Discovery by Reconstruction: Exploring Digital Archeology

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ABSTRACT

With a case study of the digital reconstruction of a village 5,000 years ago, the authors revealed the discovery process behind the scene, such as inverse physics process with decision-making and analogies. It is found that digital reconstruction enhances the understanding of archeological details, spatial relationship, and cross-referencing with field data.

INTRODUCTION

In Archeology, reconstruction of ancient artifacts and scenes is essential for scientific discovery and humanity inspiration, where science is not only logical reasoning but also creative perception, skillful crafting, and effective communication. In many cases, archeologists are more or less like detectives who try to put pieces of information together and use scientific reasoning and visual rendering to fill the gaps among the evidences.

Constructionism states that people don't simply get ideas but construct them. Simulation or reconstruction has been a key for understanding complex scene, spatiotemporal relationship and sequential context. Digital reconstruction is an emerging method for rapid and efficient prototyping of assumptions and visual reasoning.

There have been studies of how to use digital technologies to preserve or present ancient artifacts, for example, the the art restorers and computer scientists in Assisi, Italy, used computer and high-resolution scanners to piece together 120,000 pieces of a huge Cimabue fresco in St. Francis Church, after the earthquake. [Valsecchi, 1999] Digital Michelangelo Project [Levoy, 2000] that used high-resolution laser scanner to digitize the famed sculpture, and digital archiving and intelligent retrieving using geometric modeling for archiving and searching 3D archaeological vessels. [Razdan, 2001] These studies enable digital technologies for efficient reconstruction in archaeology.

In this paper, we present a case study that provides an insight about how the digital reconstruction can help archeology in scientific discovery. Instead of exploring individual tools or techniques, we intend to focus on the discovery process itself. We explore where the human 'ambient intelligence' is; e.g. spatial reasoning, common sense and level of details in the modern digital reconstruction might change the archaeological discovery in future.

The project in this paper is to reconstruct the village of Botai, including the human face, artifacts and living space. Since 1993, the Carnegie Museum of Natural History has been collaborating with the University of North Kazakhstan and the North Kazakhstan History Museum in the investigation of an eneolithic (3600-2300 B.C.) settlement known as Botai. The Botai culture is known by three large sites, the eponymous settlement of Botai, Krasnyi Yar, and Vasilkovka. The site of Botai is located on the Iman-Burluk River, a tributary of the Ishim, in Kokshetav Oblast. The settlement has at least 153 pithouses, but part of the site has been cut away by the steeply eroding river bank. The Carnegie Museum has been involved in excavating one pithouse and one large midden and their surrounds. In Fall of 2003, art students from Carnegie Mellon University collaborated with researchers in Carnegie Museum and explored the reconstruction with digital media.

RECONSTRUCTION AS INVERSE PHYSICS

The discovery process is similar to a crime scene investigation. The problem solving process involves significant '*inverse physics*.' Thus, given remaining pieces, reconstruct the artifact, process or relationship. For example, given imprints on the ground, reconstruct the ancient house.

We found the reconstruction work is beyond simple logical reasoning and crafting. There are many cognitive processes involved in the reconstruction, such as assumptions and analogies, which play a significant role in the reconstruction. Unfortunately, those inverse physics processes are hidden as 'experience', or ambient intelligence rather than explicit science. We know that 'forward physics' can be solved by mathematical equations, however, inverse physics normally has multiple solutions and mainly is pattern recognition-based. A rapid reconstruction method is desirable to verify, or often present the assumptions to archaeologists. In addition, the reconstructed models often serve as a media for the communication between people in different fields or in public media. The discovery process is illustrated as Fig.1.

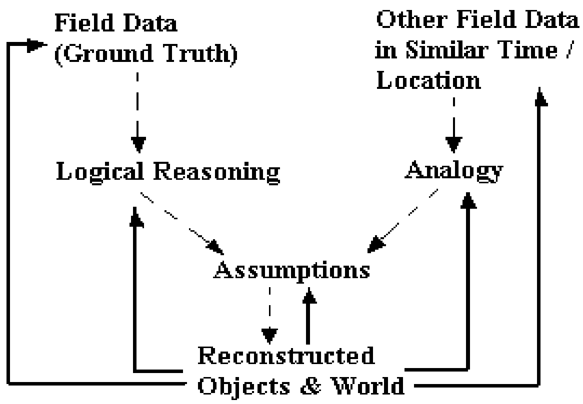

Fig.1 Inverse Physics Process

In archaeology, there are significant spatiotemporal analogies for reconstruction:

- *timeline analogy* – In archeology, history is divided by 'ages', e.g. stone age. By estimating which age the artifacts belong to, archaeologists can reason about the possible process, culture, figures that are not in the excavation scenes.
- *proxy analogy* – The figure, culture and habitation in a location today might similar to the inhabits in the past, given limited time span.

While analogy can generate endless solutions, there are some 'principles' to reduce the number of solutions:

- *physical principle* – the best possible solution is the one with less negative evidences and most consist supporting evidence.
- *minimal principle* – the selectable solution is the one with minimal assumptions and minimal supporting materials, and minimal energy consumption.

Fig.2 shows our reconstruction process for the Botai village. It is found that analogies of similar artifacts in the database fill in the void of missing puzzles. Meanwhile, scientific data and logical reasoning act as filters that reduce *uncertainty*. Therefore the reconstruction is a process of selections along with a growing decision tree. The scientific discoveries lie in the reconstruction process.

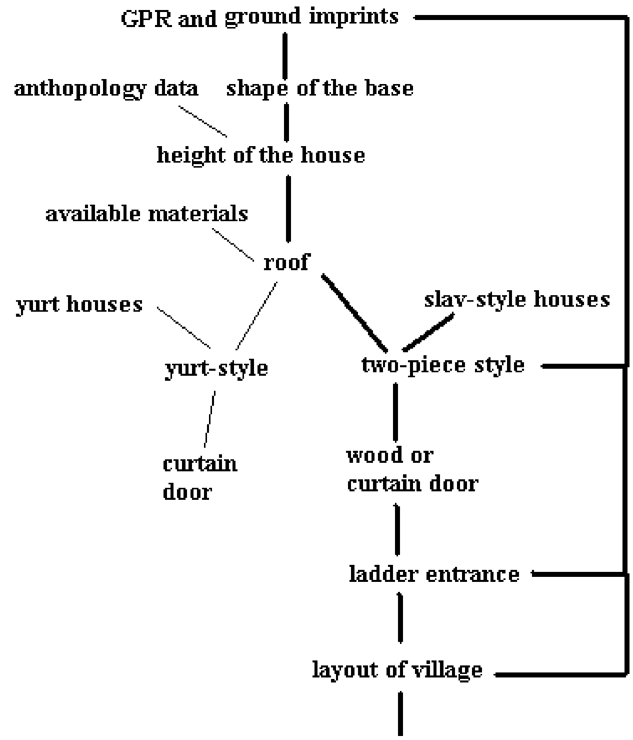

Fig.2 Reconstruction for Botai Village

In traditional reconstruction, the process is to proceed with a scientist-artist relationship. With the digital media, the modal becomes "scientist-computer-artist," or "scientist-computer relationship." There is an argument that traditional reconstruction is more flexible and often efficient to make a visual reconstruction. However, those reconstructions need experienced artists but without repeatable explicit processes. Computer-based reconstruction provides more dimensions in reconstruction. It's fast and rich in details, as well as physical modeling that provides feedback to assumptions and field data collection. However, the downside is its inflexibility. Most of current tools have strong restrictions for input data and output formats. The human-computer interfaces are less than ideal.

LEVEL OF DETAILS

Reconstructed imagery is made up from the combination of individually described component parts. We found that computer 3D model of village increased the level of details, which traditional artistic 2D illustration was lacking. For example, Fig.3 shows a two-dimensional reconstructed Botai village. There is no detail about the entrance, roof, and related materials. While we reconstructed the 3D model of the villages, we investigated additional details. For example, in the 3D model, we created a ladder for an entrance.

Object	Reconstruction Method
wall	analogy for the texture, logical reasoning the height
roof	analogy from images and logical reasoning about the available materials.
entrance	logical reasoning from the imprints on the site, with initial analogy of the entrance in northern American basement entrances.
horse	analogy with today's horses
head	logical reasoning from the muscle depth of Central Asian heads and analogical rendering with current faces of local people.

However, level of details really depends on applications. For crime scene reconstruction, studies show that line drawings do not provide enough detail. Only 47% could be identified [Graham]. Sketch quality offers a very fruitful margin for interpretation, while a photo may produce misleading detail. While computer rendered photorealistic 3D models are attractive to general audiences, some scientists still believe that "the best is to use scanned hand-drawing components, rather than photographic ones." [Taylor, 2004] Therefore, we have to balance the level of details for different purposes.

SPATIAL RELATIONSHIP

Our study shows that a 3D walk-through paranomic view of the village enhances the understanding of the spatial relationship among the artifacts. A 2D layout overview or the cross section 2D view can not replace the virtual reality view of the 3D model. With the 3D model, scientists indicated that they had a better knowledge about the village.

CROSS REFERENCING

We used multiple database/knowledge bases during the reconstruction work. For example, what were the possible colors for Botian's cloths? We investigated available plants and minerals at that time and possible processes for making those colors, and we have a prioritized list of possible colors. For future Digital Archeology, we would have better cross referencing resources over the networked database.

DATA COLLECTION FOR RECONSTRUCTION

We found that reconstruction provides feedback for future field data collection. For example, our head reconstruction software demands that the skull positions in the image should be at so called 'Frankfurt Plane.' Unfortunately, our current images didn't put it in this way. Furthermore, reconstruction software can eventually be portable for field trips and scientists can accomplish the preliminary reconstruction on site. Therefore, it may reduce the revisiting of the site. In some cases, the on-site reconstruction, or the reconstruction-oriented data collection can be meaningful for endangered sites, such as the flooded site in Turkey.

ONLINE PRESENTATION

There have been many virtual reality museum sites for archaeological presentations. How to balance the detail level and the 'affordability' of the media are practical matters. In our project, we did a usability study about the possible presentation media. Since we plan to deliver the reconstructed scenes over the Internet, we made a few limitations: 1) size of image as 640 by 480, 2) degree of freedom for 3D interaction as 2 axises, and 3) we selected only one platform, QuickTime, for a major playback tool. We used MAYA to build the 3D village model and used QuickTime VR to present the interactive 3D model without too much overhead. The delivered village model file itself is only in size of 1.3 M.

CONCLUSIONS

We found that digital technologies can bring archeology to a new era where it not only can assist archeologists for scientific discovery but it can also enrich the presentation of findings and enable the distributed scientific communication and discovery.

ACKKNOWLEDGEMENT

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Fig.3 Botai Site Today

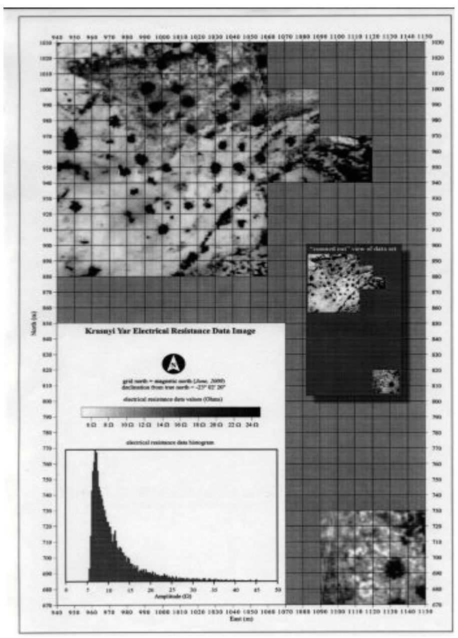

Fig. 4 Ground penetration radar data

Fig.5 Recovered 2D Village Map

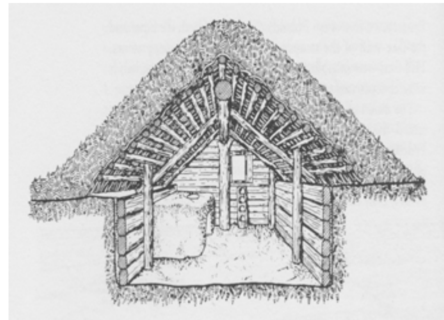

Fig.6 Slavic Hut for Analogy

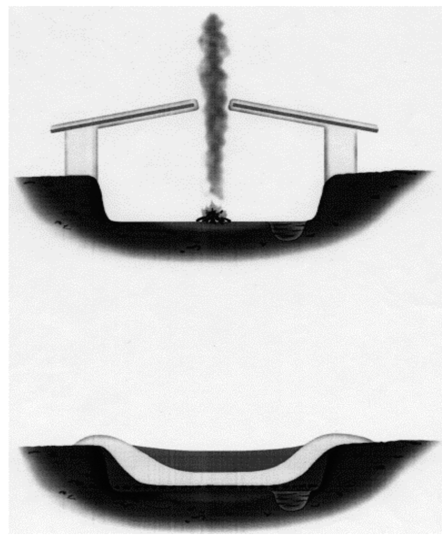

Fig.7 Recovered 2D house

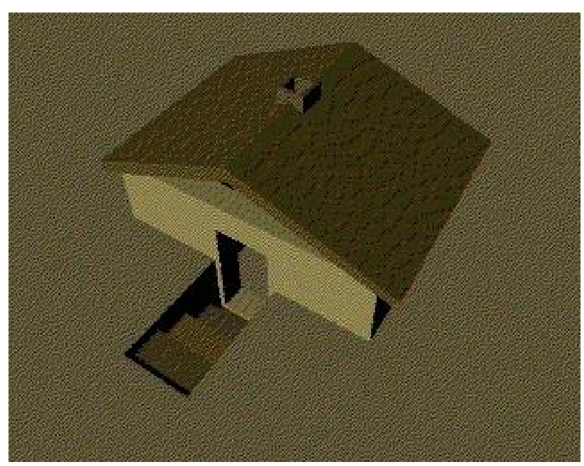

Fig.8 Reconstruction of the Entrance

Fig. 9 Recovered 3D Village

Fig. 10 Recovered 3D Village

Fig. 11 Recovered 3D Village in Paranomic View

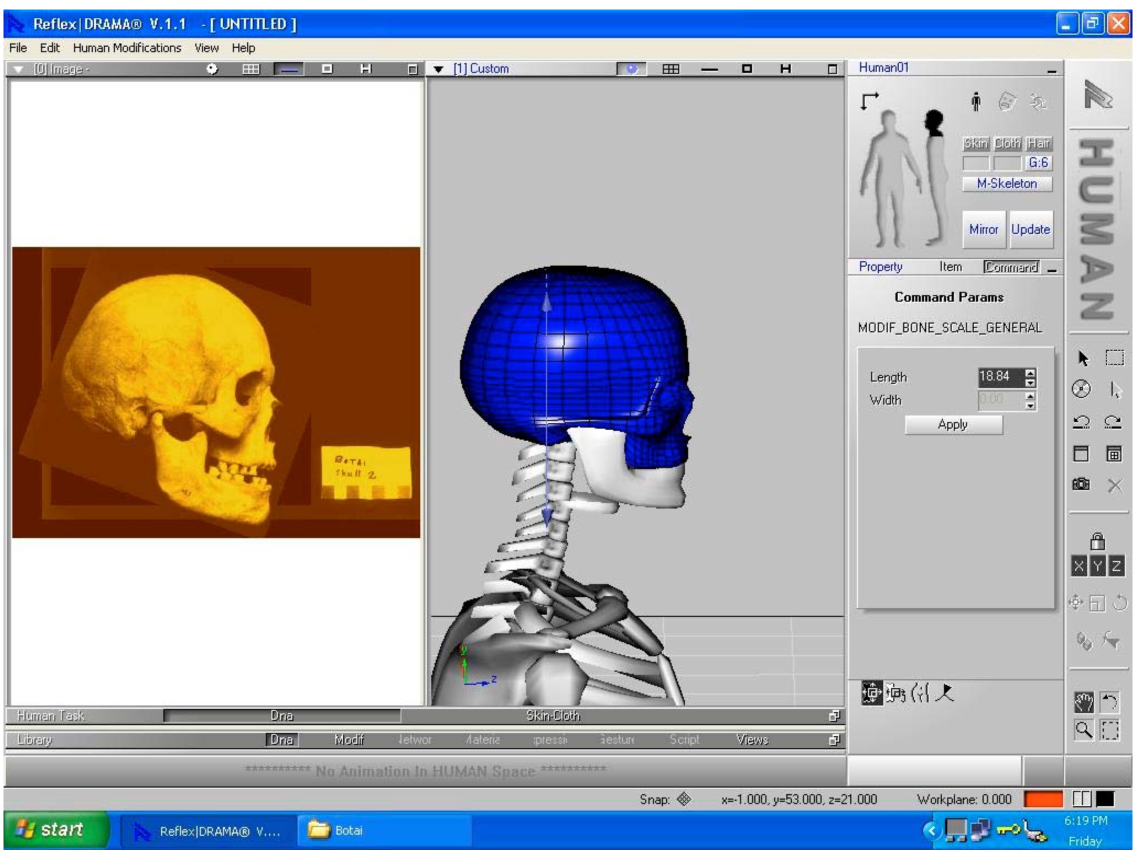

Fig.12 Reconstruction of Bota Man's Head from the Skull Images (transformed to Frankfurt Plane by computer)

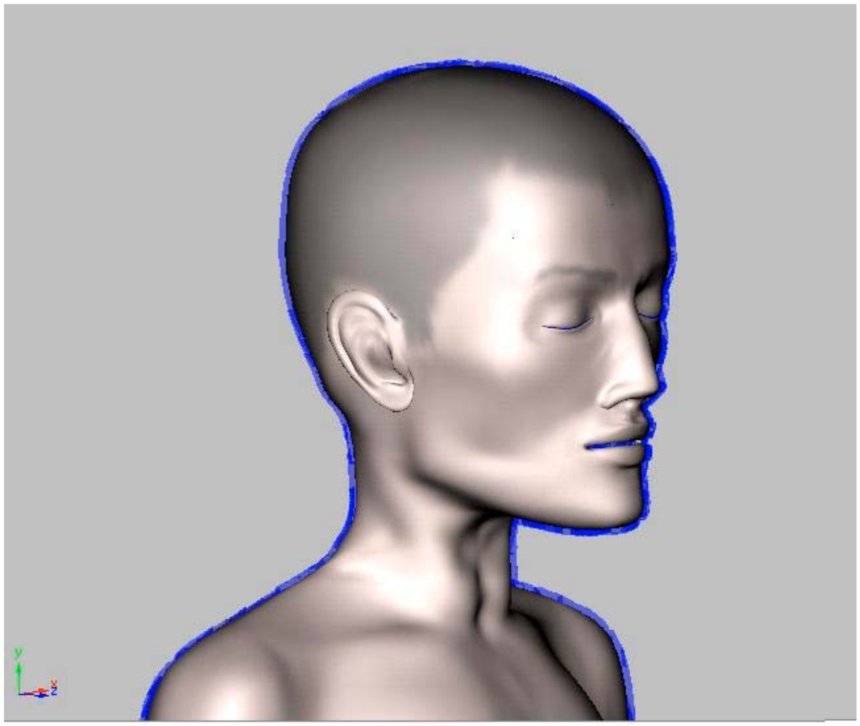

Fig.13 Recovered Botai Man's Head