for normal map creation). The low polygons for actual use are manually created separately with the CG software Blender, so they are not output here.

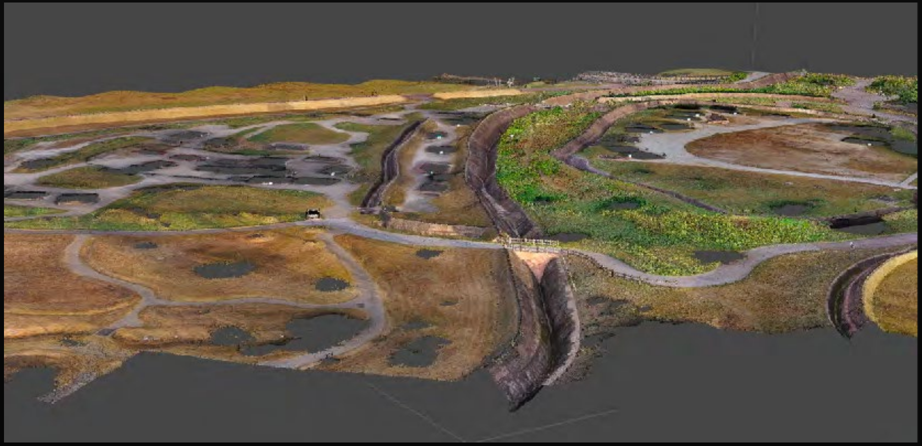
Terrain and building point cloud separation of aerial survey data

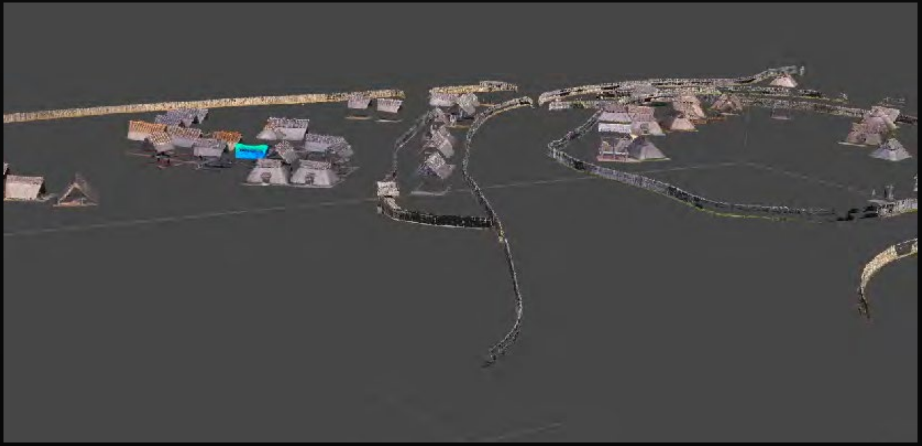
Number of terrain point clouds

- North area: 1,368,609,112
- Center area: 1,777,257,482
- South area: 2,226,905,427

Number of building point clouds

- North area: 83,539,175
- Center area: 162,476,620
- South area: 81,886,892

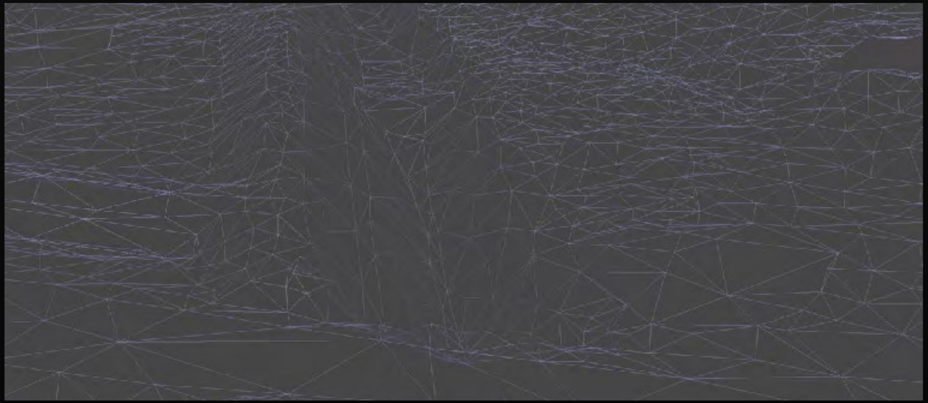




Terrain point cloud modeling process

- The highest quality polygon created from the point cloud with Metashape's "Mesh construction" has a vast number of polygons.
- The number of polygons in 3D games should be suppressed to about several thousand to tens of thousands, so try reducing it to about 100,000 polygons with the "reduce polygon count" function of Metashape.

High polygon (highest quality)
North area terrain polygon count: 440,346,287
Middle area terrain polygon count: 475,227,291
South area terrain polygon count: 574,302,980

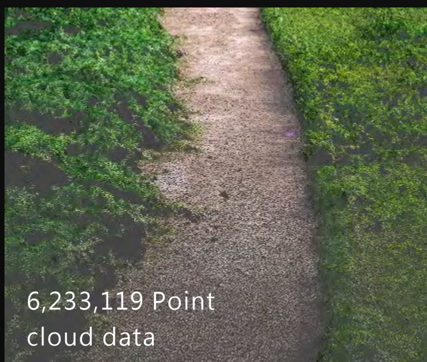


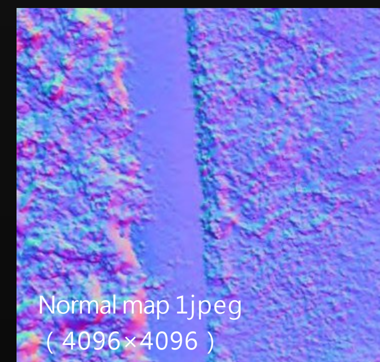
Low polygons (100,000 polygons specified)
North area building polygons: 99,999
Middle area building polygons: 99,999
South area building polygons: 99,999

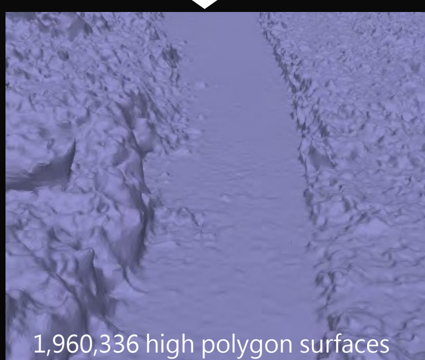
Low polygon and normal map

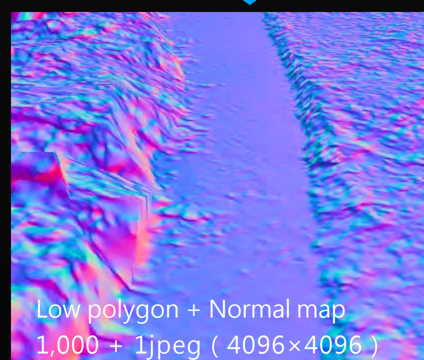
- The fine structure is lost when the polygon count is reduced. Create a normal map to complement it.
- A normal map is a type of image file (texture) pasted on a polygon and is an image of the irregularities on the polygon's surface. By imaging polygons with fine unevenness, the number of polygons can be reduced, and the unevenness of the surface of the polygon can be pseudo-reproduced from the normal map.
- Even for an object that looks small in the distance, polygons have to build all the data, but textures can compress the image according to the apparent size and do not affect the accuracy.

Effect when using normal map









Low polygons lose a lot more fine structure than high ones, but adding a normal map makes it possible to express many fine structures, even with low ones.

Creating a normal map

About 3D model creation

Metashape can compare high-polygon and low-polygon data and create normal maps for low-polygons based on high-polygons.

Terrain creates 3D of low polygon + normal map by generating high polygon and low polygon from point cloud data and creating a normal map from both data.

For the building, while creating high polygons from point cloud data, low polygon data is created separately using CG software to create 3D of low polygon + normal map.

(By manually creating the low polygons of the building, the number of polygons can be significantly reduced)

survey of buildings using a 360-degree camera

- Photogrammetric point cloud creation from 360 camera video footage to complement drone photogrammetry
- 360-degree camera used was RICOH THETA V
- Agisoft Metashape was used for photogrammetry
- Since it does not work with GPS, it is necessary to align it with drone data.

Tips for 360-degree camera surveying of buildings

Take a video using a stretcher, etc.

Always make a complete circle around the building.

Shoot in a smooth, single stroke without turning back
Normal walking speed (4-5 km/h) is sufficient.

building data of 360-degree camera Point Cloud

Since the purpose is to create building data, divide the data by building unit.

Number of point clouds generated: Tens of millions of points per building.
(Saido on the right has 17,165,392 points)

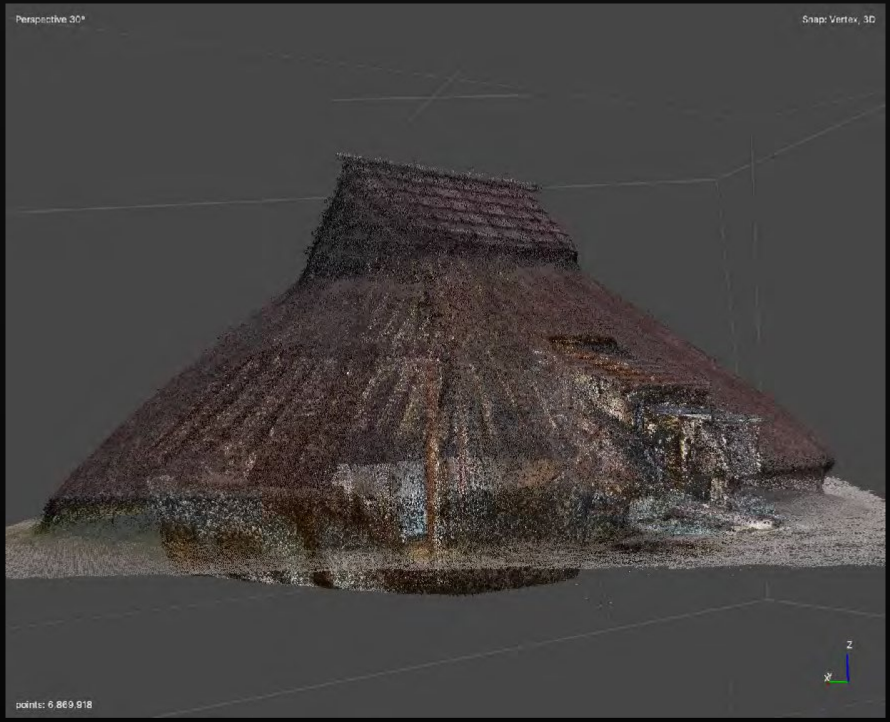
Since it is created based on a photo taken from a distance of several meters, it is also suitable for creating textures (image data of the model surface).

LiDAR survey of buildings

- Since photogrammetry generates data from photographs, it is unsuitable in dark places and requires a sufficient distance around the subject.
- LiDAR equipment uses iPhone12Pro and iPad Pro equipped with LiDAR scanner.
- Scaniverse (https://apps.apple.com/jp/app/scaniverse-3d-scanner/id1541433223) is used for LiDAR software

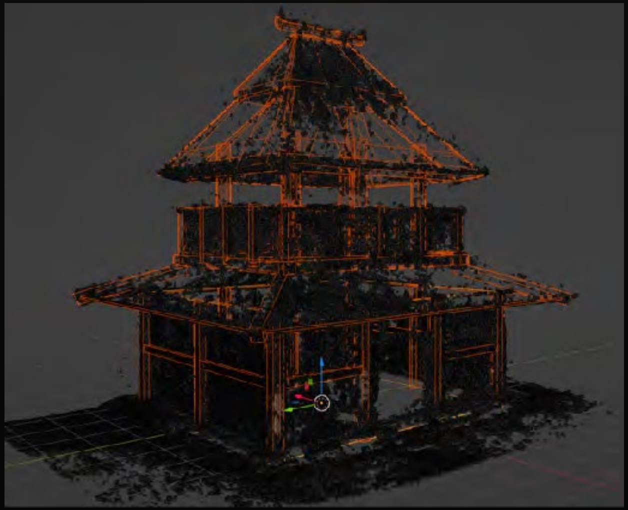
Point cloud data of LiDAR survey of buildings

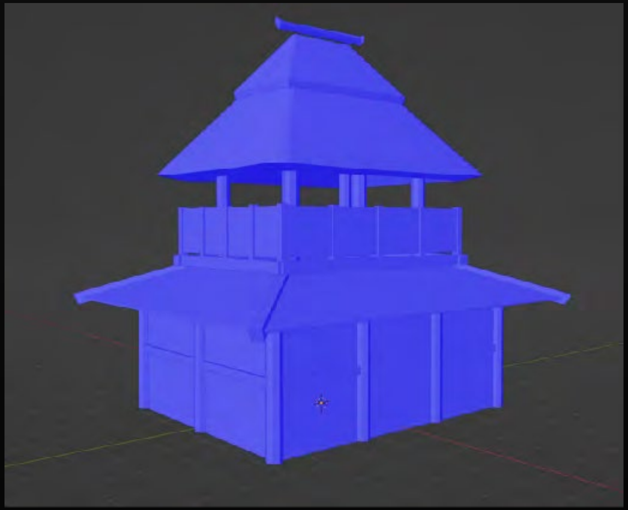
- Since the purpose is to create building data, surveying is carried out on a building-by-building basis.
- Number of generated point clouds: Tens of millions of points per building (In the case of the pit dwelling on the right, the number of point clouds is 6,869,918)
- Even in a dark and narrow room, it is possible to measure the structure as it is. However, it is unsuitable for texture creation because it is color information of discrete points.



The modeling process of buildings

- After aligning and integrating the point cloud of the building created by the 360-degree camera and the iPhone/iPad LiDAR scanner, it is read into CG software (using Blender) and modeled while referring to it.

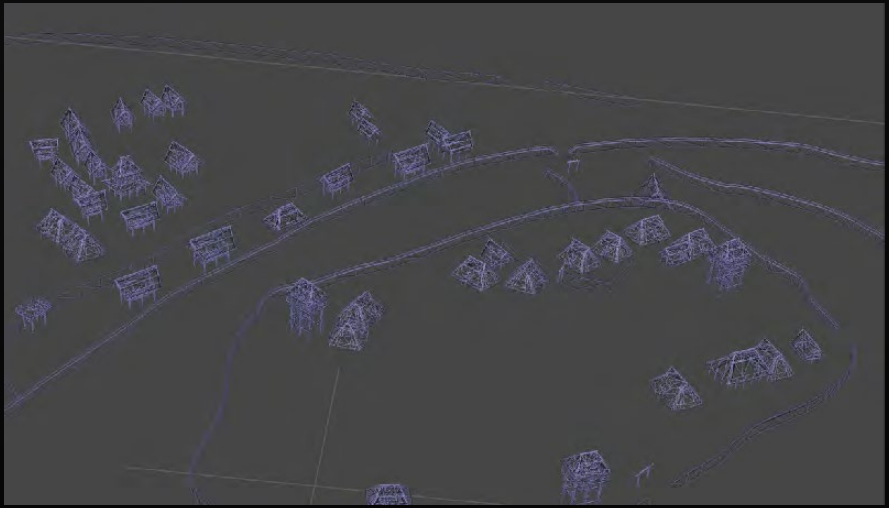




modeled by hand

Texturing of Buildings

- A 3D model of a building created with CG software is read into Metashape, and textures and normal maps are created based on this 3D model to create a high-precision model.



Overview of completed "Yoshinogari" site data

- Replacing the high polygon with a low polygon + normal map model made it possible to reduce the weight without reducing the accuracy.

- North Area Terrain: 440,346,287 polygons → 99,999 polygons + 4 normal maps
- Middle area terrain: 475,227,291 polygons → 99,999 polygons + 4 normal maps
- South area terrain: 574,302,980 polygons → 99,999 polygons + 4 normal maps

- North area buildings: 28,169,047 polygons → 13,697 polygons + 4 normal maps
- Medium area building: 49,235,942 polygons → 32,832 polygons + 4 normal maps
- South area buildings: 24,083,858 polygons → 15,813 polygons + 4 normal maps

- Total: 1,591,365,405 polygons → 362,339 polygons + 24 normal maps

limits of arcAstro-VR 3D data

- When the entire area of Yoshinogari was converted to 3D, it was too heavy to move with the highest polygon output.
- index of lightness
- Low polygon, high division, low capacity
- GPU: Radeon Pro 580, CPU: Intel Core i7, Memory: Desktop PC (iMac made in 2017) with 20GB specifications; as a model that works with arcAstroVR, it is reasonable to aim for a total of 2 million polygons or less. Felt.

The Starry Sky Seen by Himiko
- Unraveling the mystery of the Major Lunar Standstill-

This video was screened at the Yoshinogari Historical Park event "Yoshinogari Hikari no Hibiki," held in December 2021. ArcAstro-VR is used to verify the relationship between the Yoshinogari site and celestial movement. This video was announced at the "4th Archaeological Astronomy Conference" held during the above event period.

- Video time: 8 minutes 47 seconds
- scenario
- Tokai University Yoshitaka Hojo
- Narration
- Yumi Sonoda
- background music
- H/MIX GALLERY
- Production
- scienceNODE
- Toppen Co., Ltd.
- Cooperation
- Yoshinogari Park Management Center
- supervision
- National Astronomical Observatory of Japan, Tokai University, Nanzan University

The Starry Sky Seen by Himiko
-Sunrise and Moonrise as seen from the buildings-

- Video time: 7 minutes 55 seconds
- scenario
- Tokai University Yoshitaka Hojo
- Narration
- Mifuyu Shirakawa, Tokai University
- background music
- H/MIX GALLERY
- Production
- scienceNODE
- Cooperation
- Yoshinogari Park Management Center / Itoshima City Museum of History, Saga Prefecture
- supervision
- National Astronomical Observatory of Japan, Tokai University, Nanzan University