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Experimental Restoration and Reconstruction in Music Archaeology

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Abstract

Restoration attempts to recover the original shape of excavated musical artifacts that have been damaged. Reconstruction is primarily focused on unearthed musical instruments or those depicted in images, and aims either at creating reproductions of playable replicas and imitations, or at simulative manufacturing and model reconstruction. Restoration, on the other hand, can be carried out in tangible or intangible ways. Tangible restoration can be perceived visually, while intangible restoration is instead sonic, and therefore aurally perceptible. Restoration not only recovers the integrity of fragmentary instruments, but also, if possible, reconstructs the sound of the original instrument based on pitch measurement and analysis. Restoration can also be applied to musical iconographic sources and musical textual symbols, such as musical notations and surviving classical texts. The restoration of musical notation is not the same as transcription of musical score. The restoration of epigraphic texts aims mainly to restore blurry and otherwise unclear or missing characters. Reconstruction, on the other hand, is a kind of simulation experiment that uses physical or virtual manufacturing to copy, imitate, and reproduce musical remains, for the purpose of exploring ancient musical practices. Based on excavated objects, musical instruments can be copied or imitated, while simulative experiments based on iconography are necessarily limited to speculation.

Keywords

Restoration – Reconstruction

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1 Introduction

Known as research methodologies, restoration and reconstruction are lab-based experimentation in music archaeology. Restoration tries to recover the original shape of excavated musical artifacts that have suffered little damage. Theoretically, restoration involves all types of musical remains including musical instruments, iconographic representations, epigraphic texts, ancient notations, and sometimes sites and ancient venues for music performance, such as theaters, stages, concert halls, and other buildings for performing arts. Historically, restoration attempts were mainly limited to musical instruments, since other remains, especially ancient notations and theatrical buildings, are more difficult to restore.

Borrowed from experimental archaeology, reconstruction primarily focuses on unearthed musical instruments or those depicted in images, in order to create playable reproductions (replicas) and imitations. In addition, through 3D printing or VR technology it is also possible to create simulative manufacturing and model reconstruction.

This paper will examine the various methods used in restoration and reconstruction, and will compare the similarities and differences of both types of experimentation.

2 Restoration

Restoration can be carried out in both tangible and intangible ways. Tangible restoration is visible; it may be, for instance, the recovery of an instrument's shape. Intangible restoration is invisible, as it is sonic and therefore perceived aurally, for example, the retrieval of tone series and scales of musical bells and chime stones discovered by Chinese archaeology.

Restoration of musical instruments mainly focuses on incomplete finds, such as damaged or fragmentary specimens, which can be recovered through restoration techniques. The broken or damaged parts may be repaired by professional technicians, and in the case of some instruments it is even possible to recover the ways in which they were assembled.

With regard to incomplete instruments, the restoration is possible only when certain preconditions are met:

1) the broken parts of instruments are not missing or lost.
2) the broken parts of instruments can be glued or otherwise joined, or
3) although the broken parts are missing or lost, there is only one way to reconstruct their original shape.

It must be noted, however, that the recovery holds some uncertainties if there is more than one possibility for restoration, in which case the restoration cannot be considered definitive in terms of music archaeology.

Some clay ocarinas, for instance, are not well-preserved when excavated; but although the blow hole has been damaged, it is possible to restore it based on the shape of the mouthpiece. Like fragmentary Chinese chime stones with a standard pentagonal shape, it depends on different factors. They may be restored if the missing part is merely an angle of the chime stone; otherwise, it is not easy to estimate the sizes of the missing parts on both sides, so restoration in these cases must necessarily involve some imagination and hypothesizing. Sometimes unearthed bamboo or bone flutes are in a similar condition to clay ocarinas and lithophones – the broken and missing parts of the pipes cannot be exactly reconstructed; thus, it is impossible to estimate the shape and size of the instrument, which makes its recovery and restoration very difficult.

Technologically, archaeological restoration not only recovers the integrity of a broken instrument, but also, if possible, reconstructs the tone series or scale of the original instrument through pitch measurement and analysis. Two case studies may serve as a point of reference. One of them has been carried out on the late Western Zhou (877–771 BCE) chime stones *biānqìng* (编磬) unearthed from tomb M27 in Hancheng Liangdaicun (Shaanxi) in 2005–2007, and comprising ten stones in a set, five of which are incomplete, although their broken parts were found when it was excavated.[1] Before taking pitch measurements, I discussed the possibility of repairing the fragmentary pieces with the chief excavator Sun Bingjun. We let technicians glue the pieces together and thus restore all five broken stones, which produced better tones after restoration, except for one with poor intonation and sound quality. In this way the idea of restoring the scale structure of this set of chime stones has been realized.[2]

Another example is a set of 107 chime stones uncovered in pit 14 of the Western Han tomb in Zhangqiu Luozhuang (Shandong), dating to approximately 186 BCE. Some of its stones are broken into two or three, or even more pieces.[3] In the past, in most cases, such broken stones either were not analyzed with regard to the pitches they were intended to produce, or only more complete specimens were studied. Cui Dayong, the excavation leader of Luozhuang Han dynasty's tomb, proposed gluing all the broken stones in order to recover their original shape. Once the process of restoration was accomplished, the vast majority of chime stones began to emit correct sound and produce their relative pitches in the original arrangement, which enabled the recovery of the scale that was once played on them.[4]

Aforementioned studies have proved that some restored chime stones can produce sound and, indeed, can be played, while the relative pitches in the original set of some other stones will not be greatly affected, even though the timbre has more or less changed. Under these circumstances, it is possible to deduce the overall tone series and scale structure of chime stones. Nevertheless, it is not possible to recover the sound or pitch of all broken chime stones, not least due to differences between various chime sets and specimens, and the nature of these differences. So far the reason for this has been unclear, and it needs to be researched comprehensively from the perspective of petrology, archaeoacoustics, and archaeological restoration technology.

1 Shaanxi Sheng Kaogu Yanjiuyuan 2007.
2 Fang 2019a.
3 Jinan Shi Kaogu Yanjiusuo 2004.
4 Fang 2010.

It should be noted that sound or pitch restoration is not equally possible for all musical instruments, and there are considerable differences between individual finds. Some instruments become dull or even lose their sound after repairs. Although some broken musical bells *biānzhōng* (编钟), for instance, have been glued together by technical means, and their shape has been restored to the original form, they are not playable and they do not produce real sound. The fragmentary wind instruments, such as bone or bamboo flutes, are usually soundless after restoration.

Strictly speaking, due to various factors the original acoustic properties cannot be recovered in full once the instruments have been buried. In fact, sound restoration mainly aims to reconstruct the relative pitch, especially the tone series or scale structure of the percussion instruments with fixed pitch, such as ancient Chinese chime bells and chime stones, rather than their absolute pitch and timbre.

Some individual finds from sets of fixed-pitch percussion instruments, which have lost their original sound due to damage, require comparisons with the data from pitch measurement based on intact instruments of the same kind. Such measurements generally result from quantitative analysis and have certain common characteristics and rules, which can, by analogy, be used to reconstruct the pitch of the damaged, dumb instruments in the sets.

Ancient Chinese two-tone musical bells and chime stones with the same pitch arrangement, as well as others found in different sites but with the same number of pieces in a set and dated to similar periods, exhibit common tonal features, which can serve as the basis of comparison for some complete sets of damaged bells and stones that have lost their original sound. This could enable the reconstruction of their relative pitch and tone series or scale structure. For example, a set of nine Ju Gongsunzhaozi chime bells dating to the mid-Warring States period (c. 350–300 BCE) were found in a tomb in Zhucheng Zangjiazhuang (Shandong) in 1970, two of which were damaged and had lost their sound.[5] The data of pitch measurement is shown in Table 1.[6]

Chime bells with nine pieces in a set frequently occurred in China's central plain area during the Eastern Zhou times (770–256 BCE); for example, nine bells recovered from tomb M1 of Chu state in Henan Xichuan Xiasi may form a pentatonic scale with *zhǐ* (sol) mode when their first tones are played:[7]

zhǐ – yǔ – gōng – shāng – jué – yǔ – shāng – jué – yǔ

sol – la – do – re – mi – la – re – mi – la

Through comparison, we may conclude that the Ju Gongsunzhaozi chime bells formed the same scale structure (question marks indicate soundless bells):

zhǐ – yǔ – ? – shāng – jué – yǔ – shāng –? – yǔ

5 Shandong Zhucheng Xian Bowuguan 1987.

6 Weng 1992; Fang 2006: 243–45.

7 Zhao 1996: 319. Chinese pentatonic scale steps take the following names: 徵 (*zhǐ*), 羽 (*yǔ*), 宫 (*gōng*), 商 (*shāng*), 角 (*jué*), which is equivalent to sol, la, do, re, mi.

Except for the third and eighth bell, the scale produced by the remaining bells is apparently identical to the scale of the nine chime bells from the Eastern Zhou period. Therefore, it can be inferred that the two missing first tones of Ju Gongsunzhaozi chime bells are respectively *gōng* (do) and *jué* (mi), and their scale structure is the same as that of the Eastern Zhou nine-piece chime bells from the central plain area of China.

No.	First tone	Second tone
1	G♯$_4$ −32	A♯$_4$ −21
2	A♯$_4$ −24	C$_5$ + 4
3	soundless	soundless
4	D♯$_5$ − 3	F$_5$ −23
5	F$_5$ −10	G♯$_5$ +35
6	A♯$_5$ − 7	C♯$_6$ +22
7	D♯$_6$ +23	F♯$_6$ +20
8	soundless	soundless
9	A♯$_6$ −26	C♯$_7$ + 5

Table 1: Data of pitch measurement of Ju Gongsunzhaozi chime bells

The pitch measurement data of grouped instruments can also be applied to the reconstruction of tone series or scales of incomplete sets of instruments. The late Western Zhou Lái (逨) bells are a good example. After excavation of a bronze vessel hoard in Meixian Yangjiacun (Shaanxi) in 1985, a set of nine bells was first stolen and later partially retrieved; unfortunately, five bells are still missing. Four bells with inscriptions are at present stored at the Meixian County Museum (Shaanxi) in China; three of them (no. I, II and III) are larger, and each is inscribed with 117 characters, while the smallest one (no. IV) has only the last 17 characters of the entire inscription, suggesting that the other 100 words are likely inscribed on the missing bells.[8]

One Lai bell with 117 inscribed characters, like the three larger Lai bells housed in China, is displayed in the collections of Cleveland Art Museum in the US.[9] So far, the pitch of four bells in China have been measured, the data of which is presented in Table 2.[10]

No.	Specimen no.	First tone	Second tone
1	II	A♯$_3$ +34	D$_4$ −14
2	I	D$_4$ − 3	F$_4$ +37
3	III	G$_4$ −13	A♯$_4$ +35
4	IV	G♯$_6$ − 4	B$_6$ +33

Table 2: Data of tone measurement of late Western Zhou Lai bells

In Central Plain area, mid- to late Western Zhou chime bells often occurred in sets of eight pieces that formed a four-note-scale in *yǔ* (la) mode,[11] which has become a common practice in chime bells' tradition (words in square brackets refer to the second tones):

yǔ – gōng – ju [zhǐ] – yǔ [gōng] – jué [zhǐ] – yǔ [gōng] – jué [zhǐ] – yǔ [gōng]

la – do – mi [sol] – la [do] – mi [sol] – la [do] – mi [sol] – la [do]

8 Liu 1987.

9 Fang 2011: 127–32.

10 Fang 1996.

11 The ancient Chinese regarded *gōng, shāng, jué, zhǐ* and *yǔ* as the five positive tones (*wǔzhèngshēng* 五正声), and the fourth and seventh as the two changes (*èrbiàn* 二变) that were not orthodox notes. According to the records of *Zhou li* (the ritual system of the Zhou, about 3rd century BCE), the court music of the Western Zhou Dynasty used *gōng, jué, zhǐ* and *yǔ* in four notes which have been proved in the scale structure of chime bells discovered by Chinese archaeology, even though it seems they correspond to re, fa, la, and do. See Fang 2011: 159–65.

Returning to the Lai bells, a set of four bells preserved in mainland China missing four other bells may form a similar scale structure (underlined characters indicate the pitch names of missing bells, the symbol '↑' indicates higher pitch with inaccurate intonation):

yǔ – *gōng* – *jué* [*zhǐ*] – *yǔ* [*gōng*] – *jué* [*zhǐ*] – *yǔ* [*gōng*] – *jué* [*zhǐ*] – ↑*yǔ* [*gōng*]

la – do – mi [sol] – la [do] – mi [sol] – la [do] – mi [sol] – ↑la [do]

The comparison of the Western Zhou chime bells with an eight-piece set suggests that the four Lai bells in China should be the second, third, fourth, and eighth piece of the set, while the first, fifth, sixth, and seventh bell are still missing. Obviously, the Lai bell from Cleveland should be the first one of the set, with its first tone *yǔ* in the complete assemblage of eight bells.

In addition, another Lai bell was reported in George Fan's private collections in New York.[12] With 25 characters inscribed, and judging by the content of inscriptions, this bell should be the seventh piece in a set of eight, and connected to the subsequent eighth bell (the last one). Moreover, this bell produces D_6 (first tone) and $F\sharp_6$ (second tone), which corresponds to the pitch of the seventh bell in the set, in which two bells (the fifth and sixth) are absent from the complete set of eight bells. Hopefully, all eight bells will be reunited in the future.

Restoration research can also be applied to iconographic sources of music. Some three-dimensional musical images, such as the ancient terracotta figures of musicians, can be restored by reattaching the broken-off fragments; for instance, the musical instrument models held by the figures, which have fallen off and been separated from the hands, or broken musical instrument models, can be glued back together to restore the integrity of the musical image, so as to show the overall gesture, motion and musical instruments held by the terracotta figures. However, other pictorial representations, such as partly damaged mural paintings or fragments of frescoes and statuettes, can be restored, but it is sometimes difficult to precisely estimate their original appearance and therefore restoration is impossible.

Also, restoration research can be applied to musical textual symbols, such as musical notations and unearthed classical texts referring to musical activities. Unearthed fragments of writing with musical notation are usually incomplete, but it is possible to recover some symbols or deduce the missing parts from the remnants. It should be noted that musical notation restoration is not the same as the transcription of musical score. Although the transcription of ancient musical scores aims to recover ancient music to a certain extent, the transcription result does not usually produce the authentic form of the ancient music itself, due to the subjective approach of translators, as well as the unknown aspects of rhythm, meter, tuning of string instruments and so forth. According to current interpretation, Dunhuang pipa tablature (敦煌琵琶谱), for example, consists only of the symbols that represent fingering positions on the pipa lute of the Tang dynasty (618–907 CE), so different translations vary with regard to melody and rhythm. Because of the different understanding of the pipa tuning, the translated music also differs in pitch and melody. The notation

12 Shouyangzhai 2008: 121–23.

restoration is therefore the basis of notation interpretation, but the notation interpretation does not restore music in its original form.

The restoration of epigraphic texts aims mainly to restore blurry or unclear characters, or texts where just a few characters are missing. Some of them can be restored by visual observation, and some need to be restored by means of scientific and technological methods, such as infrared photography, for example, which is currently applied to the restoration of ancient Chinese bamboo slips.

As for the restoration of missing characters in surviving classical texts, some can be deduced from the context, while others can be supplemented by transferring the general rules observed in the existing unearthed musical documents. The inscriptions on the Western Zhou chime bells, for example, are intrinsically connected in terms of content. Sometimes one chime bell has an independent complete inscription; sometimes several chime bells are jointly inscribed with a complete inscription. Therefore, the restoration of characters and passages supports the study of unearthed musical documents, and once this restoration is successful, it can in turn serve in the musical restoration of unearthed chime bells.

3 Reconstruction

In music archaeology, reconstruction is a kind of simulation experiment that borrows from the methodology of experimental archaeology, and uses physical or virtual means to copy, imitate, and reproduce the musical remains, so as to explore the music practices of ancient people. The design and implementation of simulation experiments in music archaeology is normally accomplished by close collaboration between music archaeologists, instrument makers, and instrumentalists.

Theoretically, experimental reconstruction in music archaeology may concern all music-related remains. However, due to the characteristics of the research objects and the limitations of experimental conditions, research has so far primarily focused on material objects and pictorial representations of musical instruments.

The reconstruction of musical instruments comprises instrument making and playing, through which it is possible to study the design, manufacture, craftsmanship, and sound properties of the instrument, and thereby verify some conclusions or hypotheses. Although the process of experimentation is considerably suppositive, it concerns, after all, the actual production practice of musical artifacts, which cannot be replaced by reasoning and imagination. Actually, in ancient times, craftsmen who produced musical instruments may have relied on measurements and procedures[13] which are difficult for us to simulate one by one in our reconstruction of musical instruments. Therefore, parameters need to be varied across simulation experiments.

13 According to classical texts, *Kaogongji*, the ancient Chinese chime stones, were made to a certain size ratio, and there were specific grinding and tuning parts. For details, see Fang 2006.

It is almost impossible to discover the whole manufacturing process and how the instruments were played and performed. The damaged instruments that could not be properly restored and played for the sake of further study on their pitch, and the instruments that survive only in images but not as archaeological finds, can also be reconstructed to explore the possible playing methods and sound properties.

Finds of ancient musical instruments are usually individual, partial, and sometimes even fragmentary; meanwhile the reconstruction is expected to discover a relatively complete manufacturing process of ancient musical instruments, and to explore the possible musical practices in ancient society.

There are two main methods of experimental reconstruction, which are worthy of exploration: copying and imitating musical remains. It must be pointed out that the reproduction and imitation of musical remains cannot be equivalent to, or substitute for, the original. They all belong to the category of a simulation experiment, not restoration. Based on excavated objects in an archaeological context, musical instruments can be copied or imitated, while in the case of iconographic evidence, the reconstruction of musical instruments is necessarily limited to imitation.

Reconstruction can aim at either a copy or an imitation. 'Copies' and 'replicas' are strict replications from original musical remains and are different from imitations. The reproduction of unearthed musical instruments is required to be highly consistent with the originals in terms of manufacturing materials, craft skills, dimensions, weight and sound (if well-preserved). Therefore, the material and technical conditions for musical instrument replication are higher than those for imitation, and it often requires interdisciplinary study and multi-professional cooperation.

When discussing the experimental reconstruction of unearthed musical instruments, Ricardo Eichmann proposes "historical reproduction",[14] emphasizing that the ancient principles of design and production methods should be explored and applied to the reconstruction of musical instruments. He points out that ancient manufacturing tools were different from modern ones; thus the timbre of musical instruments made by ancient methods may have considerably differed from those made by modern techniques. Obviously, ancient methods should be examined and adopted for musical instrument reproduction. Undoubtedly, it is better to use ancient manufacturing tools, rather than the modern mechanical types of equipment and techniques. Nevertheless, while some ancient methods and tools might be discovered through study, others may not. This is a subject that needs to be continuously explored through simulation experimentation.

When replicating chime bells from the tomb of Marquis Yi of Zeng, the manufacturing materials and substances had to be the same as the originals. The alloy composition used to replicate the chime bells needed to be obtained through scientific testing so that the replicas could be consistent with the unearthed originals. In terms of the manufacturing method of chime bells, Chinese scholars have conducted research on the design, casting, technology, and tuning of the chime bells

[14] Eichmann 2004.

from the tomb of the Marquis Yi of Zeng.[15] In appearance, the duplicated chime bells should have been identical in color to the originals, and should have looked the same as the originals so as to give the effect of 'copy from the real'. More importantly, the pitch and scale structure of the replicas needed to be the same as the ones of the original bells.

Scholars have also done simulation experiments on musical instruments found in Europe, and explored their materials, manufacturing techniques, and methods. When reconstructing the European bronze Lurs, Peter Holmes and Nik Stanbury studied whether ancient people had used the lost-wax process.[16] Anders Lindahl made reproductions of a pottery drum from the middle Neolithic Age and another one from the late Bronze Age excavated in Skåne, Sweden. He explored the ceramic materials and firing methods of the pottery drum, and analyzed the possible manufacturing methods in the prehistoric period.[17] Lena Alebo speculates that seal skins could probably be used as the drum head.[18]

The playable replica of a musical instrument is not only required to 'look like' the original, but also to 'sound like' it. Of course, the shape and structure of a musical instrument are important, but considering its musical function, it is more crucial to reproduce the sound, i.e. the pitch and intonation of the copied instrument should be consistent with the original. However, it should be noted that it is very difficult to reproduce the timbre of an instrument in accordance with the original, thus we would call the sound of a replica 'sonic similarity' rather than 'sonic equality'.

Unlike replication, the imitation of musical instruments has no strict requirements for materials, sizes, sound, manufacturing methods, and techniques. They may differ from unearthed instruments to some extent, sometimes only having a similar shape in common. However, musical instrument imitation could also be more similar to the original, what is in Chinese called *gāofǎng* (高仿, 'higher imitation'), but even so, it is still an imitation. Some instrument imitations are toys or souvenirs, and musical archaeology is certainly not concerned with them. Thus, we can see that the musical instrument replication belongs to a higher level of simulation experiment, while musical instrument imitation represents a lower level.

As stated above, imitation of musical instruments can be divided into two types: imitation based on physical objects and imitation based on images, and there are certainly many differences between them.

The reference point for imitations of musical instruments are three-dimensional physical objects, but the iconographic sources, such as mural paintings, are two-dimensional and lack important information: for instance, the size and internal structure of the depicted musical instruments. As for figurines of musicians with musical instruments, although three-dimensional, they differ significantly from reality. Therefore, the academic value of imitated musical instruments based on iconographic sources is lower than that based on unearthed musical instruments.

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15 Hubei Sheng Bowuguan 1992.
16 Holmes and Nik 1986.
17 Lindahl 1986.
18 Alebo 1986.

Chinese scholars have carried out simulation experiments on the ancient musical instruments depicted in the Dunhuang murals in Gansu, imitating most of the instruments shown in the paintings and making them suitable for music performance.[19] However, the reproduction based on music iconography must necessarily be limited to the imitation level, and its authenticity is naturally weaker than the imitation or duplication based on the actual musical instrument. As Graeme Lawson states, making an instrument based solely on an image cannot be regarded as copying, because copying a picture can only result in another picture.[20] Ricardo Eichmann cautions that in order to rebuild ancient instruments based on musical images, one must have a knowledge of art history, musical acoustics, and archaeology; otherwise misinterpretations and mistakes will inevitably occur when imitating ancient instruments.[21] All these conclusions show the limitations of musical instrument reconstruction based on images.

In order to explore the playing methods and sound properties of instruments, 3D printing technology is currently applied to simulate their manufacture, which has become a new approach to the study of reconstructing surviving organological finds. More accurate data can be obtained by using CT tomography to measure the dimensions of unearthed instruments. On this basis, the shape of imitated instruments is more accurate and thus more suitable for 3D printing. However, materials used by 3D printing methods are only substitutes for original materials and substances, and they cannot equal the original, thus this kind of study belongs in the category of imitation.

In 1988, I made reconstructional experiments on several flutes found in China, such as Neolithic (c. 5000 BCE) bone flutes and whistles from the site of Yuyao Hemudu (Zhejiang), early Warring States (433 BCE) bamboo flutes from Zenghouyi's tomb, Western Han (202 BCE–8 CE) bamboo flutes from tomb no. 3 in Changsha Mawangdui (Hunan) and the Western Han bamboo flute from a tomb in Guixian Luobowan (Guangxi).[22] In the experimentation, plastic tubes were used as materials, and their inner diameters were different from those found in bone and naturally growing bamboo, because plastic tubes are of constant diameter, which is not true for the originals. Imitation experiments, however, help in understanding the playing method and possible tone series or scale structure of ancient Chinese flutes.[23]

In 1935, a stone-made ocarina *xue* (埙) was recovered from the M1550 tomb in Anyang Yinxu Xibeigang (Henan), dating to the first phase of Yinxu archaeological culture (1260–1235 BCE). The ocarina's top part, including a mouthpiece and some finger holes, is broken and incomplete, and its bottom is unsealed.[24] Judging by the internal traces in its empty body, this ocarina was hollowed out from bottom towards its middle part, and polished in a longitudinal reciprocating motion,

19 Dunhuang Yanjiuyuan Yinyue Wudao Yanjiushi 1992.
20 Lawson 2010.
21 Eichmann 2000.
22 Fang 2006: 3–10.
23 Due to the limitations of the technology available at the time, my imitation experiments did not involve reproductions made of bone, nor did they use 3D printing techniques. For details, see Fang 2006.
24 Liang and Gao 1976; Zhuang 1972.

while the inner circumference of the bottom hole was polished in a transverse rotational movement. Li Chunyi proposed that the inner cavity of the bottomless ocarina was easier to hollow out, but it remains unknown whether or not there was a plug in the bottom. If there was not, the instrument could be played in an upper octave; the timbre would be brighter and louder, like an open pipe.[25] If imitation experiments had been carried out on the stone-made ocarina, it would have been possible to test whether it could be blown like an open pipe or whether a piston to plug the bottom hole could be used.

Another example is the mouth organ *shēng* (笙) made of gourd and bamboo discovered in the tomb of Marquis Yi of Zeng. According to the excavation report, a blowing tube mold of the mouth organ may have been used to enclose the young gourd that later made it grow into a long tube for blowing.[26] In order to test the application of this method in the making of the original mouth organ, one might want to test this hypothesis by the simulation of gourd growth.

Imitation experiments also include the reconstruction of ancient musical remains such as soundscape sites – for instance, stages and theaters. The process of turning them into either physical objects or computer models involves experimentations and archaeo-acoustic research on the sites. Jens Holger Rindel's computer model, 3D virtual production and sound simulation experiments on an ancient Roman theatre are meaningful attempts at a respective reconstruction.[27] However, such experiments have so far been rarely conducted in comparison to the many reconstructions of excavated instruments.

Additionally, in the case of some sites of ancient architecture related to musical events, from which only foundations survive, it is possible to design models or schematic diagrams of buildings above ground through the research of archaeological data, which of course involve a considerable number of speculative parameters. For example, at the site of the important music institution Líyuán (梨园) of the Tang dynasty, which has been excavated at Huaqinggong in Lintong (Shaanxi), only the foundations of the houses remain. The point of reference for its imitation is the foundation that may provide certain evidence in terms of building area and space division.[28] However, since the above-ground buildings had been destroyed, the architectural pattern, style and construction can only be inferred from the foundation and other relevant remains, which may also require a good deal of conjecture and imagination.

Along with the continuous development of science and technology, computer-aided research has been increasingly applied in the field of experimental archaeology in order to conduct simulation experiments on archaeological finds. In the case of music-archaeological simulation experiments, the application possibilities of new technologies are quite broad. Virtual simulation and virtual reality technology may become a new developmental trend in constructing computer mathematical models of music archaeological finds. For example, computer generated models can

[25] Li 1996: 401.
[26] Hubei Sheng Bowuguan 1989: 174–75.
[27] Rindel 2008.
[28] Fang 2019b: 186–92.

be used to simulate the acoustic effects of ancient stage and theatre, and VR technology can be used to integrate the visual, auditory and even somatosensory aspects of various music-archaeological remains, so that the audience can feel and experience the realistic existence of ancient musical life as if they were part of it.

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