Investigation of historical forms by modelling

— on the forms associated with human hands

February 2023

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（千葉大学審査学位論文）

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Introduction

1.1 Positioning of the Study

The human hand is a highly flexible and complex physiological structure of the body, and its morphological variations and functional diversity directly determine some of our daily behaviours[1]. There are many artifacts in daily that either directly or indirectly imitate the form of the hand, or are extensions of the hand's function, and in this paper, two historical artefact forms (the Buddha's handprint conveying some religious meaning and the hand-made and hand-used winnowing basket) were selected as the objects, the following case studies were taken.

(1) An impression evaluation and a morphological analysis of the 3D morphology of the Buddha's handprint was carried out to determine whether its morphology can convey some religious significance in the Buddhist scriptures.

(2) According to the cross sections of the real winnowing baskets, the simplified 3D winnowing basket models were reproduced in order to explain some of the winnowing basket's morphological features and engineering characteristics, and the relationship between handcrafting methods, natural materials and form was investigated.

(3) Visualising and quantifying some human hand movement details and difficulties in the use and production of winnowing basket by mechanical learning to extend human sensory vision and better understand the principles and characteristics of human hand or wrist movements in some certain work.

As investigating the morphology of historical artifacts associated with the human hand, actually explores the process of formation and use of historical artifact morphology. In the process of simplifying and emphasizing the model, some engineering properties of historical artifacts are analysed and some responses and operations of human beings in the production and use of historical artifacts are explained, three essential connections (message

[1] J Jia., *Introduction to Functional Hand Rehabilitation,* China Electronic Industry Press, Chapter 1 Section 1, 2019

transmission, production of form and use of form,) between people, artefacts and materials are also suggested.

The approach and conclusion used in this paper seem to be expected to widely applied to the reproduction of the simplified forms of artefacts and the investigation of their morphological characteristics, as well as to the quantitative analysis of psychological and physiological quantities of human production and use of artifacts.

Keywords*：*Historical artefact, Hand-related form, Simplification, modelling

1.2 Structure of the Study (Fig.1)

Historical artefact form (Perspectives: features, function, production, use

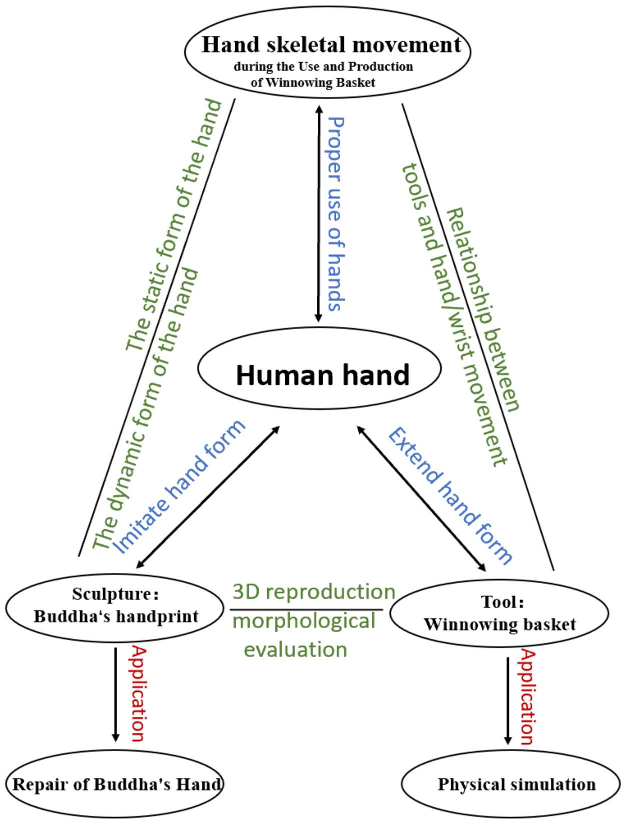

Fig.1 Relationship with human hand, Links between the research objects and **Applications of research**

1.3 Purpose of the Study

A scientific modelling[2] way is investigated to replace historical form, which tend to be difficult to evaluate in engineering terms due to their high information content, with 2D or 3D model that reduces the local morphological information while preserving the essential elements of their forms, to enable the numerical morphological evaluation among different types of the forms which respectively belong to the different categories: Buddhist handprints, winnowing basket and the movement of the hand (wrist) during winnowing basket making.

(1) In order to investigate whether the Buddhist handprint form reflects their religious significance based on the two-dimensional images and the descriptions of handprints in Buddhist classics, the information on the statue of Amitabha in Joshin Temple except the hands was reduced, and only the 3D simplified handprint from representing its universal morphological elements was retained for an impression evaluation, and the impression evaluation results were analyzed and compared also.

(2) In order to investigate some of the difficulties and points of production that cannot be verbalised or overlooked by craftsmen during production and use of winnowing basket, 3D simplified surface forms of the winnowing basket were reproduced and morphologically compared with the original form in an attempt to explain some of the points and difficulties of the manual production process and the engineering properties of the material.

(3) Using AI and Mathematical simulation analysis techniques, the simplified motion trajectory (line form) of the craftsman's hand (wrist) during production and use of winnowing basket was examined to obtain the movement essentials and details during the production and use of the baskets that are not easily observed and understood

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[2] Scientific Modelling, 科学的モデリング, from Wikipedia, https://ja.wikipedia.org/wiki/モデリング_(科学的),

Although the above are three case studies related to the human hand,, this paper does not aim to investigate the relationship between the individual cases, but rather to strengthen the constituent elements of the model and reduce the decorative elements by simplifying or transforming the model and trying to elucidate the relationship between the human hand-related form and the human being in the production and use of historical artifacts, and this relationship can be considered as an explanation for the extension of the human body's functions. This paper also attempts to explain some of the phenomena in life and to reconceptualise the practical and cultural value of historical artefacts. The method and conclusions obtained would be used in the physical simulation, the legacy of craftsmanship, and quantitative analysis of human movement/response during the production and use of historical artefacts.

1.4 Main methods of the study

The methods of 3D modelling used in this thesis

(1) Point cloud modelling[3]
(2) NURBS curves/surface modelling[4]
(3) Parametric modelling[5]

The methods of impression evaluation used in this thesis

(1) SD method[6]

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[3] Point cloud modelling, from SGS, https://www.df-sgs.co.jp/3d-modeling-of-point-cloud-data point- cloud-data-3d-modeling/

[4] Q. Wang., W. Zhou., et al., NURBS-enhanced line integration boundary element method for 2D elasticity problems with body forces, *Computers & Mathematics with Applications*, 77(7), Pages 2006-2028, 2019,

[5] K. HuaChang, *Computer-Aided Engineering Design*, Pages 125-167, 2015

[6] Ergonomics guide: *How to science sensibility,* Human Performance Laboratory (HPL), 153-155, 2014

(2) Quantification Type III analysis[7]

(3) Principal component analysis[8]

The approach to artificial intelligence used in this thesis

(1) Deep neural network human of human 2D motion parsing (Openpose)[9]

(2) 3d-pose-baseline algorithm for human 3D motion inference[10]

(3) Mathematical simulation using parameters (Matlab)[11]

The engineering approach used in this theory

Finite element method[12]

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[7] YK, Amano., *Multivariate analysis in practice*, 50-55, 2018 (in Japanese)

[8] YK Amano., *Multivariate analysis in practice*, 65-86, 2018 (in Japanese)

[9] Z. Cao, G. Hidalgo, T, Simon, S-E. Wei, Y. Sheikh., *Computer Vision and Pattern Recognitio*,2019

[10] Julieta Martinez, Rayat Hossain, Javier Romero, James J. Little, *A simple yet effective baseline for 3d human pose estimation*, ICCV 2017

[11] Parameter Estimation,from mathwork, https://jp.mathworks.com/discovery/parameter-estimation.html, form MATLAB & Simulink

[12] Finite element method, from Wikipedia, https://en.wikipedia.org/wiki/Finite_element_method

Morphological analysis and impression evaluation for the Kuhon handprints in Joshin Temple with simplified 3D model

2.1 Background

2.1.1 Origin and Definition of handprints

Handprints are in Buddhism the various poses of hands and fingers which are the inner symbols of Buddhas, Bodhisattvas and Venerable Masters. The practitioner makes the handprints of a certain Buddha to represent his or her own integraten with that Buddha.[13] Making handprints is a practice for Buddhists, especially in Tibetan Buddhism. Various kinds of handprints are also commonly found in Buddhist artworks, such as paintings, carvings, etc.

In Asian Buddhist countries, various carvings of Buddhas, Bodhisattvas and Luohans are commonly found in temples, with their various handprints relating to the content of their enlightenment, their character and their motives and methods for helping sentient beings. According to the Buddhist classic [Buddha's Sutra on the Measurements of Statues][14], the faces of Buddhas are identical and there are fixed rules and scales for Buddhist painting, which are particularly strict in Tibetan Buddhist thangka painting, so that sometimes the only way to distinguish which Buddha is by the posture of his body and the type of his handprints. So that sometimes in order to distinguish which Buddha he is, we can only observe his body posture and the type of handprints.

Buddhism originated in ancient India and found its way to Japan in Asuka Period via China. The religious culture of Buddhist carvings was also spread to Japan in the same period. But in fact the Heian period was the period when Japanese Buddhist culture flourished, and lots of Buddhist carvings from the Heian period can still be found in some temples throughout Japan today. Japanese Buddhist sculptor pay particular attention to the details of the Buddhist carving hands, for example, the flesh between the fingers of Buddha

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[13] Akiyama, SK., *Buddha Handprint Encyclopedia,*127-131, 255-259,1985.

[14] *The Sutra of Measurements for the Construction of Statues,* Chinese Buddhist Electronic Text Association(CBETA),18-19, 2002, http://buddhism.lib.ntu.edu.tw/BDLM/sutra/chi_pdf/su tra10/T21n1419.pdf(Accessed 2 November 2019) Original work published GongBu, 1742.

statues is a distinctive feature of Japanese Buddha statues (represents not abandoning all beings). In the late Heian period, with the introduction of Buddhist Tantra (Tangmi)[15] , the variety of Buddhist handprints carved varied, not only in the form of individual handprints, but also in the form of statues of Buddhas, bodhisattvas, and King Ming holding Buddhist vessels. This also enriched Japanese Buddhist culture and practice method and gave rise to a new school of Japanese Buddhism, the Tōtō Tantra. Nowadays, for historical reasons, it has also combined and separated with some Shintoism,(native Japanese religious sect), and became part of the daily life of the Japanese people, so that the representation of Buddhist handprint, a form associated with the human hand, is very important in Japanese sculpture and indeed in Japanese traditional culture.

2.1.2 Religious interpretation of "*Kuhon*" in the Buddhism

There are more than a thousand kinds of handprints in Buddhism, both manifest and tantric. Apart from the common handprints of Shakyamuni Buddha, one of the most famous of those is the *Kuhon* handprints of Amitabha, which is a typical characteristic of Amitabha and distinguishes him from other Buddhas, according to the Pure Land Buddhism classic, [The Sutra on the Contemplation of Immeasurable Life Buddha][16] [17](Fig. 2, 3), *Kuhon* has Nine Grade of Birth and can be divided into three grades (groups), each with three (handprints) images. These are[18]

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[15] Buddhist Tantra: It refers to the Eastern Tantra of Shingon Buddhism and the Tai Tantra of Tendai Buddhism in Japan, Including the same type of Buddhist thought in India and Tibet, From Wikipedia, https://ja.wikipedia.org/wiki/%E5%AF%86%E6%95%99.

[16] *The Sutra On Contemplation Of Amitayus*, Chinese Culture Lecture Hall, 2013, (in Chinese), Original work published JiangLiang's translation ,YS,424

[17] The Three Pure Land Sutras, including *[The Sutra on the Amitabha]* - also known as *[the Little Amida Sutra]*. *[The Sutra on the Contemplation of Immeasurable Life Buddha]* - also known as the Sutra of *[Kuan Amitabha]*, or *[simply the Kuan Sutra]*. *[The Sutra on the Immeasurable Life]* - also known as the Great Amitabha Sutra.

[18] SK, Akiyama., *Buddha Handprint, Encyclopedia*,127-131, 255-259,1985 (in Japanese)

High Grade handprints, also called Meditation Handprints,

include *Jobon gesho, Jobon josho, and Jobon chusho handprints*

Middle Grade handprints, also called Teaching Handprints,

include *Chubon gesho, Chubon josho, and Chubon chusho handprints*

Lower Grade handprints, also called Welcoming Handprints,

include *Gebon gesho, Gebon josho, and Gebon chusho handprints*

In fact, there are no two-dimensional images of the *Kuhon Buddha* in the above-mentioned Buddhist classics, nor any descriptions of the form of the *Kuhon* handprints, only the religious significance of the *Kuhon*. Presumably the images of *Kuhon Buddha* and *Kuhon* handprints were created by later generations based on the scriptures rather than written descriptions, so that the matching of its image and name is now highly controversial.

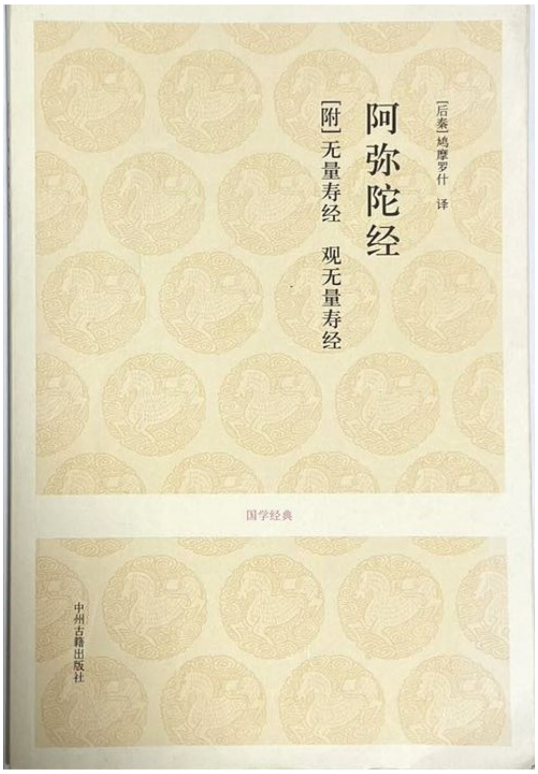
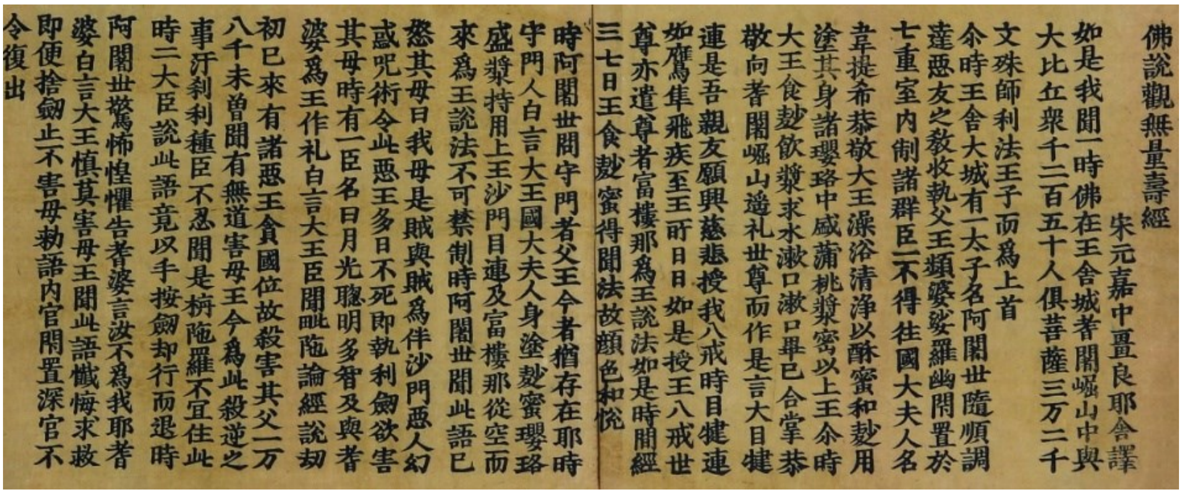


Fig 2 The Three Classics of the Pure Land and [The Sutra on the Contemplation of Immeasurable Life Buddha]



佛說觀無量壽經
宋元嘉中畺良耶舍譯
如是我聞一時佛在王舍城耆闍崛山中與
大比丘衆千二百五十人俱菩薩三万二千
文殊師利法王子而為上首
尒時王舍大城有一太子名阿闍世隨順調
達惡友之教收執父王頻婆娑羅幽閉置於
七重室內制諸群臣一不得往國大夫人名
韋提希恭敬大王澡浴清淨以酥蜜和麨用
塗其身諸瓔珞中盛蒲桃漿密以上王尒時
大王食麨飲漿求水漱口漱口畢已合掌恭
敬向耆闍崛山遙礼世尊而作是言大目揵
連是吾親友願興慈悲授我八戒時目揵連
如鷹隼飛疾至王所日日如是授王八戒世
尊亦遣尊者富樓那為王說法如是時間經
三七日王食麨蜜得聞法故顏色和悅
時阿闍世問守門者父王今者猶存在耶時
守門人白言大王國大夫人身塗麨蜜瓔珞
盛漿持用上王沙門目連及富樓那從空而
來為王說法不可禁制時阿闍世聞此語已
怒其母曰我母是賊與賊為伴沙門惡人幻
惑呪術令此惡王多日不死即執利劍欲害
其母時有一臣名曰月光聰明多智及與耆
婆為王作礼白言大王臣聞毗陀論經說劫
初已來有諸惡王貪國位故殺害其父一万
八千未曾聞有無道害母王今為此殺逆之
事汙剎利種臣不忍聞是栴陀羅不宜住此
時二大臣說此語竟以手按劍却行而退時
阿闍世驚怖惶懼告耆婆言汝不為我耶耆
婆白言大王慎莫害母王聞此語懺悔求救
即便捨劍止不害母勅語內官閉置深宮不
令復出

Fig 3 Part of the [The Sutra on the Contemplation of Immeasurable Life Buddha]

Fig. 4 *Kuhon* Mandala[19]（The diagrams of the *Kuhon* are in the blue border and their enlargements are in appendix section of the paper）

[19] [當麻曼荼羅 3 -九品来迎図], 2013/07/05, http://avantdoublier.blogspot.com/2013/07/blog-post_5.html.

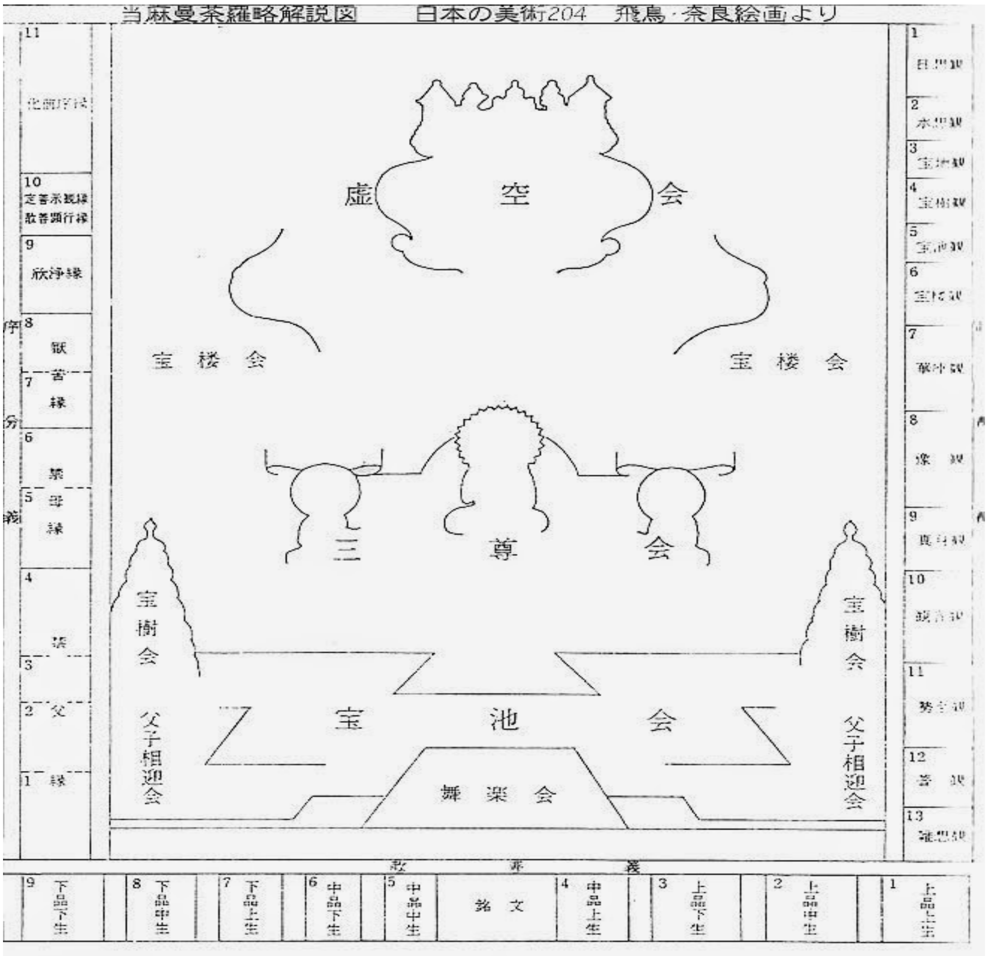


Fig. 5 *Kuhon* Mandala's layout[17]

However, it is said that at the end of the Tang dynasty, the Hyeun[20] exponent of the Ansho[21] temple brought many Mandala[17]of *Kuhon Buddha* (Fig.4,5) back to Japan (but I have not been able to find any Mandala with images of the *Kuhon Buddha* by Hyeun exponent), so at least it can be assumed that images of the *Kuhon Buddha* existed at the end of the Tang dynasty, and it seems that the Pure Land sect in Japan also holds the *Kuhon* culture and the *Kuhon Buddha* form in high esteem.

Thus the variation of Kuhon Buddha with the Kuhon Handprints are as follows: Textual description in [The Sutra on the Contemplation of

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[20] Hyeun, the Ansho temple's founding monk, from the Tang dynasty, is said to have brought the *Kuhon* Mandala to Japan.

[21] Ansho Temple, is located in Goryo Hirabayashi-cho, Yamashina-ku, Kyoto, belonging to the Shingon sect, the main shrine is the eleven-faced Avalokitesvara.

Immeasurable Life Buddha] ~ 2D image in Manjara ~ 2D image (Thangka etc.) or 3D sculpture in modern (Joshin Temple etc.)

Two-dimensional clear images of the *Kuhon Buddha* is found in a Japanese book [collection of Buddhist images] [22](Fig. 6), as follow:

Jobon josho

Jobon chusho / Chubon Josho

Jobon gesho / Gebon

Chubon josho / Jobon chusho

Chubon chusho

Chubon gesho / Gebon chusho

Gebon josho / Gebon Gesho

Gebon chusho / Chubon Gesho

Gebon gesho

Fig. 6 Two-dimensional images of the Kuhon Buddha

[22] Tm Ito, *Collection of Buddhist images*, Pages35-37, Yawata Shoten,2005,12

2.1.3 Environmet of the Joshin Temple(Fig.7-17)

Since the original intention of the Joshin Temple at that time was to follow the environment of the Pure Land of Great Happiness as described in the Buddhism classic of [The Sutra on the Contemplation of Immeasurable Life Buddha], the environment of the Joshin Temple also needs to be introduced in order to understand the meaning of *Kuhon Buddha* and *Kuhon* handprints.

Kuhon Buddha Joshin Temple of the The Pure Land Sects of Buddhism is located in Okusawa, Setagayaku, Tokyo, Japan. The temple is one of the most famous those in the Kanto region of Japan, second only to Daihonzan Zojoji Temple, with a precinct area of approximately 36,000 tsubos and a complete seven hall complex.The complete name in Japanese is［九品山唯在念仏院浄真寺 （浄真寺）］Joshin temple was founded by the high priest Kaseki Shonin (1617-1694) in the early Edo period. The temple was founded in 1678 (Enpo 6) by the fourth shogun, Tokugawa Ietsuna, on the site of Okusawa Castle. The layout of the temple complex, including the main gate, Niomon gate, main hall, Sanbutsu hall, Kaisan hall and bell tower, is magnificent, and is a copy of the phases described in the Kanmuyoju Sutra.

Joruri Temple in ShimoKamo Town, Kyoto Prefecture, is also famous as a temple dedicated to the nine Amitabha statues (The Triple Pagoda is also dedicated to Yakushi Nyorai of the Eastern Pure Glazed World), which is said to be the twin of the Eastern and Western nine Amitabhas.

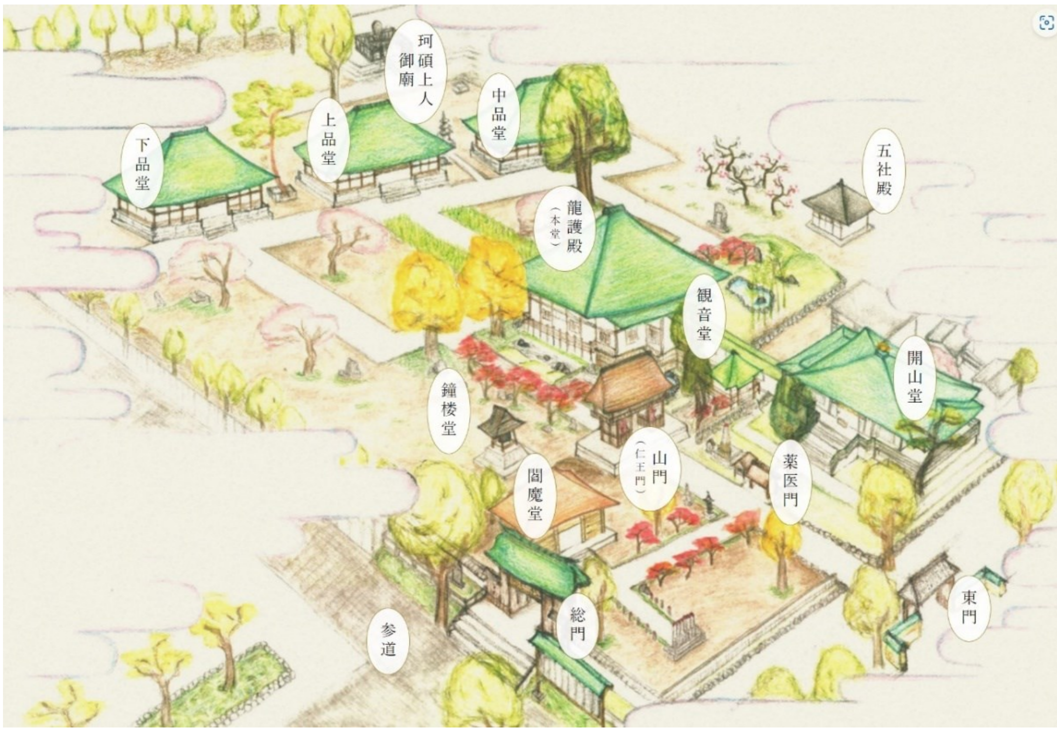

Fig. 7 Hand-drawn layout of the Joshin Temple (from the Joshin Temple official website)

Fig.8 The Entrance of Joshin Temple

Fig.9 The bell tower of Joshin Temple

Fig.10 Ginkgo trees in Joshin Temple

Fig.11 Interior of the Shakya Hall (Main Hall)

Fig.12 Red Leaf in Joshin Temple

Fig.13 Preparation for the Buddhist ceremony

Fig.14 Buddhist ceremony of Joshin Temple(お面かぶり)

Fig.15 Interior of the Jobon Hall

Fig.16 Interior of the Chubon Hall

Fig.17 Interior of the Gebon Hall

2.1.4 *Kuhon* Buddha and *Kuhon* handprints in Joshin Temple(Fig. 18)

The Sanbutsudo Hall of the Joshin Temple contains a total of nine Amitabhas, three in each of the three halls, which are called Joshin Temple *Kuhon Buddha*[23].

In the Jobon Hall of the Sanbutsu Halls, there are three Amitabhas:

Jobon Gesho, Jobon Josho and Jobon Chusho Amitabhas.

In the Chubon Hall of the Sanbutsu Halls, there are three Buddhas:

Chubon Gesho,Chubon Josho and Chubon Chusho Amitabhas.

In the Gebon Hall of the Sanbutsu Halls, there are three Buddhas:

Gebon Gesho, Gehon Josho and Gebon Chusho Amitabhas.

These nine statues of Amitabha statue each have their own distinctive features and different handprint.

Joshin Temple *Kuhon Buddha* are representative of the founder Kaiseki Shonin[24], who excelled at sculpting Buddhist statues, and are worshipped not only in the local area but also in the whole of the Kanto region and Joshin

[23] *Kuhon Buddha origin,* The brochure of Joshin Temple, 201X

[24] Kaiseki Shonin, https://ja.wikipedia.org/wiki/珂碩上人

Temple *Kuhon Buddha* were assessed as the cultural heritage in Tokyo Capital[25]. All of the *Kuhon Buddha* statues are known to be carved by him and his disciplein in the Edo period, using *yosegi zukuri*[26] techniques and traditional techniques, Since the *Teicho* period[27], and are thought to be authentic statues following the ancient style.

The Amitabha body is said to be the body of the fulfilment of the Buddha's main wish, the body of the intake of light and the body of the reception of light, so it seems that the main image of Amitabha in the Pure Land Sect of Buddhism is often in the Welcoming handprint. The right hand is in the upper phase and the left hand in the lower phase.

Acording to the inheritance of Joshin Temple, the *Kuhon* Buddha have nine distinct handprints (*Kuhon* Handprints) that can be divided into three grades (groups), each with three handprints (Fig. 19).

(1) Upper Grade handprint (Jobon Gesho, Jobon Josho, Jobon Chusho): In upper grade, the hands are folded in front of the belly, regardless of which fingers are used to form the circle, meaning stability.

(2) Middle Grade handprints (Chubon Gesho, Chubon Josho, Chubon Chusho): In middle grade, the hands are raised in front of the chest, showing the palms, regardless of which fingers are used to form the circle, meaning teaching.

(3) Lower Grade handprints (Gebon gesho, Gebon Josho, Gebon Chusho): In middle grade, regardless of which fingers form the circle, raises the right hand and hangs the left hand downwards (both showing the palm), meaning welcoming.

In short, the position of two hand determines the meaning of Grade（品） (stability, teaching, welcoming)

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[25] Joshin Temple, *Comprehensive survey report on cultural heritage*, Tsuda Photo Printing,1986, 浄真寺

[26] Yosegi zukuri, from ニッポニカ, https://kotobank.jp/word/寄木造

[27] Teicho period, from Wikipedia, https://ja.wikipedia.org/wiki/定朝様

Jobon Gesho

Jobon Josho

Jobon Chusho

Upper Grade Handprints (Meditation Handprints)

Chubon Chusho

Chubon Josho

Chubon Gesho

Middle Grade Handprints (Teaching Handprints)

Gebon Gesho

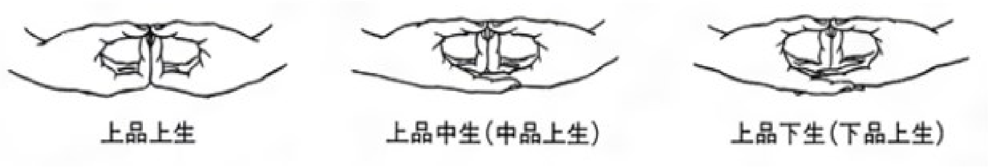
Gebon Josho

Gebon Chusho

Lower Grade Handprints (Welcoing Handprints)

Fig. 18 The statues of *Kuhon Buddha* in Joshin Temple

定印



Upper Grade: *Stability* | **Jobon josho (Chubon Josho)** | **Jobon chusho** | **Jobon gesho (Gebon josho)**

説法印

Middle Grade: *Teaching* | **Chubon josho (Gebon chusho)** | **Chubon chusho** | **Chubon gesho (Gebon chusho)**

来迎印

Lower Grade: *Welcoming* | **Gebon josho (Jobon Gesho)** | **Gebon chusho (Chubon Gesho)** | **Gebon gesho**

Fig. 19 *Kuhon* handprints and their corresponding name label

In this case, Upper Birth, the index finger and thumb form a circle, no matter where the hand is positioned.

Middle Birth, the middle finger and thumb form a circle, no matter where the hand is positioned.

Lower Birth, the ring finger and thumb form a circle, no matter where the hand is positioned.

In short, the key point of Birth（生）is which fingers form a circle.

Of these, Jobon Josho handprints is known as the Meditation Handprints, Chubon Josho, Chubon Chusho and Chubon Gesho are also known as Teaching handprints, Gebon Josho is known as the Welcoming handprints.

The nine Amitabha handprints are the symbols of the Amitabha who saves all beings to the Pure Land of Amitabha.

2.1.5 Purpose and Method of this Survey

Purpose:

In order to investigate whether the historical artefact *Kuhon* handprints form in Joshin Temple reflects their religious significance, and to obtain a more accurate 3D form of the Buddha Sculpture, the information on the statue of Amitabha in Joshin Temple except the hands was reduced, and only the 3D simplified hand form was retained for an impression evaluation, and the impression evaluation results were analyzed and to some extent corrected for some perceptions of the religious significance of *Kuhon* handprints.

Method:

(1) Investigate the historical background and religious significance

(2) A visit to Joshin Temple and A practical photographic assignment

(3) Synthesis and restoration of 3D model of *Kuhon* handprints

(4) Curvature analysis for 3D model of *Kuhon* handprints

(5) Impression evaluation of a 3D model of *Kuhon* handprints (SD method and Quantification Type III)

(6) Extraction of the coordinates of the centre of gravity of the 3D model

(7) Comparison of impression evaluation results and religious significance

(8) Analysis of the results of the comparison to identify the most appropriate interpretation of the religious meaning for *Kuhon* handprints in Joshin Temple.

2.2 Morphological Analysis of the Kuhon handprints

2.2.1 Model scanning

Modelling scanning was conducted in April 2017. However, only conventional photography (rather than 3D scanning or measurement at short range) was possible because of the dark environment, lack of power supply, and the cultural heritage status of the subject. Photos were taken with a single lens reflex camera (Nikon D200) with no light source in the temple. 360 degree images of each statue were obtained from an average of 100 high resolution photos taken from multiple angles (Fig. 21, 22).

Jobon josho handprint is an example, which is photographed from several angles below by digital camera (Fig. 20).

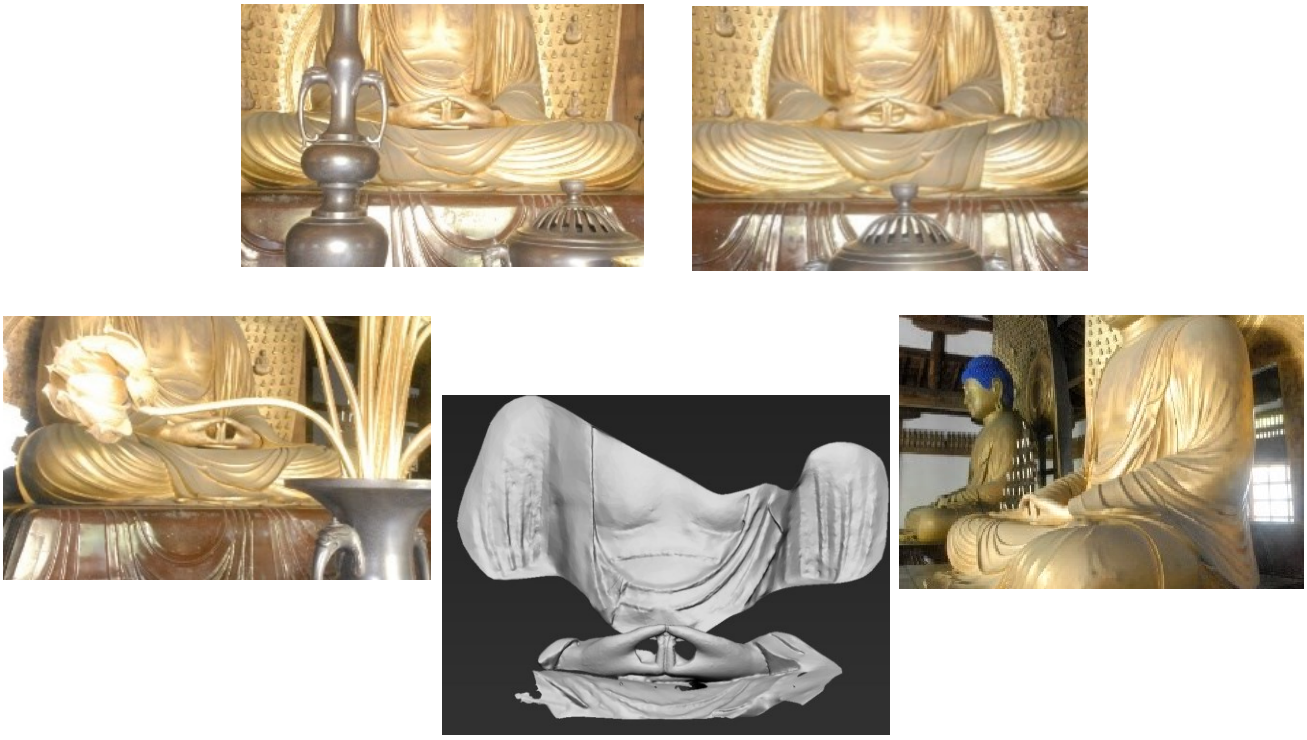


Fig 20 Photographs taken and models composited

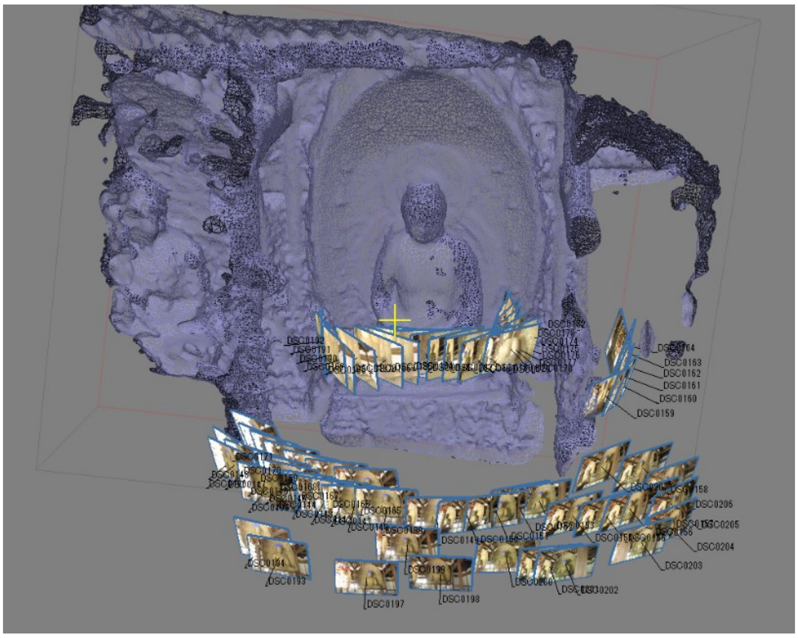


Fig. 21 Composing point cloud models using the software agisoft metashape[28]

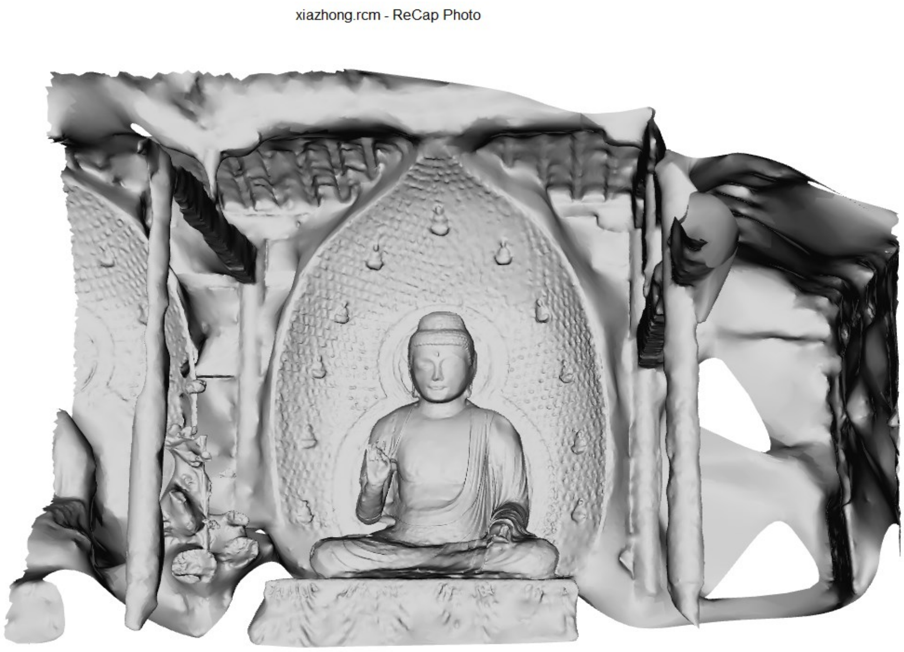


Fig. 22 Composing 3D model using the software Autodesk recap photo[29]

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[28] Agisoft metashape, from Agisoft Company, Photogrammetric processing of digital images and 3D spatial data generation software.

[29] Autodesk recap photo, from Agisoft Compnay, Digitalisation of objects into digital data software.

2.2.2 Extraction of 3D handprints

The images were imported into Autodesk Recap software or Agisoft photoscan to construct the 3D models. The initial 3D data were sorted, and extra points and extra parts were removed. By referencing the photos and other relatively complete Buddha images, adjustments were made for defects, all colour was eliminated, the surfaces were polished, and the finger poses were extracted to create simplified 3D handprint models. Restoration process are below (Fig. 23, 24), The repaired 3D model of *Kuhon* handprints are shown in Fig. 25.

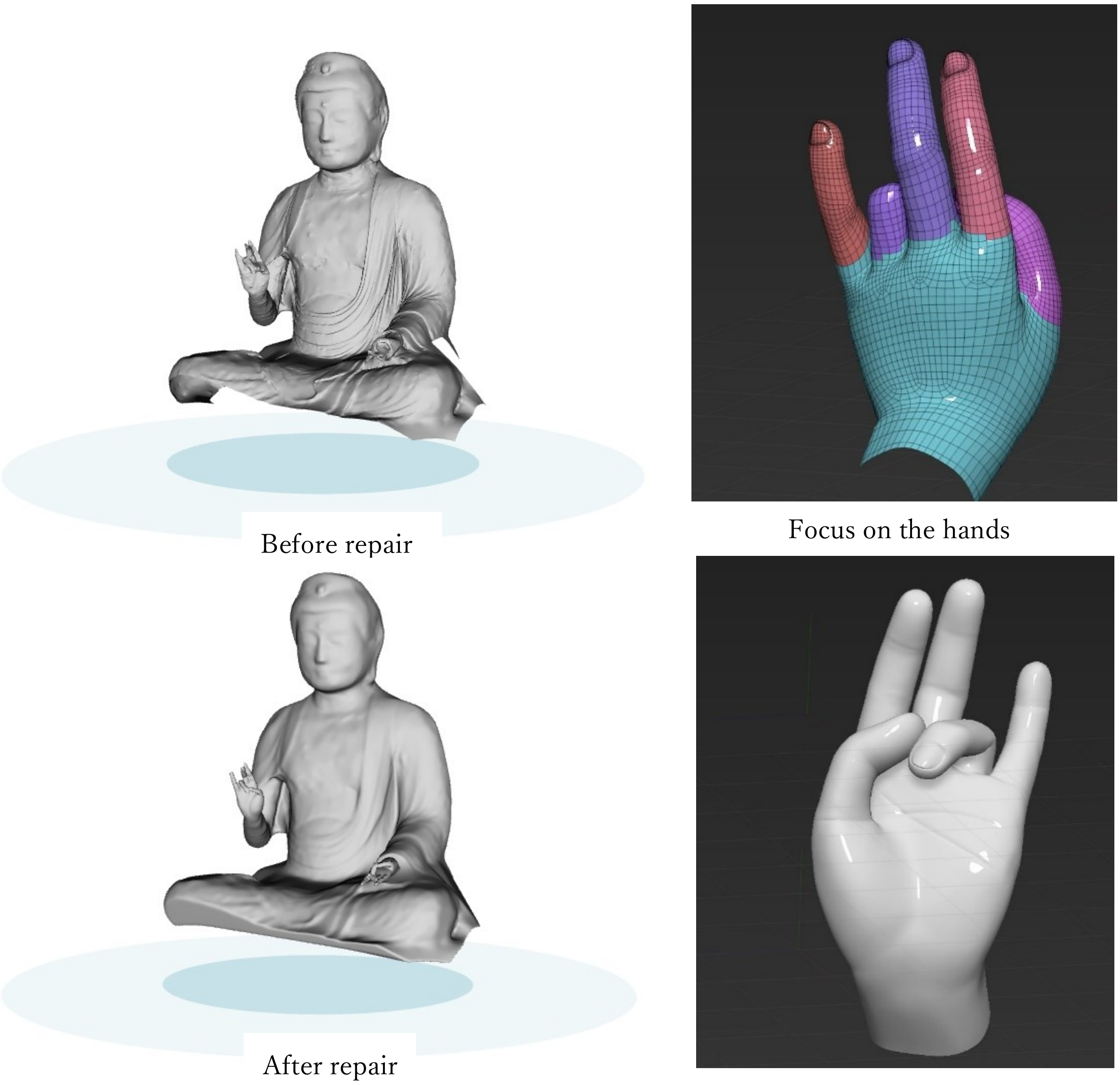
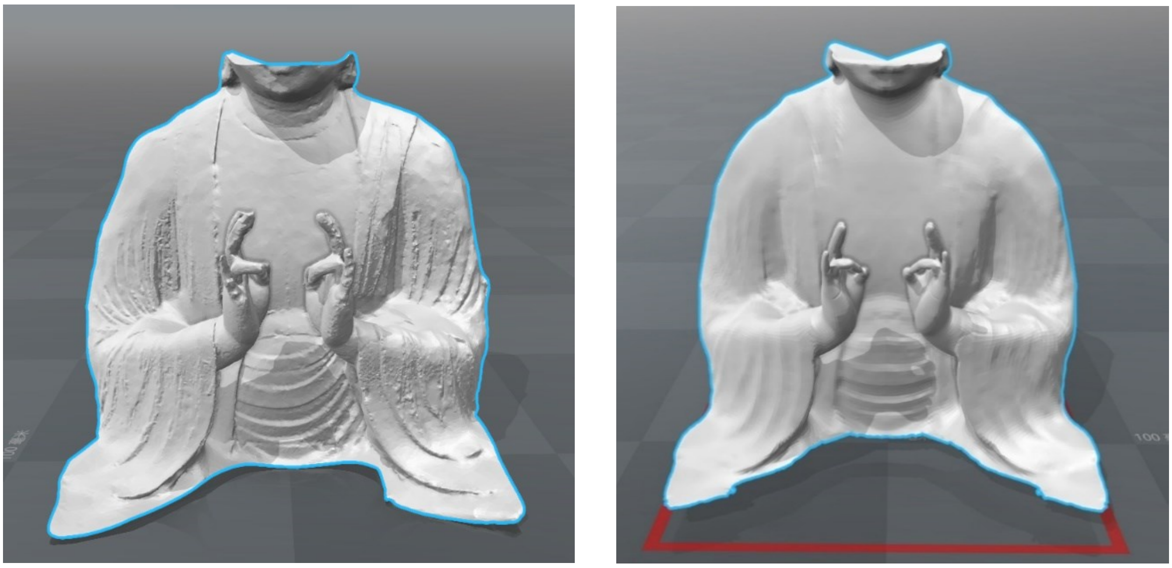


Fig. 23 Repair of the 3D model of the Buddha and focused on the hand



Before repair　　　　　　　　　After repair

Fig. 24 Repair of the 3D model of the Buddha

According to Jun Noguchi's paper [3D measurement of stone tools, disclosure of results and common use][30], The benefits of 3D modelling are

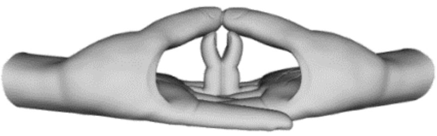
(1) The 3D model can be unified and standardised (removal of decorative elements, uniform lighting, highlighting of local features, etc.)

(2) The 3D model can be viewed and measured from multiple angles (e.g. measurement of sections)

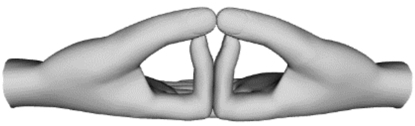
(3) It can be applied to physical analysis (e.g. measurement of the centre of gravity, distribution of curvature, etc.)

(4) 3D data can be easily stored and made public

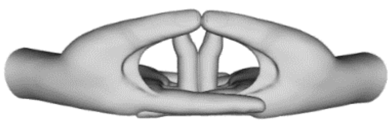
Therefore, this paper also attempts a 3D simplification of the morphology of *Kuhon* handprints of the Amitabha in Joshin Temple in order to draw out more engineering regulations and to easily evaluate impression.



Jobon gesho

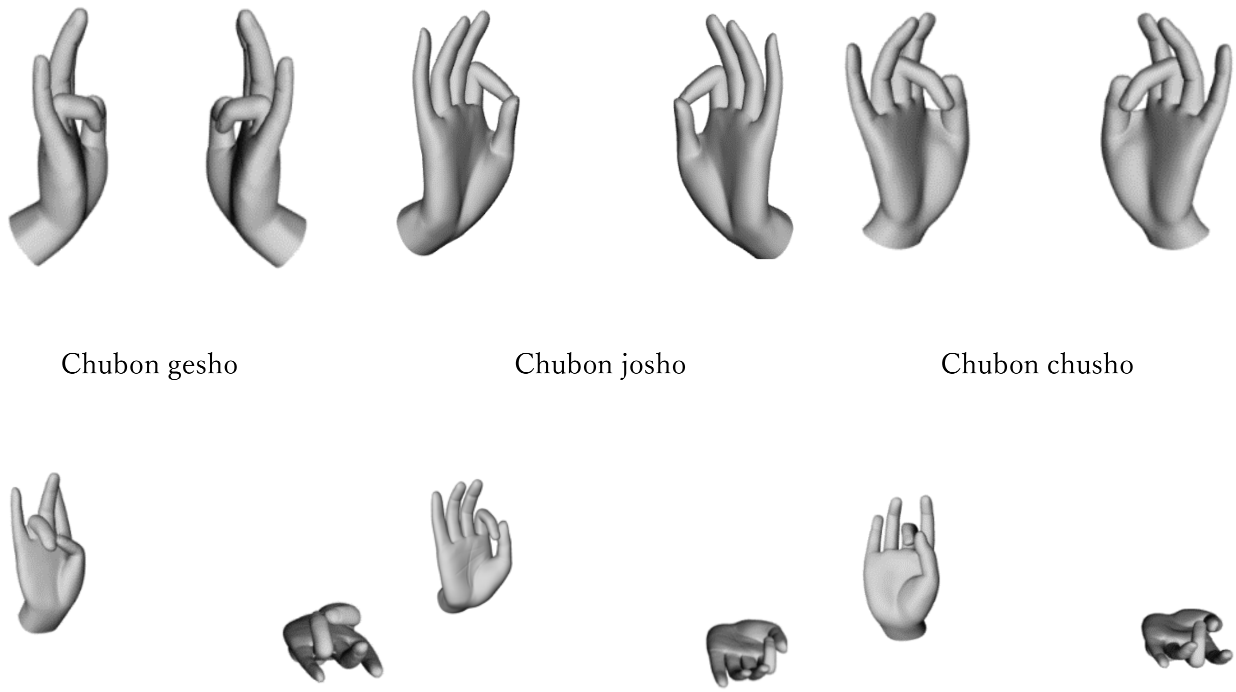


Jobon josho



Jobon chusho

[30] J Noguchi, 3D measurement of stone tools, disclosure of results and common use, 1st Data Science Salon for Archaeology and Cultural Heritage, 2019.



Chubon gesho Chubon josho Chubon chusho

Gebon gesho Gebon josho Gebon chusho

Fig. 25 Repaired 3D model of *Kuhon* handprints

2.2.3 Morphological Analysis of the 3D handprint models

Kuhon handprints are important hand form of Buddhist carving. The morphological features are of a general nature and reflect, to some extent, the sculptural characteristics of Heian period Buddhist statues in Japan. According to the curvature distribution of the 3D handprint model, the morphological structure can be reclassified, and a number of morphological features of religious significance can be observed (Fig.26, 27).

Method: The surface mesh was unified by using the software meshlab for nine 3D *Kuhon* handprints. The unified data was imported into Geomagic Studio software, where the sensitivity was unified to 70 in millimeters (with a relatively clear distinction), The contour lines divided by curvature are easier to be observed. An example of this is shown in the following Fig.26: Fig.26's red represents areas of high curvature distribution and blue represents areas of low curvature distribution, and based on the curvature division, contour lines like the corresponding ones are automatically generated in Fig.27, through which the external shape and local features of the handprints can be easily observed.

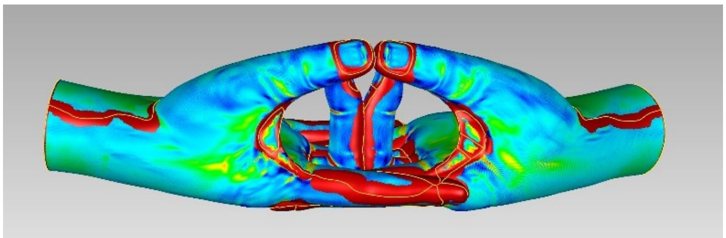


Fig. 26 The curvature distribution of the 3D model of Jobon Chusho

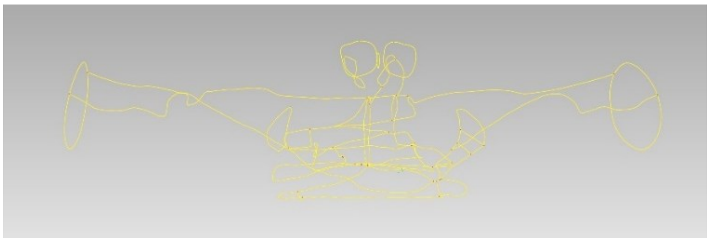


Fig. 27 The contour lines drawn from the curvature distribution of Jobon Chusho

Through the curvature distribution and the extraction of contour lines, it is easily observed that the nine *Kuhon* handprints form has the following morphological features. Of three upper grade handprints, the flesh（水かき） between protruding thumb and forefinger is the most obvious in Jobon Chusho 3D handprint, Jobon Gesho handprint is next in line. Jobon Josho handprint is the least obvious in the upper grade.

Of three middle grade handprints, the flesh between the fingers of all three middle grade handprints is not easily observed, and the palms of all three handprints are essentially the similar. The thickness of the Chubon Gesho fingers is greater than that of the Chubon Josho handprints and the Chubon chusho handprints. The two hands of the Chubon Gesho handprint open at a smaller angle than the other two handprints. The distance between the two hands of Chubon Gesho handprint is closer than the other two.

Of three lower grade handprints, the flesh between the fingers of the three handprints is not easily observed. The fingers of the Gebon gesho handprint are thinner and longer than the other two. The two hands of the Gebon Gesho handprint open at a smaller angle than the other two handprints.

2.2.4 Position of the centre of gravity of upper grade handprints using software of FreeCAD[31](for examing the perception of stability of the 3D form in relation to the position of the centre of gravity)

The centres of gravity of the three upper grade handprints are slightly below the metacarpus centre of the vertical plane, but their positions before and after in the horizontal plane for frontal view are very different.

The centre of gravity of the Jobon Josho is at the posterior part of the index finger.

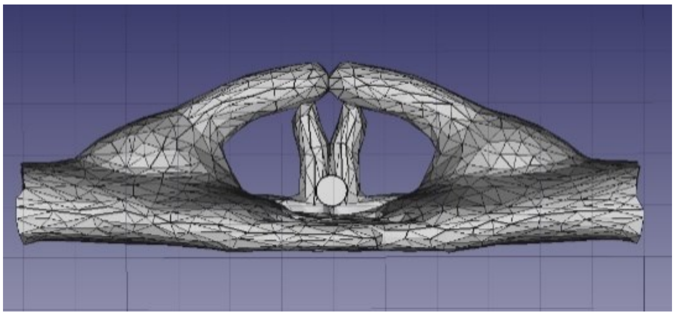


Fig.28 The position of the centre of gravity of the 3D model of Jonbon Josho handprint

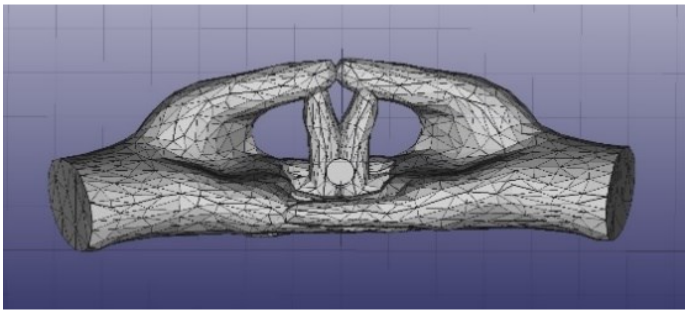


Fig. 29 The position of the centre of gravity of the 3D model of Jonbon Chusho handprint

[31] Freecad, A software of 3D parametric model, from Freecad Company.

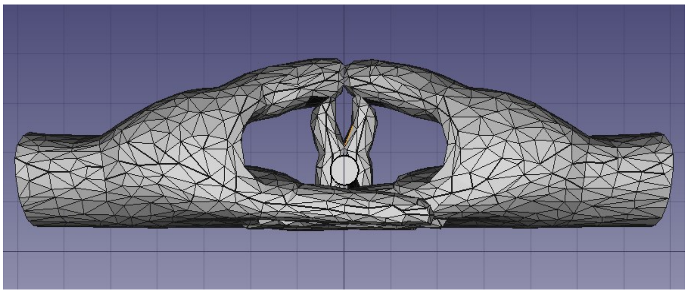


Fig. 30 The position of the centre of gravity of the 3D model of Jonbon Gesho handprint

The centre of gravity of the Jobon Chusho is close to but still behind middle finger.

The centre of gravity of the Jobon Gesho is at the front of the ring finger.

It has been shown in Fig. 28,29,30, which the position of the centre of gravity of similar forms affects their stability, and in the next chapter [Impression Evaluation of the Kuhon handprints], the visual stability of the upper three handprints will be investigated and compared with their centre of gravity position of 3D models.

2.3 Impression Evaluation of the Kuhon handprints

2.3.1 Impression Evaluation of *Kuhon* handprints with SD Method

In order to study the relationship between visual perceptions of the Buddha's handprint forms and their religious meaning, a questionnaire survey was conducted among 33 observers and their ages are from 18 to 65 years old. They were 17 males and 16 females including Japanese, Chinese, Korean and European who tended to have less strong faith in the Buddhist religion. Participants in the survey were told that the survey sought their impression of the Buddha statues and each was shown photos of all nine of the *Kuhon Buddha* (Fig.32). They were then asked to view one of the nine simplified 3D handprint models and to indicate on each of 14 semantic differential (SD) scales the point that best described what they felt. Each participant completed a set of nine questionnaires as there were nine samples of *Kuhon Buddha* handprint.

The adjective pairs (antonyms) used to define the 14 SD scales on the questionnaires were based on:

(1) Frequently occurring adjectives from a previous study (Arita, 2013, 2014) regarding the appreciation of Buddha statues.[32]

(2) Ergonomics guide: How to science sensibility (HPL, 2014).[33]

(3) An interview with Joshin Temple's Shimizu abbot[34].

(4) The opinions of expert of the design researchers.

The following steps were taken in order to fit the research purpose and ensure the rigor of the experiment:

(1) All of Buddha's body parts except the handprint were removed.

(2) Colour and texture were removed from the model.

(3) Any damage to the model caused by the photography technology and 3D synthesis was repaired according to the symmetry of the right and left hands or by comparing photos.

(4) All the sample sizes were reduced and standardised in proportion

(5) According to Buddhist rules and historical placement of *Kuhon Buddha* in Joshin Temple, all the sample angles shown in the questionnaires were adjusted to the proper angle so that the frontal orientation of handprint model is level with the observer's line of vision[35](Fig. 31).

(6) The direction of the light source is parallel light in the positive direction.

On this basis, a preliminary questionnaire with 25 pairs of adjectives (50 subjects) was constructed. By the KJ method (or 'thematic analysis'), among

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[32] YK,Arita., Art Appreciation Lessons though Verbalization of Styles in Japanese Arts: Using Catch Phrases in Appreciation of Buddhist Sculptures, *Art Education: Journal of Art Education* of JSSD, 34, 33-37,2013 (in Japanese); SD-Method Research on Reactions of Observers of All Ages to Buddhist Sculpture Styles 35,45-59,2014 (in Japanese)

[33] Ergonomics guide: *How to science sensibility*, Human Performance Laboratory (HPL), 153-155, 2014(in Japanese)

[34] Eisuke Shimizu, 17th abbot of Joshin Temple(清水英碩).

[35] The height of the Buddha's statue：The Buddha's statue is generally required to be viewed at an angle of 10 degrees above the line of vision, from Baidu.

these adjectives (subjects), those with the similar meaning were unified, and those not related to this evaluation were removed based on the opinions of observers and design experts. Producing the questionnaire with 14 pairs of adjectives scales (28 subjects) is shown in below Fig. 32.

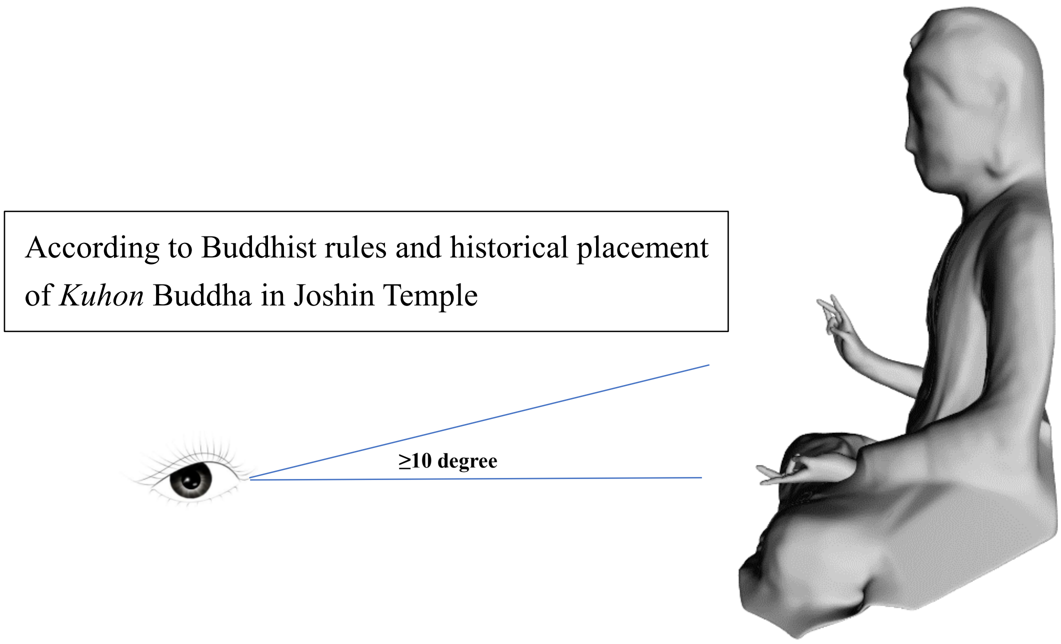

Fig. 31 The angle of the Buddha handprint as viewed by the observer at the Joshin Temple

2.3.2 Impression evaluation with Quantification Type III

As there were nine 3D *Kuhon Buddha* handprints, the number of samples is less than the number of adjectives (14*2). Given that the study's purpose was to determine the relationship between the observers' perceptions of the form of the handprints and the handprints religious meaning, Quantification Type III[36]was used to conduct an impression evaluation. A dummy variable with value 1 (dominant) or 0 (recessive) was assigned to the adjective's frequency distribution according the SD results, and then imported into CAnalysis[37] for

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[36] YK,Amino., Multivariate analysis in practice, 50-55, 2018

[37] Fukui M, A software for social system analysis education: College Analysis, Annual Meeting (19), Japan Society of. Educational Information, 148-151, 2003

the Quantification Type III analysis.

The following is an example of the ‘Rough-Mild’ aspect frequency distribution for the Chubon chusho simplified model (Fig. 33). The results of the SD method are arranged in ascending order; level 4 is the median value.

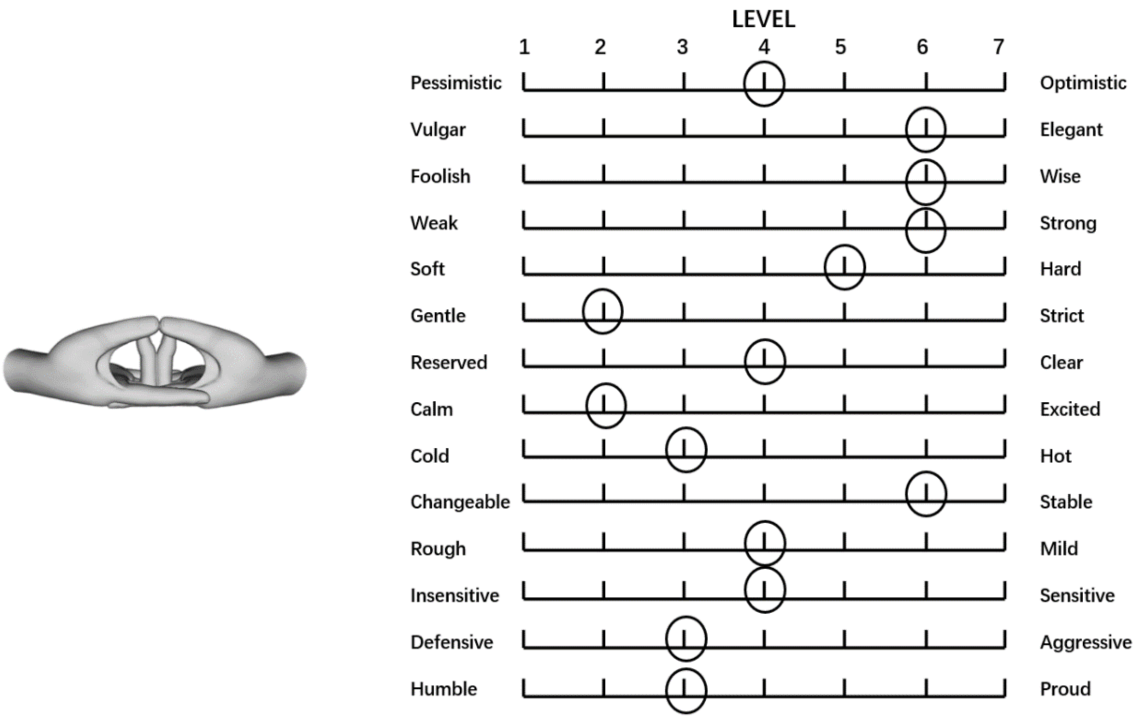

Fig. 32 Questionnaire for impression evaluation (SD method)

According to the results histogram, the ratings of observers 1 to 5 were below 4, meaning that five observers thought that this particular handprint suggested rough feeling. Observer 5 to 12’s rating was 4, indicating that seven observers thought that the handprint was neither rough nor mild. The ratings of observers 13 to 33 were all above 4, indicating that these twenty one observers thought that the handprint had a relatively mild feeling. As a result, the high frequency distribution adjective for the Chubon chusho simplified handprint model regarding the ‘rough-mild’ contrast was determined to be ‘mild’.

The high frequency and low frequency distributions of all the adjectives for all of the 3D handprints were produced. For the Quantification Type III analysis, the adjective selected by observers with higher frequency is assigned a dummy variable value of 1 and the adjective selected by observers with lower frequency is assigned a dummy variable value of 0.

Because the adjectives on the left and right sides of the SD scale have opposite meanings, there were two special cases that needed to be considered:

(1) The frequency of the adjectives on the left and right side are the same or close, and there is no high frequency region for the adjective pair, or

(2) The high frequency of the pair of adjectives appears at the value 4.

In the above two cases, either of the two adjectives would be assigned a dummy variable value of 0.

The dummy variable values of 1 and 0 (Table 1) for all the simplified handprint models were imported into the CAnalysis statistical software for statistical analysis using Quantification Type III. Before importing the data, adjectives for which the dummy variable values were 0 for all handprints were removed, since these adjectives provided no degree of discrimination in the handprint evaluation. These adjectives were 'rough', 'foolish', 'vulgar', 'hard', 'weak' and 'insensitive'.

According to the results of our Quantification Type III analysis, the simplified handprint models can be represented on eight axes (eight axes of adjectives).

However, since the cumulative contribution of the first three axes in the evaluation exceeded 0.757 and the relationship for each axis exceeded 0.3[38], we treated the first three axes as the main factors in the experiment and focused on these three axes in our analysis (Table 2).

Table 1 Quantification Type III input data (a dummy variable 0 or 1 for each adjective of each handprint)

	Pessimism	Optimistic	Elegant	Wise	Strong	Soft	Strict	Gentle	Reserved	Clear	Calm	Excited	Cold	Hot	Changeable	Stable	Mild	Senstive	Defensive	Aggressive	Humble	Proud
JobonJosho	0	0	1	1	0	0	0	1	0	1	1	0	0	0	0	1	1	0	1	0	0	0
JobonChusho	1	0	1	1	1	0	1	0	0	0	1	0	1	0	0	1	1	0	1	0	0	0
JobonGesho	1	0	0	1	1	0	1	0	1	0	1	0	1	0	0	0	1	1	0	1	0	0
ChubonJosho	0	1	0	1	0	1	0	1	0	0	0	1	0	1	1	0	1	1	0	0	1	0
ChubonChusho	0	1	1	1	0	1	0	1	0	1	0	1	0	1	1	0	1	1	0	0	0	0
ChubonGesho	0	0	1	1	1	0	1	0	0	1	0	0	0	1	0	1	1	1	0	1	0	1
GebonJosho	0	1	1	1	0	1	0	1	1	0	1	0	0	0	0	1	1	1	1	0	1	0
GebonChusho	0	1	1	1	1	1	0	1	1	0	0	0	0	0	0	0	1	1	1	0	0	1
GebonGesho	1	0	1	1	1	0	1	0	0	1	0	0	1	0	1	0	0	1	0	1	0	1

38 Statistical Analysis Laboratory Ice Tat Co., Ltd.: https://istat.co.jp/ta_commentary/method3_03 (Accessed 2 November 2019)

Table 2 Eigenvalues from Quantification Type III

	Axis No.1	Axis No.2	Axis No.3
Eigenvalue	0.397	0.256	0.147
Relationship	0.630	0.506	0.384
Contribution	0.375	0.242	0.139
Cumulative Contribution	0.375	0.617	0.757

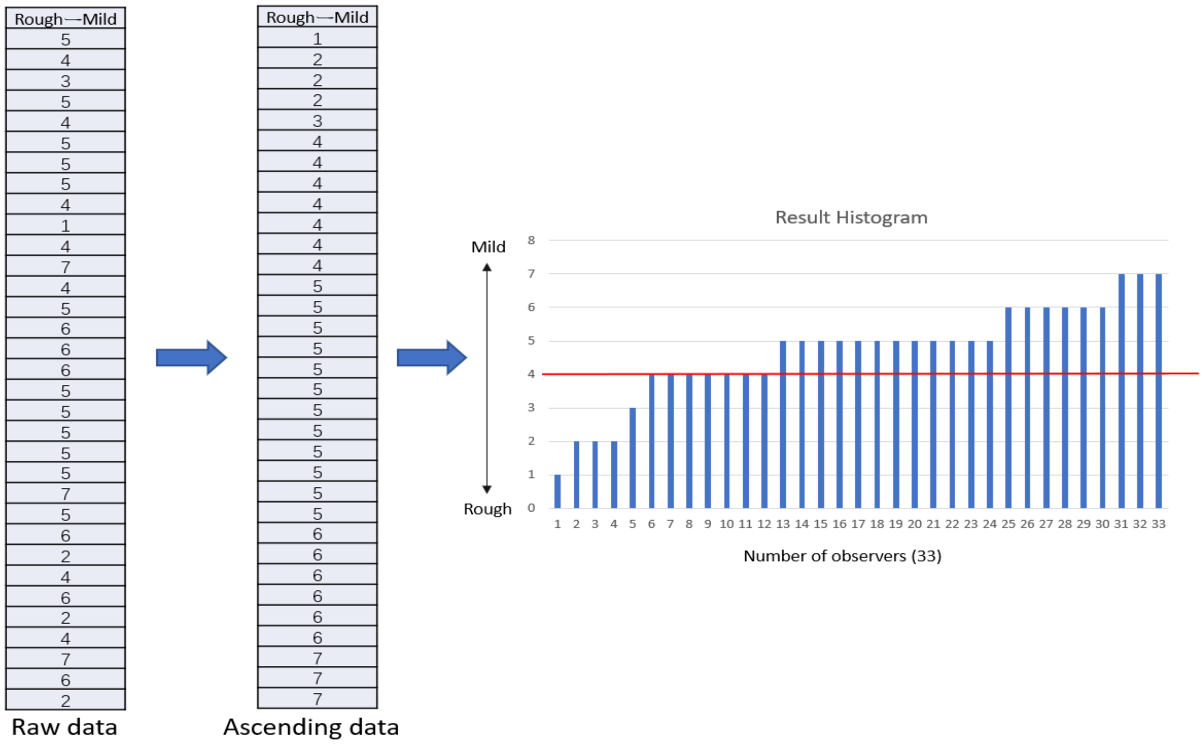

Fig. 33 Adjectives of rough and mild frequency distribution of Chubon Chusho simplified model

Definition of three axes according to the distribution of each adjective

(1) Axis *No. 1* and *No. 2* (Fig.34)

Fig. 34 shows the distribution of adjectives along Axis No. 1 (the horizontal axis) and Axis No. 2 (the vertical axis). As shown, the adjective meanings on the left side of the horizontal axis—that is, Axis No. 1—tend toward ‘excited’, ‘humble’, and ‘optimistic’, while the adjective meanings on the right tend toward ‘cold’, ‘pessimism’, ‘strict’ and ‘aggressive’. Thus, the adjectives nearer the left end of Axis No.1 convey a strong positive feeling, whereas the adjectives nearer the right end convey a negative feeling. Consequently, I used ‘positive’ to describe the overall characteristic of Axis No.1.

The adjective meanings near the upper end of the vertical axis (Axis No. 2) tend toward ‘changeable’, ‘hot’, and ‘excited’, while the adjective meanings nearer the bottom tend toward ‘clam’, ‘defensive’ and ‘stable’. Thus the adjectives in the upper range of Axis No. 2 convey a changeable feeling, whereas the adjectives in the lower range convey a stable feeling. Consequently, I used the word ‘stability’ to describe the overall characteristic of Axis No. 2.

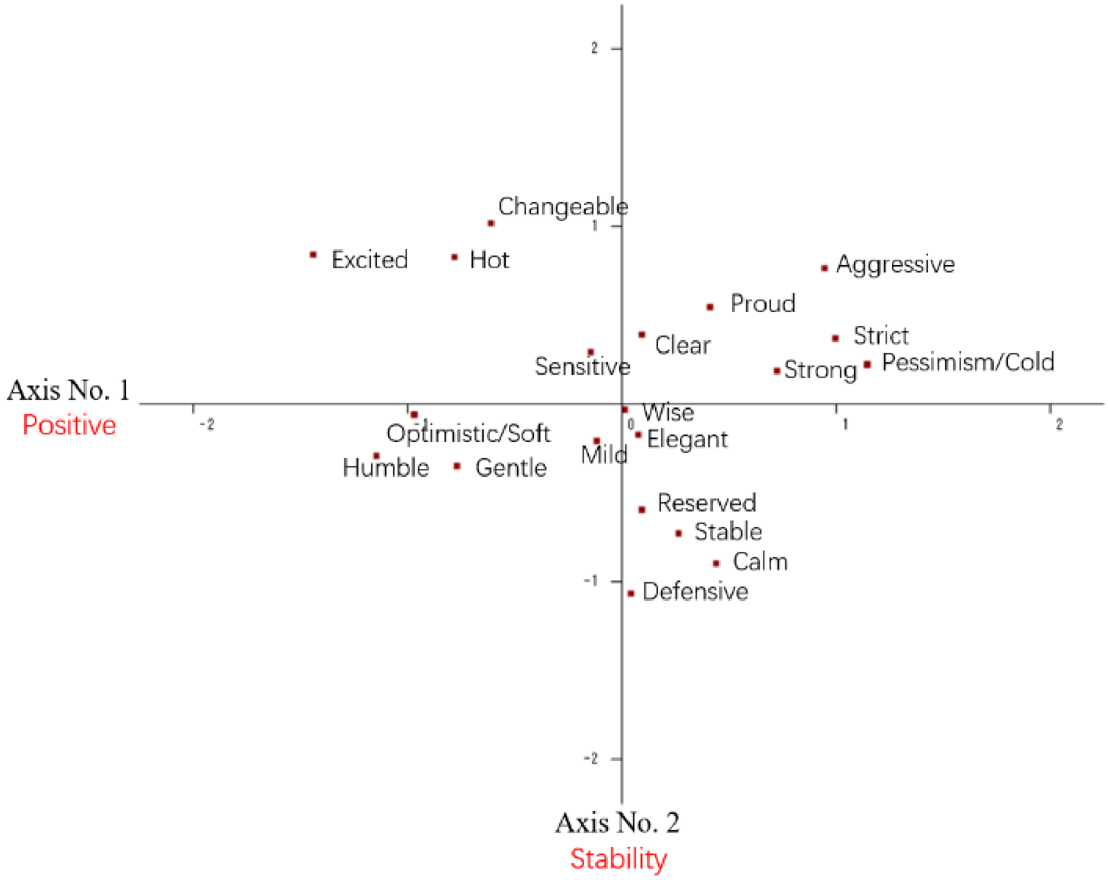

Fig. 34 Distribution (point) of adjectives on Axis No. 1 and Axis No. 2

(2) Axis *No. 3* (Fig. 35)

According to the distribution of adjectives along Axis No. 3 (vertical axis) in Fig. 35, the adjective meanings nearer the lower end of the axis tend toward ‘clear’, whereas the adjective meanings nearer the upper end tend toward ‘reserved’,‘humble’. Thus, the lower adjectives convey a clear feeling, whereas the adjectives on the upper side convey a vague feeling. Consequently, I used the word 'clarity' to describe the overall generic feature of Axis No. 3.

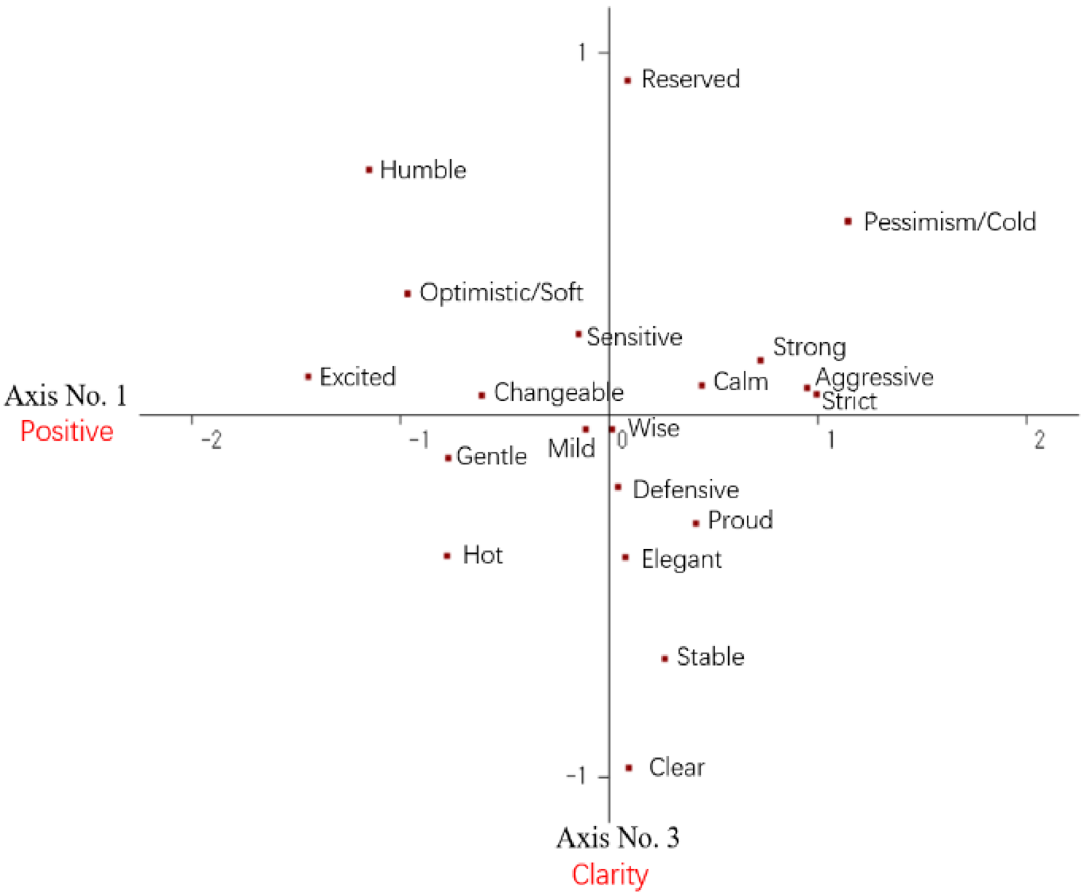

Fig. 35 Distribution (point) of adjectives on Axis No. 1 and Axis No. 3

(3) Additional explanation of the defined axes

On all the observation axes, the word 'wise' and 'mild' tends toward the origin and can be thus be considered the centre of all the defined axes. This indicates that 'wise' and 'mild' represents the common feeling of most observers regarding the handprints and that 'wise' and 'mild' can be used as the basis point of the evaluations on multiple axes.

The characteristics of each handprint on each axis (Fig. 36, 37)

(1) The position of the handprint models on Axis *No. 1 (Positive)*

With respect to the Positive axis, the two Upper Grade handprints of Jobon gesho and Jobon chusho tended to occupy rather high positions, suggesting that observers felt that these two handprints conveyed a negative, strict and cold feeling; The Upper Grade of Jobon josho was located the middle of Positive axis, which neither give observers a positive nor negative feeling

The two Middle Grade handprints of Chubon josho and Chubon gesho are at rather low point in the Positive axis, but the Chubon gesho handprint at a slightly higher point in the Positive axis. This shows that the observers of the Chubon josho and Chubon chusho handprint models feel that they convey a sense of excitement and positiveness, while the Chubon gesho handprint model conveys some negative feelings.

Two of the Lower Grade handprints—the Gebon josho and Gebon chusho handprints—register a little lower on the Positive axis. However, the Gebon gesho handprint appears as the relatively high point on the axis. This suggests that when the observers viewed the Gebon gesho handprint models, they sensed pessimistic and strictness, but when they viewed the Gebon chuho and Gebon josho handprint models, they didn't have such feeling.

(2) The position of the handprint models on Axis *No. 2* (Stability)

With respect to the Stability-axis, of the nine handprints, in the Upper Grade handprints Jobon josho handprint and Jobon chusho handprint occupied the lower positions, but the Jobon gesho handprint relatively close to the middle of the Stability-axis. This suggests that the observers felt that the two Upper Grade handprints of Jobon josho and Jobon chusho conveyed a feeling of stability and calmness, but the Upper Grade handprint of Jobon gesho not.

The three Middle Grade handprints occupied relatively high positions on the Stability-axis among the nine handprints, with the Chubon josho handprint, Chubon chusho handprint and Chubon gesho handprint. This suggests that the observers saw these three handprints as conveying a sense of being 'excited' and 'changeable'.

Finally, on the Stability-axis, both the Gebon josho and Gebon chusho of the Lower Grade handprints occupied the lower positions, which indicates that when the observers saw these three handprints, they had a little sense of 'stability and calmness' However, the Gebon gesho handprint occupied a rather high position on the Stability-axis, an unexpected result (an excited and changeable feeling) insofar as it was not in or near the area occupied by models of similar form.

(3) The position of the handprint models on Axis *No. 3* (Clarity)

With respect to the Clarity-axis, the nine handprints, ranked from highest to lowest point, were Jobon gesho, Chubon josho, Gebon josho, Gebon chusho, Jobon chusho Gebon gesho, Chubon chusho, Chubon gesho and Jobon josho.

The models with higher positions on this axis evoke a feeling of reserved; the lower position models convey a clear feeling.

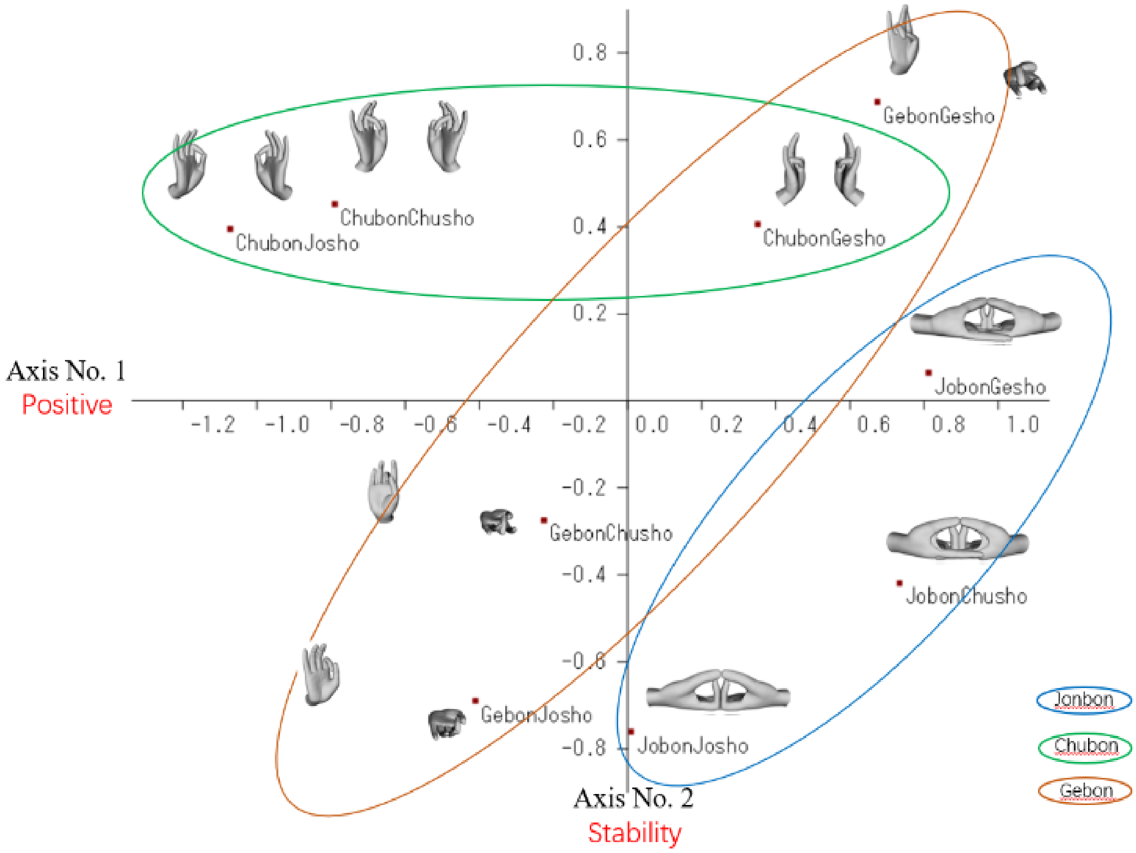

Fig. 36 Location of the handprint models on Axis No. 1 and Axis No. 2

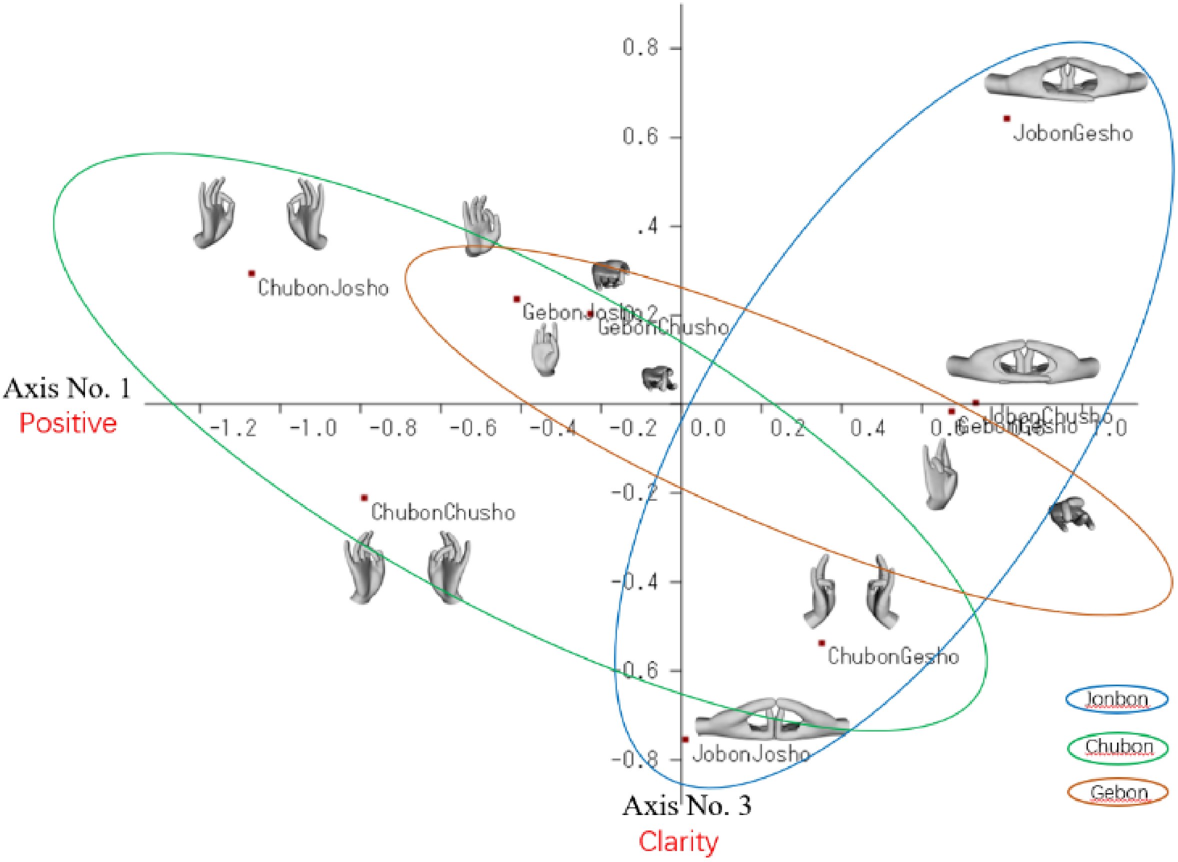

Fig. 37 Location of the handprint models on Axis No. 1 and Axis No. 3

2.3.3 Relationship between the results of the impression evaluation and the religious significance

2.3.3.1 Religious Meaning of *Kuhon* Handprints

The Buddha's static handprints are important not only in terms of their indication but also for their mysterious religious significance in the Buddhist system. According to the Buddhist Dictionary of Ding Fubao[39]:

(1) the image's handprint, a part of the Buddha's body, can be used to judge the statue's identity and the religious meaning being expressed, even if it is extracted separately from the image of the Buddha's body;

(2) Handprints bearing the same name have a similar general meaning

In fact, there are many controversies of *Kuhon* handprint religious meaning

[39] FB, Ding , *Buddhist Dictionary*, Explanation of Buddha three secrets, 2011

among different Buddhism schools. Sometimes two different Buddhism schools have the completely opposite religious meaning of *Kuhon* handprints, Therefore, according to Akiyama Buddha Handprint Encyclopedia[16], the following explanation for *Kuhon* handprints religious meaning serves as the most widely accepted and also used by Joshin temple.

(1) The Upper Grade handprints (Jobon josho, Jobon chusho, and Jobon gesho) are collectively known as Dhyana Meditation Handprints or Contemplation Handprints. Amitabha assumes such a hand print during meditation, bring inner peace, calmness and stability to all. It is said that Sakyamuni entered into a meditative state under the Bodhi tree and was enlightened with a similar handprint (the handprints of Shakyamuni Buddha are only crossed hands, no fingers bent).

(2) The Middle Grade handprints (Chubon josho, Chubon chusho and Chubon gesho) are known as Teaching Handprints or Turning the Basket of Law Handprints. The Buddha teaches beings with this handprint. The right hand represents Amitabha and the left hand represents beings. The Buddha’s teaching is flexible and changeable. Using different methods depends on the roots of all beings. All beings are enthusiastic and excited when they listen to the Buddha's teaching.

(3) The Lower Grade handprints are known as Welcoming Handprints （Gebon josho, Gebon chusho, Gebon gesho）, indicating that the Buddha welcomes, guides, helps and blesses all the beings whatever root they having. Sometimes Lower grade handprints also represent also mean that evil people (with negative tendencies in Buddhism) having committed serious crimes can also get the help and guidance of Amitabha.

2.3.3.2 Relations between the centres of gravity of the Meditation（Jobon） handprints and [stability].

It is not easy to observe where the bent fingers are located on three Jobon handprints, especially on the Jobon chusho handprint and Jobon gesho handprint, which are morphologically similar. Yet, the 3D coordinates of the three handprints’ centres of gravity can be easily generated through a 3D positional analysis using the software of freecad CAD. As revealed by the generated coordinates, the three handprints' centres of gravity are similar on the vertical plane but significantly different on the horizontal plane for frontal view. As seen from the Fig.28, 29, 30, the centre of gravity of the Jobon josho handprint's model is frontmost, followed by that of the Jobon chusho handprint's model, while that of the Jobon gesho handprint's model is rearmost. Judging from results about centres of gravity and the impression evaluation results, it can be known that at the same viewing distance, the feeling of [stability] increases with the proximity of a handprint's centre of gravity to the front most position. In other words, the feeling of [changeable] or [instability] increases with the proximity of a handprint's centre of gravity to the rearmost position. The feeling of stability seems to be positively correlated to the position of the centre of gravity. The research "Stability from Standpoint of Dynamics and Kinematics"[40] holds that the position of an object's centre of gravity has implications for its physical stability, but it provides no clear evidence for the implications of the centre of gravity for the [stability] on the Kansei engineering level. Furthermore, the correlation of a handprint's centre of gravity to its visual stability may be a result of local morphological differences or perspectivity. Therefore, the study of this paper on Joshin Temple's Nine handprints is just a case study, which cannot be concluded as a general theory. Despite that, the visual [stability], [balanced], etc. resulting from barycentre positions are worth attention.

2.3.3.3 Relationship between the results of the impression evaluation and the religious significance of handprints (Table 3 on the next page)

[40] Y,Tanino., Stability from Standpoint of Dynamics and Kinematics, [関西理学], 59-62, 2003.

Table 3 Relationship between the results of the impression evaluation and the religious significance of hand

	Religious significance	**Results of impression evaluation**	**Similarities, differences, conclusions**
Upper Grade or Meditation Handprint (Jobon josho, Jobon chusho, Jobon gesho)	It indicates the Buddha's meditation to bring inner peace, calmness and stability to all.	The observers felt that the simplified 3D models of the Jobon josho handprint and Jobon chusho handprint made them feel more stable and calm in comparing with the other handprints, but not Jobon gesho handprint. Jobon gesho handprint additionally gave the observers a negative and aggressive feeling.	The Jobon josho handprint and Jobon chusho handprint conveyed to the observers a meaning (a sense of stability and calmness) similar to that depicted in the Buddhist classics. The form indicates the religious meaning. While, Jobon gesho handprint additionally have a negative, aggressive feeling, which is not found in religious interpretations.
Middle Grade or Teaching Handprint (Chubon josho, Chubon chusho, Chubon gesho)	It indicates the Buddha's teaching. The Buddha's teaching is flexible and changeable. Using different methods depends on the roots of all beings. All beings are enthusiastic and excited when they listen to the Buddha's teaching.	The observers felt that the simplified 3D models of the Middle Grade handprint seemed more changeable and excited in all the handprints.	All the Middle Geade handprints conveyed to the observers a meaning (a sense of excitenment and changeable) similar to that depicted in the Buddhist classics. The form indicates the religious meaning. But, Chubon gesho handprint has a slightly negative, aggressive feeling, which is not found in religious interpretations.
Lower Grade or Welcoming Handprint (Gebon josho, Gebon chusho, Gebon gesho)	It indicates the Buddha welcoming, guidance, help, power, and blessing for the beings, whatever root they having. Sometimes Lower grade handprints also represent also mean that evil people (with negative tendencies in Buddhism) having committed serious crimes can also get the help and guidance of the Buddha.	The observers felt that the simplified 3D model of Gebonjosho handprint and Gebon chusho handprint gave them a little stable and positive, But Gebon gesho handprint made them feel very negative.	Two Lower Grade handprints of Gebon josho and Gebon chusho conveyed to the observers some positive sense which is a little similar to religious meaning (Buddha's welcoming, guidance, help, and blessing) in the Buddhist classics. But Gebon gesho handprint have rather a negative feeling which is not found in Buddhist classics.

Gesho Handprint (Jobon gesho, Chubon gesho, Gebon gesho)	All the Gesho handprints in Jobon, Chubon and Gebon gave people a pessimistic, aggressive and strict feeling, but the Chusho and Gesho handprints not (except Jobon chusho handprint), which is not found in the Buddhist classics. In other words, the *Kuhon Buddha* owning bent ring finger, no matter which grade is, easily lead a negative impression. On the contrary, the bent index finger and bent middle finger can't lead a pessimistic impression, and sometimes even lead a positive and optimistic impression.
Handprint corresponding to bent finger	Among the nine *Kuhon Buddha* handprints, a bent ring finger implies instability, nonclarity, and negativity, while a bent index finger points to stability, clarity, and positivity. A similar record could be found in theThe Sutra on the Contemplation of Immeasurable Life Buddha, a classic of the Pure Land School[15]: A bent ring finger represents living creatures of the bottom class, who are unstable, slack, negative, or even vicious (This is why the impression evaluation results in the first paper proved a bent ring finger points to negativity); a bent index finger represents living creatures of the top class, who are industrious and virtuous (This is why the impression evaluation results in the first paper proved a bent index finger points to stability, clarity, and positivity). However, the different naming methods and religious interpretations, this religious theory has not been adopted by Joshin Temple. Here, morphological and religious implications of bent fingers are described as a supplement to the first paper.

2.3.4 Reasons for individual impression evaluation results not reflecting their religious significance

Therefore, more extensive discussions and more research are needed. One possibility is to apply the results of impression assessment to the modification of form in order to find a more suitable form. Regarding those cases that did not match expectations, the following reasons are offered:

(1) Although the carving styles of the nine handprints are similar, careful observation shows that the Gebon josho and Gebon chusho are quite different from the Gebon gesho in morphology (e.g. the circumference of the fingers and the proportion of the hands). According to an interview with Joshin Temple's abbot, these three handprints were completed by different sculptors in different years. This may be the cause of the inconsistency between the impression evaluation and religious theory.

(2) For the 3D model impression evaluation, the position of the model and the observation angle of the observer will affect the evaluation results. The models used in this paper are all viewed from the front and placed in the middle of vision field, but the actual situation is that the observers can see the handprints in Joshin Temple from the unexpected observation angle. This may

lead to different meaning of Jobon gesho handprint. And another possibility is to reveal its hidden religious meaning that is still unknown.

(3) Buddhism has many sects, which means that the interpretation of finger language can differ among the various sects. In this study, only the most widely accepted religious interpretations were used for the comparisons, which may have led to inconsistent impression evaluation results and observer perceptions.

(4) The choice of adjectives for the impression evaluation is also an influential factor. Although the collected adjectives have been supported with references and expert opinions, it is difficult to correctly summarize the characteristics of all handprints, since handprints can be abstract, mysterious, and difficult to explain in words. This also reinforces the notion that even if known adjectives are used, it is difficult to assign a name to Axis No. 3 in the Quantification Type III analysis that was conducted.

For the investigation of this chapter: the results of the impression evaluation do not reflect to its religious significance, preferring the interpretation of (3). As the recorded of [Kuhon Buddha origin][41] by Joshin Temple, the Amitabha sculptures represented by the nine handprints are currently divided into three groups: Meditation handprint group (Jobon josho, Jobon chusho, Jobon gesho), Teaching handprint group (Chubon josho, Chubon chusho, Chubon gesho), and Welcoming handprint group (Gebon josho, Gebon chusho, Gebon gesho).

However, during the process of the culture of *Kuhon Buddha* handprint being introduced from ancient China to Japan in the Tang Dynasty, there was much controversy about the naming of and religious interpretation of it. The impression evaluation results support a controversial theory rather than the religious interpretation and naming currently used by the Joshin Temple.

(1) According to one of the controversial religious interpretations, among Amitabha handprints, only the Jobon josho handprint may be taken as an Amitabha meditation handprint with meditation significance, whereas the

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[41] *Kuhon Buddha origin,* The brochure of Joshin Temple, 2018(九品仏縁起)

Jobon gesho handprint, and Jobon chusho handprints may not be mentioned. In other words among the three Jobon handprints, only the Jobon josho handprint conveys a very stable feeling. Yet, the Joshin Temple, taking all the three Jobon handprints as meditation handprints, does not uphold the theory.

(2) Three Jobon handprints are as argued by both the naming used by Joshin Temple and the religious interpretation, each of them may be taken as an Amitabha teaching handprint. This also echoes with the impression evaluation results.

(3) According to the controversial religious interpretation, of three Gebon handprints, only the Gebon josho Handprint may be taken as a welcoming handprint that represents how Amitabha welcomes all living creatures, while the other two may not. This has been proved by some other standing statue of Amitabha, like Ushiku Daibutsu located in Ibaraki[42], Japan, which uses only a Gebon gesho handprint to express “welcoming”. Although the view is also supported by the conclusion, it has not been adopted by the Joshin Temple. They take Gebon josho handprint, Gebon chusho handprint, and Gebon gesho handprints as welcoming handprints.

The two Figures (38,39) below visualize what (1), (2) and (3) argue

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[42] Ushiku Daibutsu, Guinness World Records for the largest statue of the Great Buddha, Bronze Standing Statue of Amitabha, in Ibaraki of Japan, 1995.

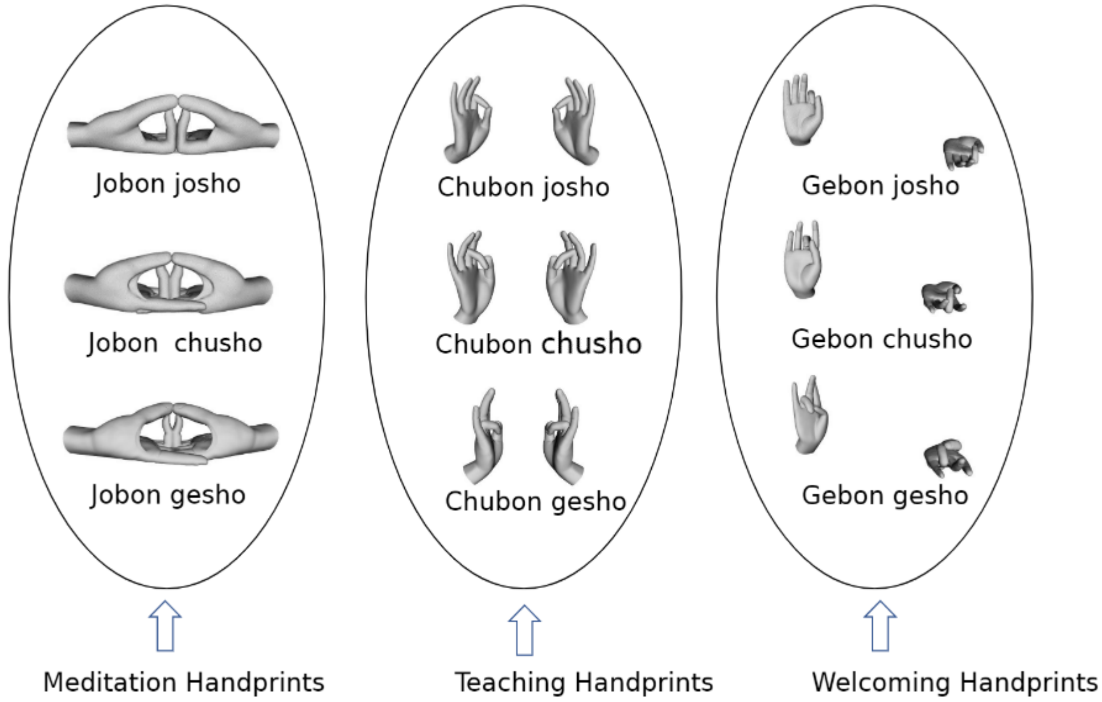


Fig. 38 The label names of *Kuhon* handprints used by the Joshin Temple

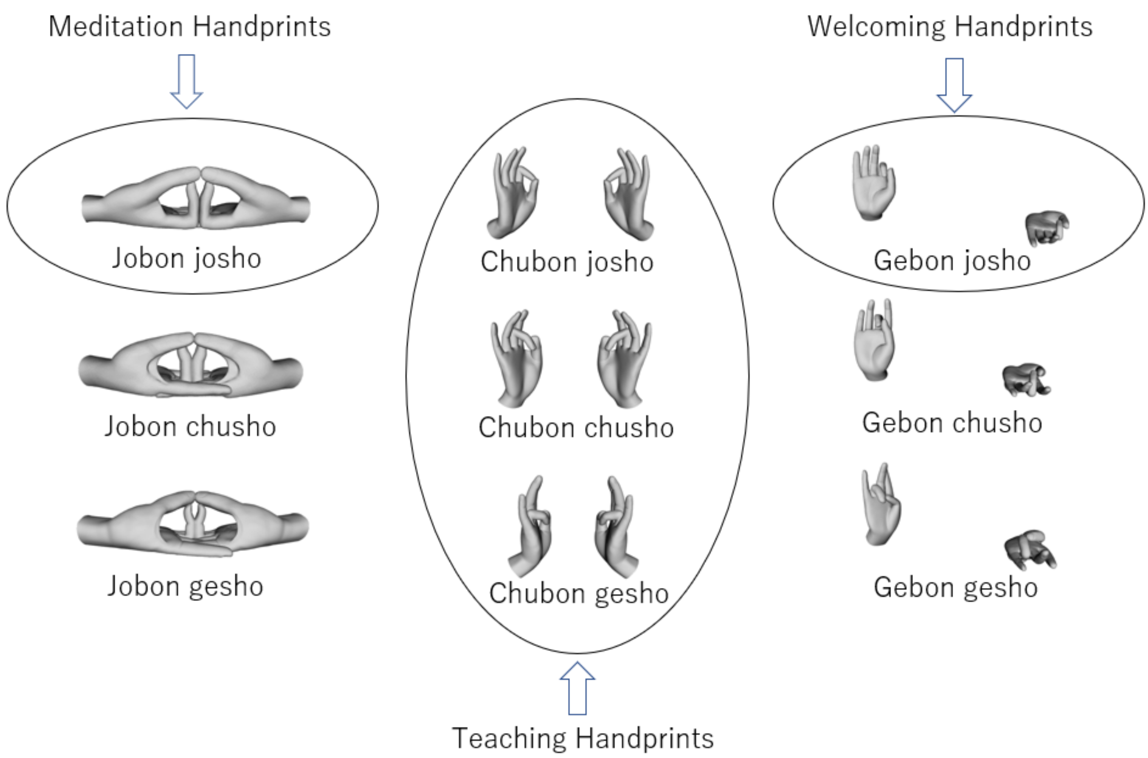


Fig. 39 Universal label names of *Kuhon* handprints

2.4 Short Summary

By comparing the religious significance of nine body (finger) languages and the impressions of neutral observers, this part explored the observer high dimensional perceptions of the nine grade impressions in media design. Many similarities were found between ancient religious theories and the first impressions of the observers. It was also shown that feelings and religious meaning which are difficult to express in language can be defined, classified, and analysed using statistics technology.

Although there were some cases in which the results did not conform to expected results (for example, the Jobon gesho handprint can't reflect its stable meaning), the vast majority were consistent with expectations.

This demonstrated the feasibility of using a simplified scientific 3D model for the evaluation of the morphology of historical artefacts related to human hand (highlighting as many local features as possible and reducing decorative elements), where this is not possible using 2D photographs. There are advantages of making the engineering features more visible and, as a visual medium, the form is more easily and uniformly observed, making it a good method of evaluating impression.

As the historical artefact, the statue design should be reasonable in appearance (e.g. in terms of visual angles and mechanical stability) and should take into account the audience's psychological feelings. Most Asian statues are related to religion; however, religious meaning is abstract and it is generally difficult to understand nonlinguistic elements. How best to reveal the meaning that the artist wishes convey to the observer is a primary concern. To ensure accuracy of expression, creating a design based on impression evaluation and applying morphological analysis to clarify the characteristics and meaning of the forms and correct incorrect the religious meaning can be useful.

Extraction of morphological elements composing winnowing basket and 3D reproduction of the simplified form

3.1 Background

3.1.1 What winnowing basket is

Winnowing basket is a tool which has long been used in agricultural work to blow away and sort unwanted small pieces from the harvest, mainly grain, and has also been diverted to picking, transporting, cleaning and excavating in various traditional work, as it can also be used as a container for the time being. The appropriate size and form is selected according to the nature of the work. Winnowing basket is also called" hand winnowing basket(手箕、てみ)", to distinguish it from mechanical tools. In Japanese it is called "mi(箕、み)", In Chinese it is called"（簸箕, boji）"[43].

Fig 40 Sorting of soya beans by hand winnowing basket(from Youtube)

3.1.2 Function of the winnowing basket (Fig.40, 41)

In Japan and Europe, winnowing basket are used in the process of threshing and conditioning the grain to separate the kernels from the husks by agitating the threshed rice. This is called *hiru*. The winnowing process adopts a method called "Winnowing", which is, holding the winnowing basket with both hands, shaking it up and down, to generate wind on the curved surface of the entire winnowing basket. When the winnowing basket is swung downwards, a downward air current is drawn in from the *Udeki*, both sides of the winnowing basket, causing a forward flow towards the *Misaki*, the open part of the

[43] Winnowing basket(箕), Containers for removing husks and dust during the sorting of rice and other grains. from Wikipedia.

winnowing basket. This air flow on the winnowing basket surface blows away light chaff and small debris to sort the seeds. The continuous curved surface of the winnowing basket surface is also used to sort out large, good formed kernels that roll easily from those that roll poorly, making use of the differences in the ease with which kernels roll according to their form.

In modern time, the winnowing basket is sometimes made into a machine-processed alternative. In this case, the winnowing basket is made of plastic or other materials.

Fig 41 Function of the winnowing basket

3.1.3 Materials for winnowing basket

The material used for winnowing basket is tree bark (rattan, including rattan), which is widely used around the world. Bamboo has been widely used in regions where it is produced, such as eastern Asia, particularly because of its high processability and usefulness. Since the spread of synthetic resin products, plastic and other synthetic resin made winnowing baskets have become common only in developed countries where they are more prevalent (e.g. in Japan, where plastic is more prevalent). Plastic winnowing basket are lightweight, strong and inexpensive, so there is a strong tendency for them to replace older materials in regions where they are more readily available. However, they are still the exception when looking around the world. Other materials are also made of metal.

In Japan, winnowing basket has traditionally been done with bamboo. Some are woven with Japanese cherry bark to increase the strength of the tip and make the surface smooth. On the other hand, the winnowing basket used by the Ainu in the past, were carved out of linden or *katsura* wood. As the production of winnowing basket requires skilled craftsmanship, in Japan, the *Mi-tsukuri*, who made the winnowing basket, and the *Mi-naoshi*, who repaired them, went around rural villages to take orders[44] (Fig.42).

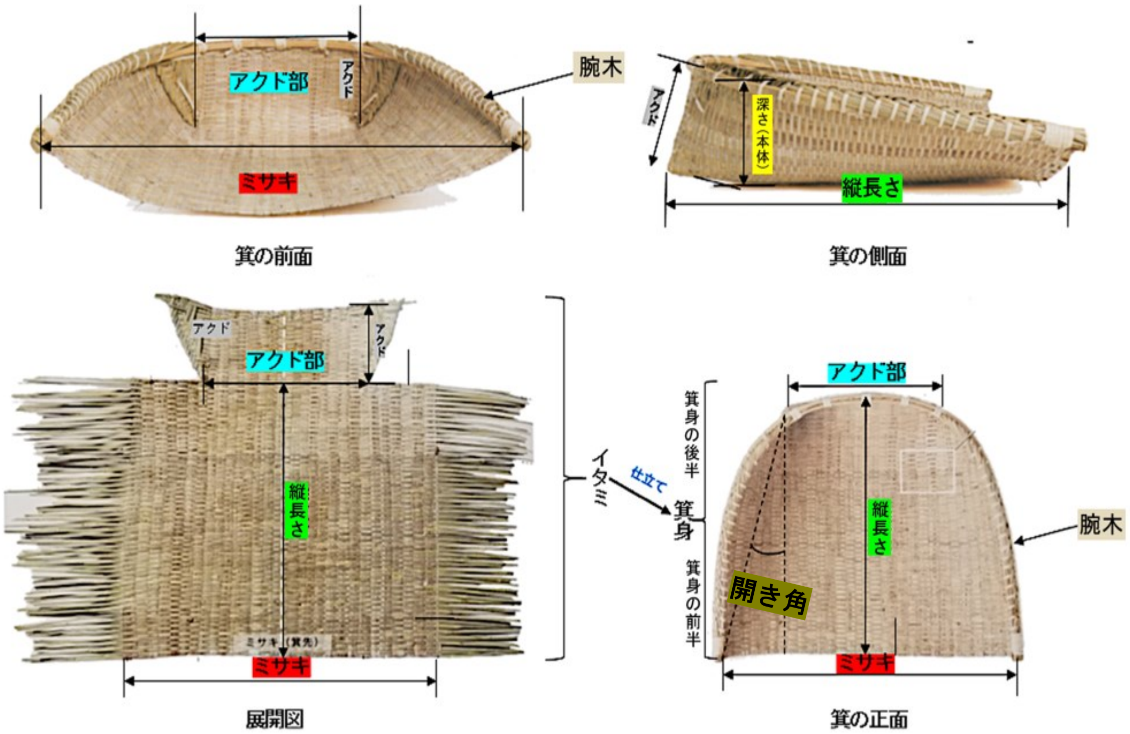
Fig 42 Kizumi winnowing basket Production Heritage Class in Chiba

3.1.4 Basic form of winnowing basket(Fig.43)

When making a single-sided winnowing basket（片口箕：Subject of this

[44] Mitsukuri(箕作り), Minaoshi（箕直）, https://ja.wikipedia.org/wiki/Mitsukuri, form Wikipedia

study）, an *Itami*（イタミ）is made using the *Amiage*（編み上げ）forming method, and then the winnowing basket is made into a three-dimensional winnow in the "*Shitate*（仕立て）process. Therefore, in order to clarify the name of each part of the winnowing basket, the two-dimensional *Itami*（イタミ）is easier to understand than the tailored three-dimensional form of the winnowing basket. The main parts are *Misaki*（ミサキ）, *Akudo*（アクド）, *Udeki*（腕木）, depth (body), first half of the winnowing basket body, second half of the winnowing basket body, angle of opening, etc[45].



イタミ：Itami

ミサキ：Misaki

アクド：Akudo, Udeki

腕木：Udeki

開き角：angle of opening

深さ（本体）: depth (body)

箕身の前半：first half of the winnowing basket body

箕身の後半：second half of the winnowing basket body

Fig.43 Basic form of winnowing basket (single-sided winnowing basket)

[45] M,Imaiashi, conveying the art of winnowing, *Tokyo Institute for Cultural Properties*, 2017

3.1.5 Forming Methods of winnowing basket

There are several types of forming method of winnowing basket, two of the most important of which are *Amiage*（編み上げ）forming(Fig.44) and *Nu-iawase*（縫い合わせ）forming(Fig.45) in Japan[46]. In the *Nuiawase* forming method, the winnowing basket is done by weaving *Itami* in a two-dimensional state, then setting up an *Akudo* and sewing the two sides of the *Itami* together to obtain the form of a winnowing winnow (typical examples Kizumi winnowing basket in Chiba and Togakushi winnowing basket). In contrast, in the *Amiage* forming method, the basket of the winnowing basket is made first (by bending the braid into the form of a *Katakuchi*), and then the body of the winnowing basket is knitted along the form of the winnowing basket. Anyway, in *Amiage*, the final form of the winnowing basket is directly finished in the process of weaving the vertical and horizontal materials. (typical examples include the Nara *Ajiro* winnowing basket).

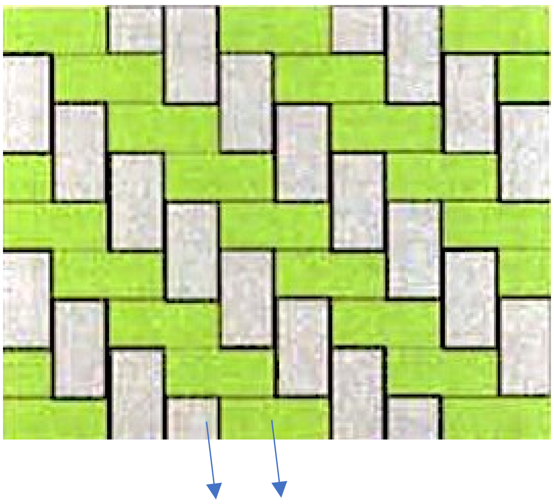
Fig 44 Nui-awase forming method[46]

Fig 45 Amiage forming method[46]

[46] Shape of a winnowing basket- Document collection, from the Document collection From the Department of Intangible Cultural Heritage of Tokyo National Research Institute for Culture Properties, https://www.tobunken.go.jp/ich/research/mi/

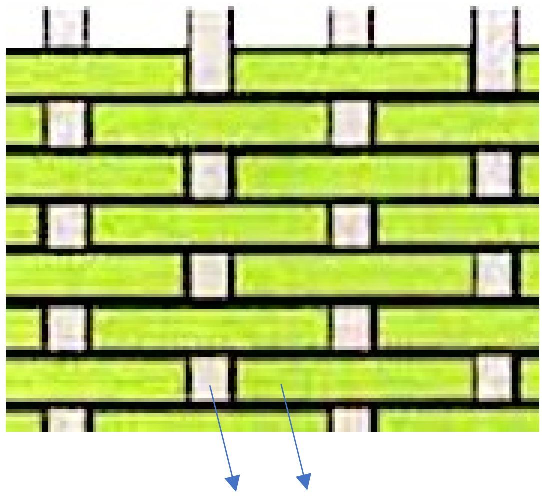
3.1.6 Weaving method of winnowing basket

There are two main methods of weaving the body of winnowing basket in Japan: '*Ajiro* weaving' and '*Gozame* weaving'. *Ajiro* weaving is made by braiding the strands horizontally and vertically or diagonally, and the movement of the horizontal strands is called "over", "under" or "feed". As shown in Fig. 46, the number of strands passing over the top of the vertical rungs is indicated by 'over', the number of strands passing under the vertical rungs is indicated by 'under' and the number of strands deviating from the top row is indicated by 'feed'. This method is used for sieves and baskets as well as winnowing basket. In contrast, the '*Gozame* weave' is a method in which the bark of the wood or rattan used as the core bone is made stronger, while the strips woven in the horizontal direction are made softer. The wood or wisteria bark is placed at regular intervals and the horizontal strips are woven with a tight weave (Fig.47). *Gozame* weave is also known as colander weave and is used to make fish tackle and colanders. In *Gozame* weave, the material appears in a positive cross form with different types of horizontal and vertical material, whereas in '*Ajiro* weave' the material appears in a diagonal cross form. Some winnowing baskets use both of these two weaving methods together, while others, conversely, are woven in one or the other way.



Same material

Fig 46 Ajiro Weaving method



Different material

Fig 47 Gozame Weaving method

3.1.7 Purpose and Method of the Survey

In this part, focusing on the 3D morphology of the winnowing baskets, 3D scanning, synthesis and organization of 3D data were carried out on 22 winnowing baskets (22 pieces) from various regions of Japan.

The measurement items determining the morphological characteristics of 14 of these domestic winnowing baskets (including foreign winnowing baskets similar to the domestic ones) were extracted and the morphology of the winnowing basket were classified according to these measurement items. The final target was to reproduce the simplified 3D forms (three winnowing baskets: Echigo winnowing basket, Nara *Ajiro* winnowing basket, Tokushima *Ajiro* winnowing) based on a set of feature curves that determine the cross sectional form of the winnowing baskets. The simplified 3D morphology being reproduced will be applied as a 3DCAD model in physical simulations to elucidate the engineering properties of the winnowing baskets (which simulated the process of the winnowing by human hands).

The reproduced 3D morphology is compared with the 3D morphology of the original winnowing baskets and the morphological elements are extracted as mathematical feature curves by investigating how to efficiently reproduce the winnowing baskets morphology on 3DCAD. Through the process of reproducing the form of the winnowing baskets and its morphological identification, a characteristic mathematical surface of the winnowing basket was generated from the NURBS curve. By comparing the generated surfaces with the 3D morphology of the original winnowing baskets made from natural materials, the influence and necessity of feature curves on the reproduction of the morphology is determined.

Through 3D reproduction process some importance and difficulties of the handcrafting process are explained and further would illustrates the relationship with the manual work in the production of the winnowing baskets (For example, the fixation of the *Udeki* affects the central axis of the form of the winnowing basket, the form of the deepest position of the winnowing basket affects the capacity of the winnowing basket and the form of the *Akudo* is relevant).

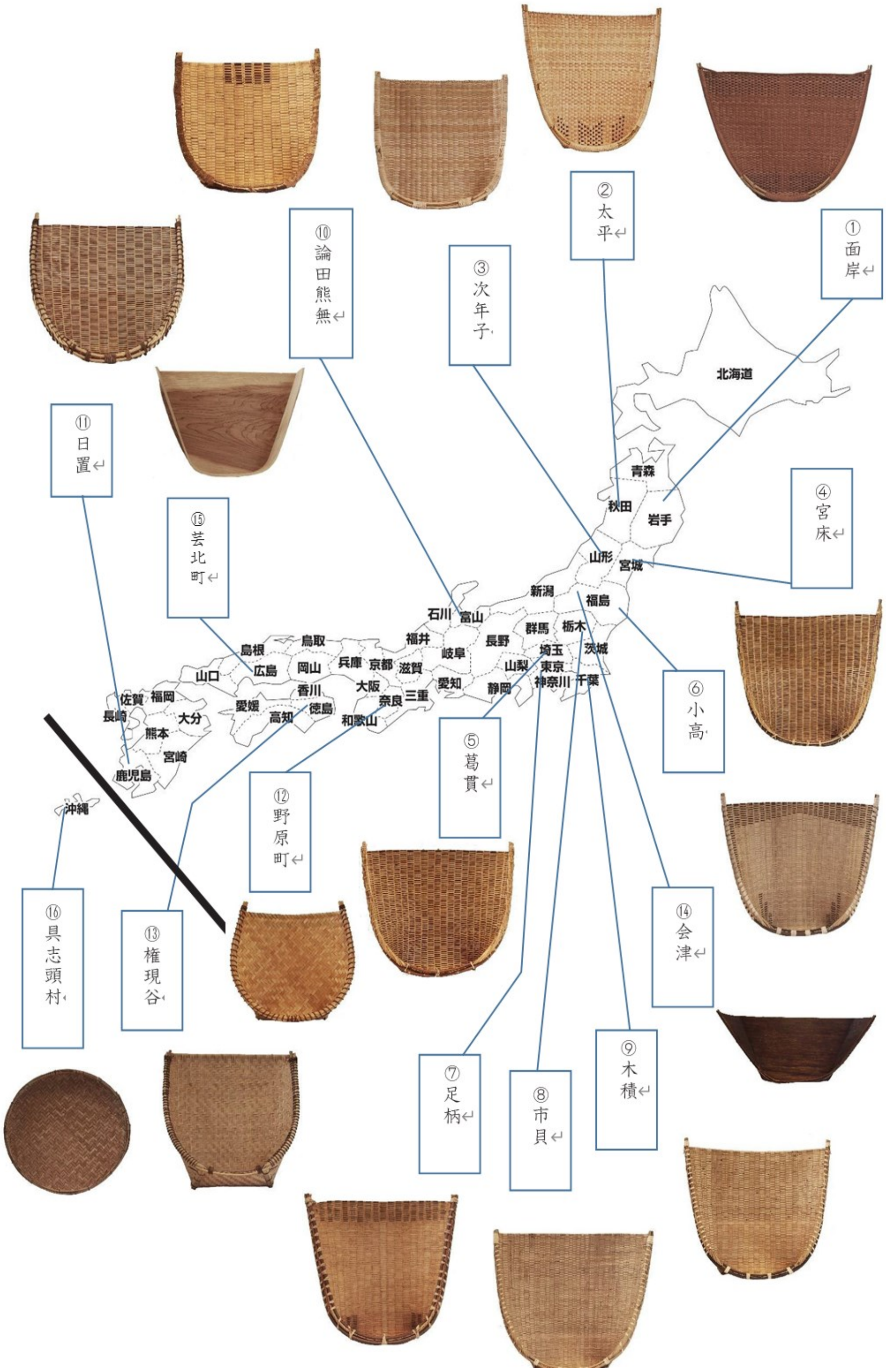


Fig.48 Distribution of winnowing baskets throughout Japan（From Tokyo National Research Institute for Cultural Properties）

3.2 Measurement of winnowing basket

3.2.1 Acquisition of 3D form of winnowing basket

The current collection of winnowing baskets in the Department of Intangible Cultural Heritage of Tokyo National Research Institute for Culture Properties, accounts for 2/3 of the typical Japanese winnowing baskets. Some winnowing baskets from other Asian countries, such as China, Malaysia and Korea, are also in the collection.

In this study, in order to clarify the characteristics of the morphology of the winnowing baskets, the 3D morphology of the winnowing baskets in the collection at Tokyo National Research Institute for Culture Properties until May 2019 were measured, and the morphologies of these winnowing baskets were then classified and 3D reproduced.

The 3D measurement tool was a noncontact 3D digitizer, KonicaMinolta VIVID 910[47] with a MIDDLE lens and a measurement distance of 0.6 m to 1 m (measurement accuracy 16 μm, from the machine's specifications), the form measurements and 3D CAD modelling of the winnowing baskets form were carried out. The 3D data were then imported into the Polygon Editing Tool for synthesis and organization. The 3D data acquired from multiple angles were synthesized into complete 3D data using the automatic synthesis function of the software Polygon Editing Tool. If automatic synthesis failed, manual synthesis was used to ensure a relatively low error tolerance. An example of the noncontact 3D digitizer VIVD910 is shown in Fig.49 and the winnowing basket during measurement is shown in Fig.50 and Fig.51 shows an example of the situation during synthesis of 3D data in the software Polygon Editing Tool.

3.2.2 Dimensions of the basic form of winnowing basket

All synthesized 3D data of the winnowing baskets were imported into the

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[47] Konica Minolta： Polygon Editing Tool, Polygon editing software dedicated to VIVID., https://www.konicaminolta.jp/ins rumentst/support/discontinued_products/vivid910

Fig 49 The head of KonicaMinolta VIVID 910

CAD software KeyCreator2019 SP2 [48] and measurements of the basic morphology were carried out. In accordance with the opinions of the experts and makers of the winnowing baskets in study group, the important parts for measuring the morphology of winnowing baskets were measured: ***vertical length, the length of the Misaki, depth*** (the height where the grain enters), ***the height of the Akudo, the opening angle*** (angle of the opening of the *Misaki*) and ***the length of the Akudo part*** (distance between the two corners). As an example, the measurement sites and results of the bamboo Ajiro winnowing baskets are shown in Fig.52 from four different perspectives.

Figure 50 winnowing basket during measurement

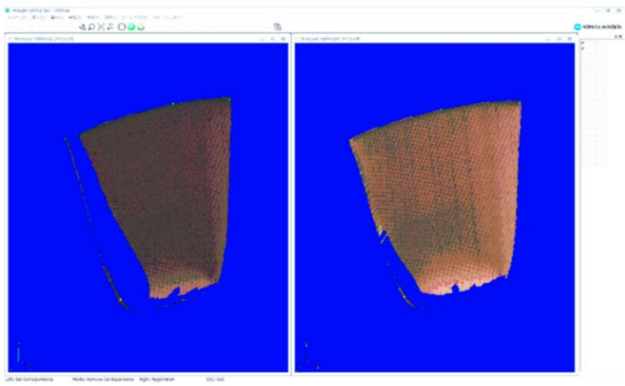

Fig.51 Synthesizing of 3D data in the software Polygon Editing

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[48] Kubotek 3D: KeyCreator 2019 SP2, a 3D CAD Software, https://www.kubotek3d.com.

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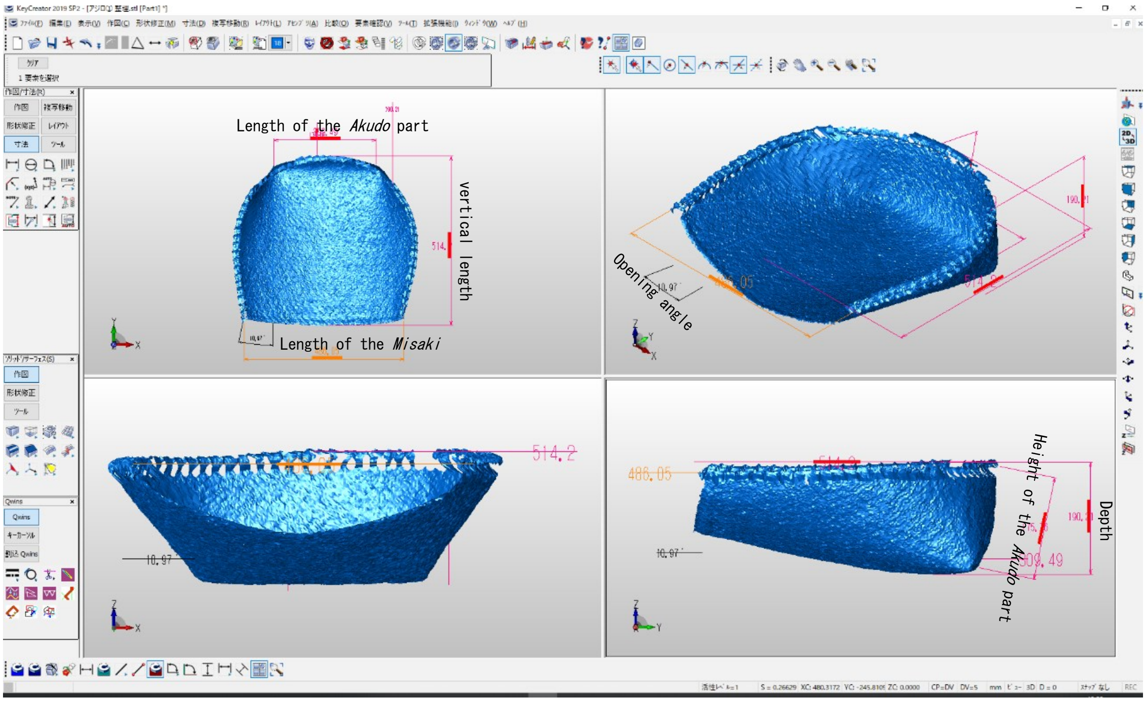

Fig. 52 Measurement of the synthetic model of the *Ajiro* winnowing basket

Fig. 53 The 3D model of the winnowing basket collected and the measurement of them

3.2.3 Classification according to the form of the winnowing baskets

The winnowing baskets referred to in this paper are described in using two naming methods.

(1) If they have names, use their names (*Jinenshi* winnowing basket, *Awa* winnowing basket).

(2) If they don't have names, use the name of their collection place (e.g. Echigo winnowing basket, Nara *Ajiro* winnowing basket).

Since Japanese winnowing baskets are geographically circulated, the winnowing basket using the name of their collection place do not indicate regional differences, and the winnowing baskets collected by the Tokyo Research Institute for Cultural Properties represent individual differences (differences in production methods and materials).

The measurement items that determine the morphological characteristics of the winnowing baskets were extracted and the forms of the winnowing baskets in the collection were classified according to the measurement items. The principal component analysis was conducted to clarify the tendency of the influence of the measurement items on the forms. The number of samples was 14 (Korean and Chinese winnowing baskets were excluded because their forms and production methods differed greatly from those of Japanese winnowing baskets), and six measurement items were used (Fig:52 length of the *Misaki*, vertical length, depth, height of the *Akudo* part, length of the *Akudo* part and opening angle).

As the aim was to clarify the differences between the forms of the winnowing baskets, standardisation was carried out to ensure that the length of the *Akudo* part was identical in order to allow for the classification of the forms. Therefore, the input data for the principal component analysis did not include a measurement item for the length of the *Akudo* part. The values in Table 4 are the rates of the measured values to the standardized length of the *Akudo* section in Fig.43, the distance between the two *Akudo*). According to the eigenvalues in Table 5, even for the initial eigenvalues of principal component 1 and principal component 2, the sum of squares of the loadings after the extraction of the initial eigenvalues are both greater than 1 and the cumulative rate of the two is 88. 317%, thus concluding that they can be generally classified as 1st Principal Component and 2nd Principal Component.

According to the distribution of the factor loadings of the principal components in Fig.54, 1st principal component has a high positive correlation with length and opening angle of winnowing baskets, and the sample score mapping in Fig. 55 shows that the morphology of the winnowing baskets at the left end of the coordinate axis of the 1st principal component has a more distinct quadrilateral outline, while those at the right end of the coordinate axis of the 1st principal component have a contour smooth and have a larger opening angle. As shown in Fig.54, the 2nd principal component is positively correlated with the depth and *Akudo* height. In the sample score map in Fig. 56, the depth of the winnowing baskets below the 2nd principal component axis is shallower and the depth of the winnowing baskets above the axis is deeper. It can be read that the depth of the winnowing baskets tends to become shallower as one moves from top to bottom along the two principal component axes. In this study, the influence of surface properties such as texture and material were excluded, as the aim was to classify, simplified morphology of the winnowing baskets in order to reproduce the simplified CAD models.

At least one *Amiage* method winnowing basket and one *Nui-awase* method winnowing basket were selected for each forming method, referring to the opinions of experts and the results of principal component analysis. Finally, three forms of Echigo winnowing basket, Nara *Ajiro* winnowing basket (*Amiage* method) and Tokushima *Ajiro* winnowing basket (***Nui-awase*** method) were reproduced.

These winnowing baskets selected for form reproduction were each of them on morphological characteristics were most evident in the principal component analysis result, and while the Nara *Ajiro* winnowing basket and Tokushima *Ajiro* winnowing basket were selected because their weaving methods, production processes and textures are the same, their forms are quite different so that they were judged ideal for analysis and reproduction of their morphology. In this study we attempted to reproduce the three simplified forms of holding the winnowing function mentioned above and to compare individual differences.

In this principal component analysis, we were able to express the classification of the collected winnowing baskets by their simple measurable parameters, but we have not yet directly measured the curved surfaces and curves of the *Itami*, which strongly influences the form of the winnowing basket as an analytical parameter.

Table 4 Data for principal component analysis

	ミサキの長さ	縦長さ	深さ	アクド部の高さ	開く角度（rad）
マレーシア　箕	1.846	1.987	0.310	0.249	0.207
越後　箕	1.387	1.241	0.297	0.249	0.133
オエダラ　箕	2.460	2.415	0.579	0.497	0.298
下妻　白箕	1.411	1.325	0.316	0.270	0.194
戸隠　箕	1.237	1.221	0.456	0.313	0.073
次年子　箕	1.784	1.756	0.360	0.354	0.247
奈良アジロ　箕	1.570	1.661	0.615	0.568	0.191
徳島アジロ　箕	1.652	1.650	0.520	0.448	0.187
日置　箕	2.464	2.176	0.589	0.501	0.310
日置小型　箕	1.972	1.948	0.563	0.514	0.243
氷　箕	0.758	1.382	0.475	0.435	0.191
面　箕	2.325	1.716	0.580	0.490	0.389
毛呂山　箕	2.017	1.484	0.600	0.503	0.304
木積　箕	2.130	1.810	0.584	0.459	0.339

Japanese & English

ミサキの長さ：the length of the Misaki

縦長さ：vertical length

深さ：depth(the height where the grain enters)

アクド部の高さ：the height of the Akudo

開く角度：the opening angle（angle of the opening of the Misaki）

Table 5 Eigenvalues and cumulative rates in principal component analysis

Component	Initial value			Sum of loadings squared after extraction		
	Total	Dispersion	Accumulation	Total	Dispersion	Accumulation
1st	3.395	67.894	67.894	3.395	67.894	67.894
2nd	1.012	20.424	88.317	1.021	20.424	88.317
Method：Principal component analysis						

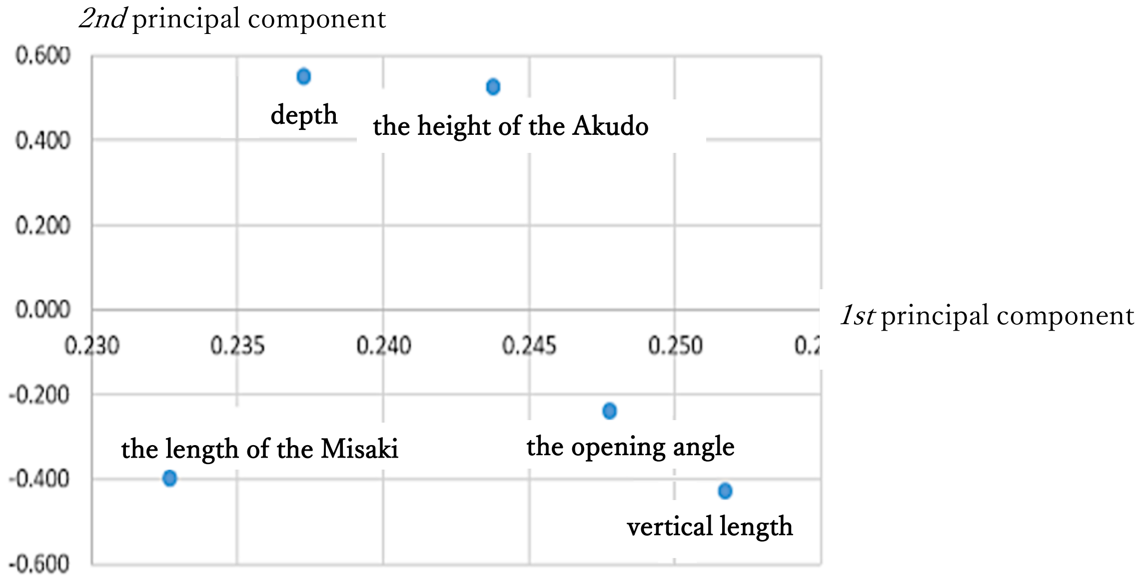

Figure 54 Factor loadings

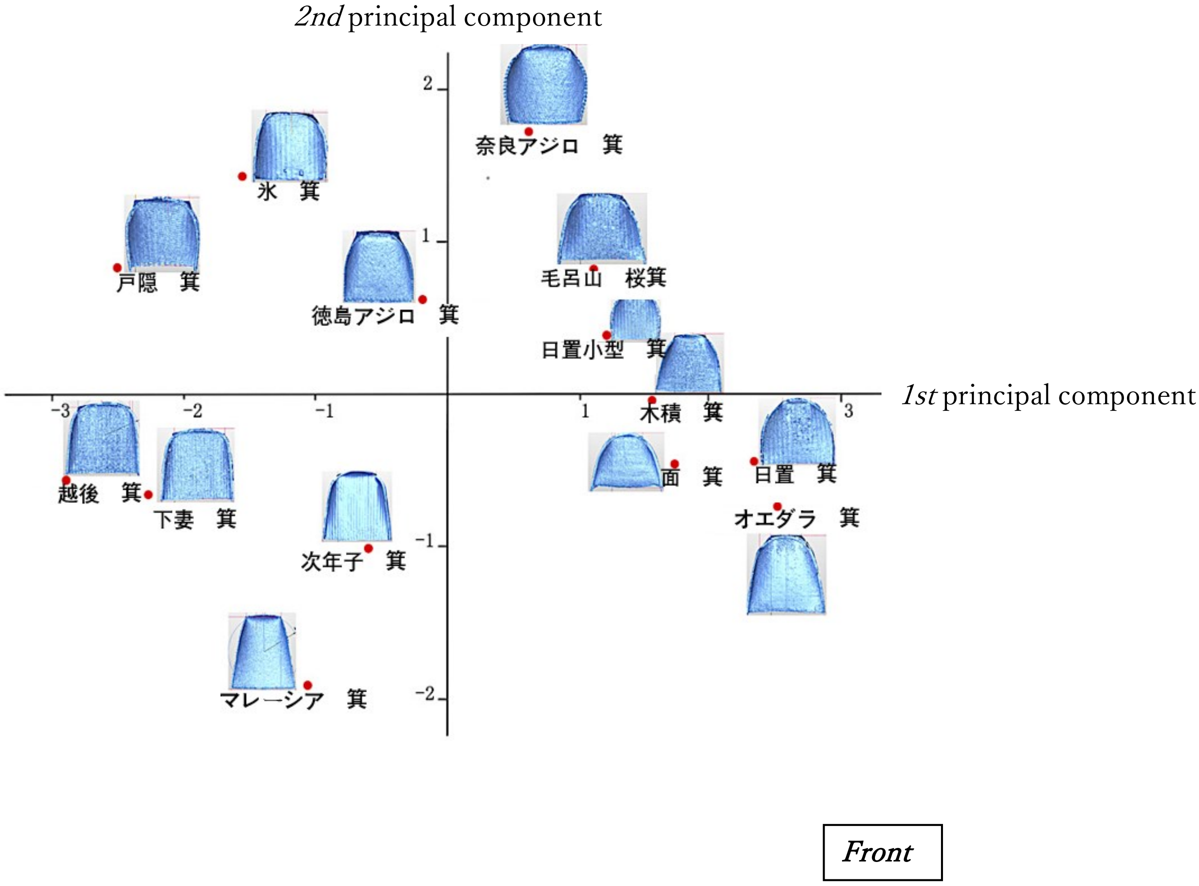

Fig 55 Distribution of samples in 1st principal component and 2nd principal component

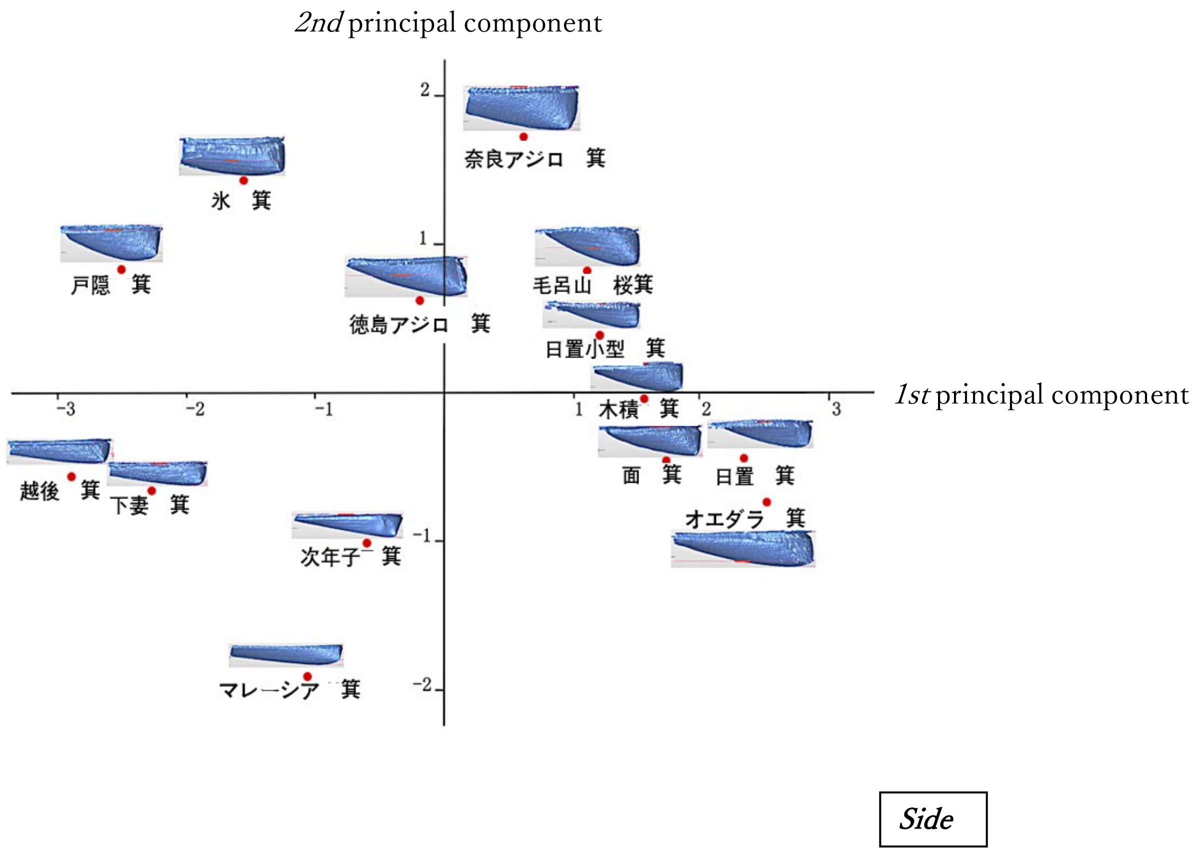

Fig 56 Distribution of samples in 1st principal component and 2nd principal component

3.3 3D Reproduction of winnowing basket

3.3.1 3D Reproduction principle of winnowing basket

There are 4 common 3D modelling methods, Direct Modelling by 3D software, Polygon Modeling, NURBS Modeling, Parametric Modeling. The method used in this study was NURBS Modeling by the software of Autodesk Alias AutoStudio[49]. All generated surfaces of winnowing baskets are NURBS surfaces, NURBS stands for Non-Uniform Ratenal B Spline, which is often used for high precision replication and reconstruction of surfaces, as its properties are based on the mathematical representation of freeform surfaces[50]

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[49] Autodesk: Alias, An Industrial Design And 3D Surface Modeling Software, from alias.design.

50 Q. Wang.,　W. Zhou.,　et al.,　NURBS-enhanced line integration boundary element method for 2D elasticity problems with body forces,　*Computers & Mathematics with*

[51] modelling of NURBS surfaces is determined by the spatial position of the control points of the surface. The greater the number of control points on a single surface, the more complex the form the surface can present, while a relatively small number of control points can easily result in a smoother surface. In the present reproduction, the approximate curves generated were converted to NURBS curves to reduce the influence of material surface properties on the modelling of the winnowing basket form, limiting the number of control points of curves representing a single cross sectional form to less than 20 and the order of the NURBS surface to less than 20[52]. The function used to generate the surfaces from the curves was the Alias square function; one property of NURBS surfaces is that they have four edges, and in this reproduction the previously extracted feature curves were also used as the four edges The COONS surface generation principle[53]was used to generate the surface from the four edges, and it is the form of the four edges and the weight coefficient of each edge that determines the form of the generated surface (e.g. The default state of the square function is that its weight coefficients are the same for all edges), and all surfaces reproduced in this study were generated.

3.3.2 Extraction of feature curve of winnowing basket

Although it has been confirmed by experts that winnowing forms can be classified almost adequately into 3D forms by the measurement items used in principal component analysis, it is difficult to reproduce their morphological (characteristics). Since the aim of this study is to express the (inherent) elasticity (change) characteristics of the form of a winnowing basket with a

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Applications, 77(7), 2006-2028, 2019,

[51] NS, Imai., 分かりやすい NURBS 解説, *UNISYS 技報*, 32(3), 173-186, 2012

[52] Kruth. JP., Kerstens. A., Reverse engineering modelling of free-form surfaces from point clouds subject to boundary conditions, Journal of Materials Processing Technology, 76(1-3), 120-127,1998

[53] XF. Zhang., P. Hu., et al., A new surface parameterization method based on one-step inverse forming for isogeometric analysis-suited geometry, *International Journal of Advanced Manufacturing Technology*, 65(9-12), 1215-1227, 2013

small number of mathematical elements, an attempt was made to reproduce the winnowing basket form by selecting curves that show characteristic cross sectional forms (feature curves) in the winnowing basket form (a simple modelling method to reproduce the winnowing basket in 3D form in order to observe the engineering features and functions, as well as some detailed forms related to production).

The method involved importing the 3D data of the winnowing basket into Keycreator 2019 SP2, extracting all the point groups on the section to be cut from the 3D data, and fitting or manually completing the extracted point groups with a pline to generate an approximate curve. shows a point cloud showing the cross-sectional position and cross sectional form of the winnowing basket, and Fig.57 shows the point cloud on the cross section as an example. Fig.58,59 shows the approximate curve generated by fitting a set of points on the cross section as an example.

The approximate curves (feature curves) mentioned in this study are all abbreviations for curves showing the form of the stringer cross section and all approximate curves are obtained by the method described above.

3.3.3 Digitalization of winnowing basket

As the method of manufacturing the winnowing basket is based on flat *Itami* being fixed to curved *Udeki* and the *Itami* being fixed in close proximity to the *Akudo*, it is appropriate to establish a coordinate system based on the *Udekis* and the *Akudo*. As a result, a coordinate system was defined with the winnowing *Udeki* in the x-y plane and the direction of the *Misaki* in the x-axis direction. As the winnowing baskets are handmade, their form is not perfectly symmetrical. x-z plane should be set up as close as possible to the ideal plane of symmetry, and its position is specified at the midpoint of the line connecting the x-axis direction and the reference point of the foldup of the two *Akudo* of the winnowing basket (Fig.60,61), intersection point of the sewing

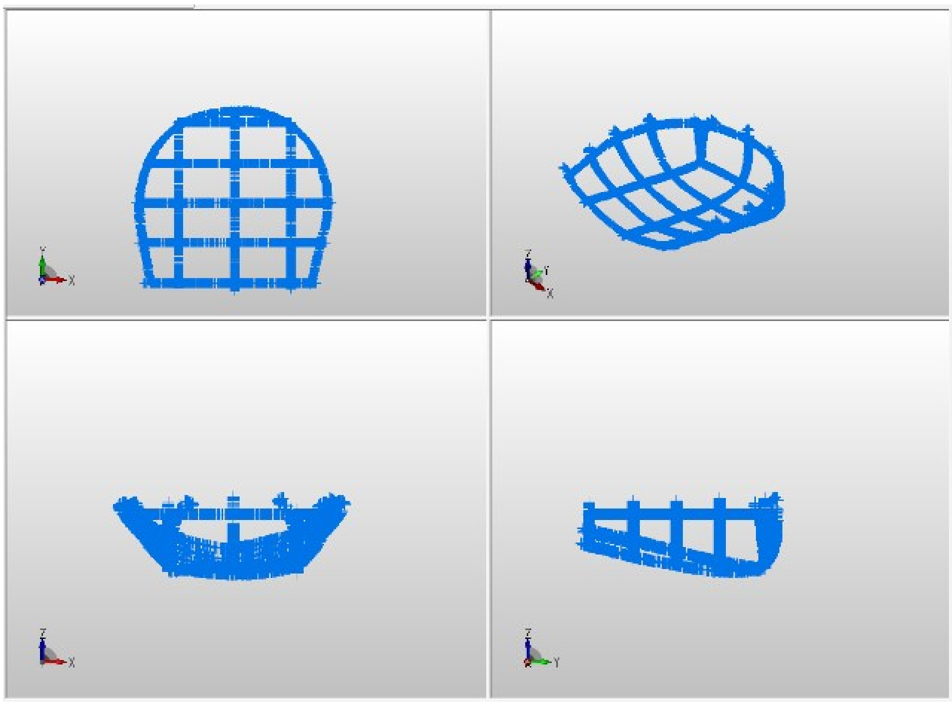


Fig. 57 Point cloud showing the cross-sectional shape of the winnowing winnow.

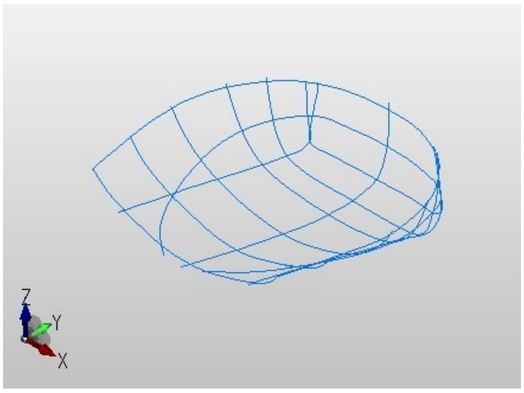


Fig.58 Cross-sectional curves showing the point cloud shape(Keycreator 2022)

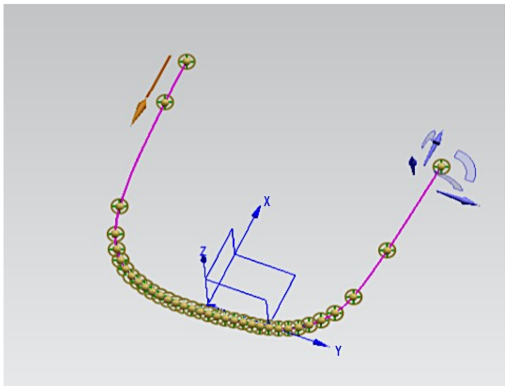


Fig. 59 Generated fitting curves(Siemens NE)

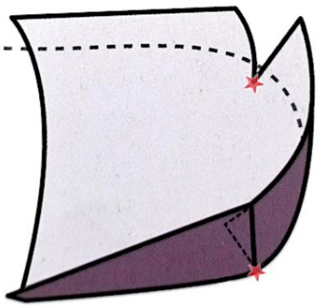


Fig 60 Reference point for fold-up of *Akudo*

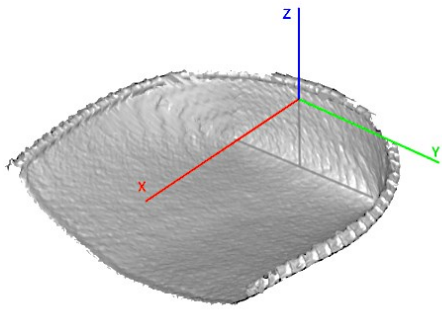


Fig 61 Spatial coordinate system(Autodesk Alias)

part of the *Akudo* and the body of the winnower). y-z plane also passes through this point and is defined as the x-axis direction, and the y-z plane is defined as the y-axis direction. z-plane is also defined as the plane passing through this point and intersecting the x-z plane perpendicularly (Fig.61).

The winnowing basket is then cut in the x-y plane (horizontal section), x-z plane (longitudinal section) and y-z plane (transverse section) in the coordinate system and the feature curves in the three directions are extracted. NURBS surfaces were generated based on the extracted feature curves to reproduce the winnowing basket form. The location chosen for the feature curve (where the form is cut) is usually the contour line of the form and the area where the form changes more sharply in this study.

3.3.4 Process of reproducing the winnowing basket form

The form of the winnowing baskets in different regions is influenced by various factors such as the materials used, weaving methods, forming methods and manual techniques, but in order to find the relationship between the form of the winnowing baskets in different regions and forming method and weaving method, it is necessary to digitalize and analyze the form of these winnowing baskets. By extracting the feature curves of the winnowing basket, the form of the winnowing was reproduced on a curved surface by using the lofting function of 3D modelling software and by various combinations of the extracted feature curves. By comparing this with the scanned data of the reproduced winnowing basket, the feature curves that have a significant influence on the winnowing basket can be found, while other curves with less influence can be omitted.

In the actual measurement process, the following curves were extracted and numbered in Fig.62 as potential feature curves. The cross section in which curve A1 is located was the position where a fully continuous feature curve could be extracted, as the edges on the *Misaki* side were not aligned. The cross section in which curve A5 is located is where it passes through the apexes of the two sides of the *Akudos*.; all the cross sections in which feature curves A1 to A7 are located are perpendicular to the x-y plane defined by the U-formed *Udeki*; A2, A3 and A4 quarter the surfaces from A1 to A5; and A4 is perpendicular to the x-y plane defined by the U-form. The plane in which feature curve A6 is located passes through the deepest location (defined by the greatest distance to the horizontal plane located on the *Udeki*, which is also the site of measurement 'depth' in Fig.52). The cross section where curve A7 is located is in the middle of the two planes where feature curves A1 and A2 are located; B1 is the feature curve closest to the *Udeki* and can reflect the degree of curvature of the Udeki. The B2 cross-section lies below the B1 cross-section, parallel to the *Misaki* direction, and is half the height of the *Akudo.* The section in which curve C1 is located passes through the midpoint of the line connecting the apexes of the *Akudo* and is perpendicular to the two planes in which feature curves A5 and B1 are located. Feature curve C2 is divided into two parts, left and right, and the cross section in which it is located is parallel to the cross section of C1 and passes through the apexes of the *Akudo* on both sides. These feature curves were transformed into NURBS curves and the winnowing basket surfaces were generated using the method described previously. The effect of the reproduction was assessed by comparing the form of the reproduced surfaces with the scan model. Geomegic ControlX was used to compare the agreement[54].

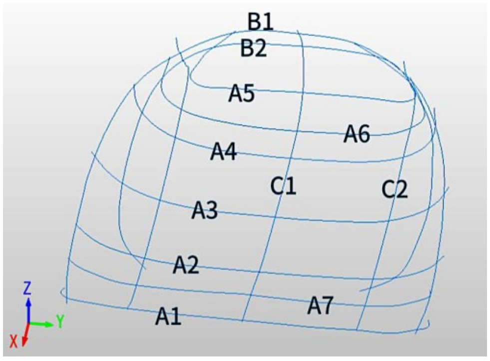


Fig. 62 Extracted feature curves and numbering

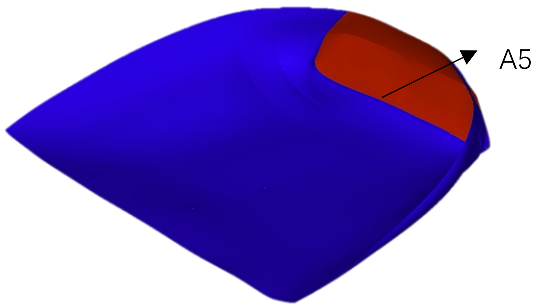


Fig. 63 Reproducing the shape of winnowing basket on two curved surfaces

[54] 3D Systerm: Geomagic ControlX, A 3D Inspection and MetrologySoftware, https://jA.3Dsystems.com/software/geomagic-control-x

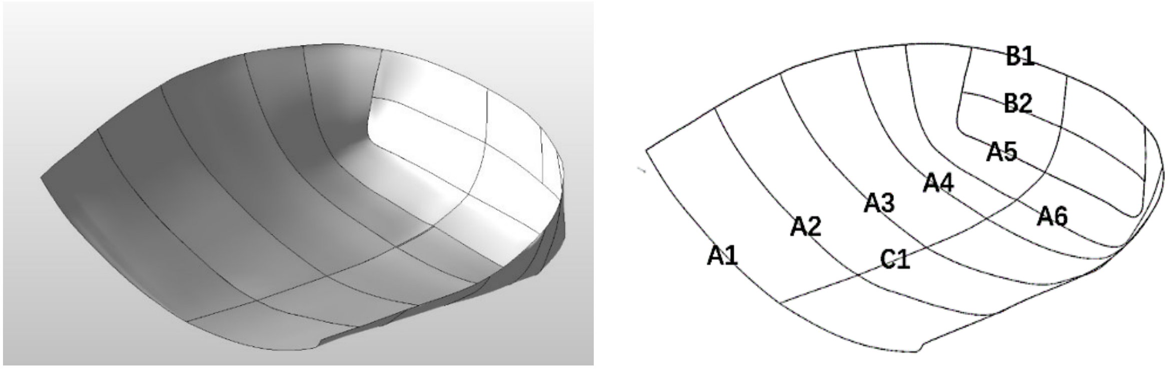


Fig 64 Extraction of feature curves of Nara *Ajiro* winnowing basket

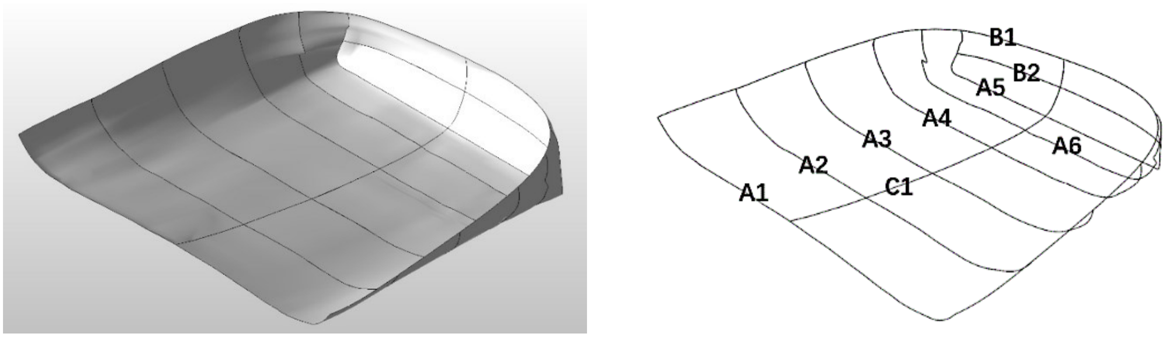


Fig 65 Extraction of feature curves of Echigo winnowing basket (Niigata)

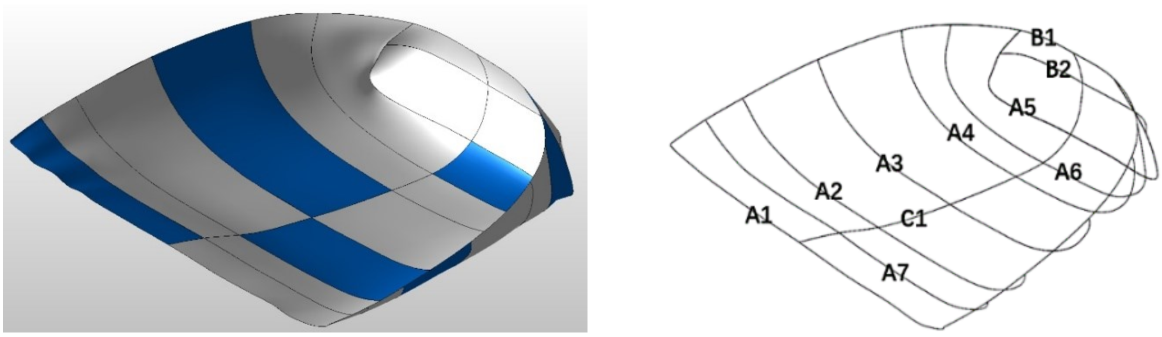


Fig 66 Extraction of feature curves of Tokushima *Ajiro* winnowing basket

3.3.5 Reproduction of 3D Nara *Ajiro* winnowing basket (Fig.64)

The Echigo winnowing basket (Niigata), Nara *Ajiro* winnowing basket and Tokushima *Ajiro* winnowing basket selected from the morphological characteristics and the results of the principal component analysis were reproduced.

Reproduction of Nara *Ajiro* winnowing basket

(1) Analysis of the characteristics of Nara *Ajiro* winnowing basket

By observing the weaving process, it was found that the form of the winnowing basket was mainly influenced by the elasticity inherent in the material and the form around the *Akudo*, which is formed by overlapping and sewing together parts of the edge of the *Itami*. When selecting feature curves, it is efficient to first extract from the position where the overlapping structure exists. The superposition structure and the *Akudo* allow the form of the winnowing basket to be easily divided into two surfaces (Fig. 63): one is the large surface of the winnowing basket body from the *Akudo* to the *Misaki* (the blue part in Fig.63). The other is the surface of the *Akudo* part (red part in Fig. 63). The idea is to reproduce the entire form of the winnowing body with the two surfaces, using the characteristic curve A5 as the demarcation line in the spatial coordinate system described previously.

(2) Extraction of feature curves

Each feature curve contains some characteristic information of the winnowing basket form. The extent to which each feature curve reflects the characteristics of the overall form can be determined by its effect on the agreement rate of the reproductions. The form of the Nara *Ajiro* winnowing basket is relatively rounded among the three selected winnowing baskets. Five feature curves A1 and A5, parallel and equidistant from each other, were extracted to reproduce the curved surface corresponding to the blue area in Fig.63. To reproduce the form of the *Akudo* part, feature curve B1 and feature curve C1 passing through the centre of the winnowing basket were extracted.

(3) Addition of feature curves

Analysis of the areas of low agreement in the modelling reproduced by feature curves A1 to A5 (Fig. 68 Nara *Ajiro* winnowing, left 1) showed that the morphological feature at the deepest position may have a significant influence on the reproduction of the second half of the Nara *Ajiro* winnowing basket (Fig.

31), and so Feature curve A6, which passes through the deepest position, was added. The agreement between the second half of the winnowing basket body (Fig. 68) reproduced with only feature curves A5, B1 and C1 and the original scan model is lower, but the addition of feature curve B2 can increase the agreement.

(4) Effect of feature curves on morphology

Various combinations of feature curves showed that the agreement between the form of the reproduced surface and the original scan model was clearly reduced when A3, A4 or A6 were absent, except for A1 and A5 on the *Misaki* and *Akudo* sides. fter removing any of the feature curves A2, A3, A4 and A6, taking into account the manufacturing process, the order of the expression formulae of the remaining feature curves was reduced, and the numerical values of the curvature of the reproduced surfaces were also reduced. The decrease in the one-sided agreement rate may reflect the influence of handcrafting. As the curvature depends on the uniformity of the two dimensional *Itami*, the curvature of the A-series curves, in addition to being affected by the resilience of the *Itami* material, also reflects changes in form due to the fact that they were produced by craftsman's hand.

3.3.6 Reproduction of 3D Echigo winnowing basket(Fig.65)

(1) Feature analysis of Echigo winnowing basket

Similar to the treatment of the Nara *Ajiro* winnowing basket described above, feature curves were extracted for the Echigo winnowing basket. As there is a large change in the curvature of the surface around the *Akudo*, it can be inferred that the feature curve around the *Akudo* has a large influence on the reproduced form. The influence of the form of the C1 cross section on the form of the Echigo winnowing basket is assumed to be small because the area of the plane of the Echigo winnowing basket is larger.

(2) Extraction of feature curves

The surface of the winnowing body is reproduced by extracting five equidistant feature curves (A1, A2, A3, A4, A5), the deepest feature curve A6 and the central feature curve C1. The surfaces corresponding to the red part of Fig. 23 are further extracted B1 and B2 for reproduction.

(3) Addition of feature curves

No new feature curves are added during reproduction in Echigo winnowing basket.

(4) Influence of feature curves on the form

As the overall form of the Echigo winnowing basket is close to a plane, when A2, A3 and A4 were eliminated, the decrease in the agreement rate was slight, but only when A6 was removed, the agreement rate around the *Akudo* dropped significantly (a wide blue area appeared). Because the turn of the curvature change is not the line connecting the bottom of the *Akudo*, but there is also a position indicating the capacity of the winnowing basket, the deepest part of the Winnowing basket, which is not easily observable without the 3D modeling.

3.3.7 Reproduction of 3D Tokushima *Ajiro* winnowing basket(Fig.66)

(1) Characteristics analysis of Tokushima *Ajiro* winnowing basket

The same extraction method as that used for the Echigo winnowing basket technique was also used for the Tokushima *Ajiro* winnowing. As the *Udeki* near the *Misaki* side tends to be deflected towards the centre, the curved surface near the characteristic curve A7 near the *Misaki* of the Tokushima *Ajiro* winnowing basket is bulged upwards, which is assumed to be due to the fact that the tension by the partial *Udeki* is not sufficiently effective. Fig. 67 shows the wavy form in the middle of the future curve A7 (blue line) of the Tokushima *Ajiro* winnowing basket. Due to this feature, when A7 is not used, feature curves A1 and A2 do not have the wavy form as A7, the curvature at the intersection of A1, A2 and C1 is smaller than at the intersection of A7 and C1. The curvature of the surfaces generated by the square features used did not exceed the edges in the parallel direction, thus reducing the agreement on the *Misaki* side. However, referring to the views of the sculptors who are members of the winnowing basket study group, it seems that the features shown near A7 are not features of the original form (form at the time of production), but

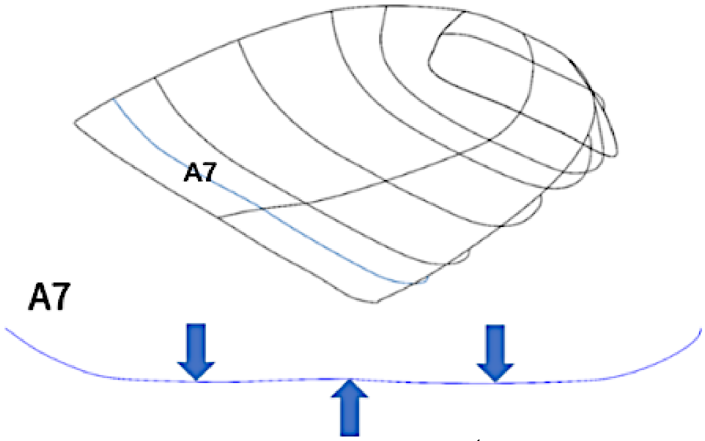


Fig.67 The middle part of feature curve A7 bulges upwards (Tokushima *Ajiro* winnowing basket).

transformations caused by the use and storage conditions of the winnowing basket.

(2) Extraction of feature curves

For the surface of the winnowing body curves, five equidistant feature curves (A1, A2, A3, A4 and A5), one feature curve A6 at the deepest position, and an additional feature curve A7 and feature curve C1 between A1 and A2 were extracted. The surfaces corresponding to the red part of Fig. 23 are the same as described above, and feature curves B1 and B2 were extracted.

(3) Additional feature curves (Fig. 67)

The added feature curve A7 shows that the structure of some of the surfaces of the first half of the winnowing basket body is not completely tensile in the transverse direction, but its form is likely to be transformed by the use and storage conditions of the winnowing basket body.

(4) Effect of feature curves on morphology.

The deletion of any feature curve had a certain effect on the agreement rate: although the importance of A6 may be lower than that of the Nara and Tokushima *Ajiro* winnowing basket, the addition of A6 clearly reduced the area of the red area on the right side.

3.3.8 Relationship between feature curves and the 3D morphological characteristics of winnowing basket

A comparison of the reproduced surface form with the original form is shown in Fig.68. In order to clarify how the feature curves affect the local morphology of the winnowing basket and to be able to compare more rigorously the differences between each winnowing basket model and the scanned data, a quantitative analysis comparing the agreement rate by increasing or decreasing the number of feature curves was carried out.

In the first half of the Nara *Ajiro* winnowing basket, the agreement between the reproduced form and the scanned model can be greatly improved by increasing the number of feature curves in the A-series, so it is possible that feature curves A2─A4 reflect more structural changes during production by craftsmen's hand. According to the results of reproducing the form of the winnowing basket by 3D CAD and comparing the forms, the feature curve A6 at the deepest point of the form of the Nara *Ajiro* winnowing basket has a significant influence on the form near the winnowing basket Akudo, and the reproduced form has a significant influence on the form of the Nara *Ajiro* winnowing basket. It was found to have an influence on the reproduced morphology (the agreement rate increased from 20.89% to 24.75%). To analyse the influence of each feature curve on the morphology, each feature curve was eliminated in turn and the magnitude of the influence of each feature curve on the morphology observed in the numerical change in agreement was compared in terms of the numerical change in agreement. When all six A series curves are used (A1A6 in Fig. 62) as a reference, the The agreement for the Nara Ajiro Mino is 24.75%; when A3 is removed, the agreement drops by 7.65% to 17.10%. The results showing the magnitude of the effect of each feature curve on the overall morphology are A3 (7.65%) > A2 (4.03%) > A6 (3.86%) > A4 (2.98%).

The surface the Echigo winnowing basket was reproduced by five equidistant feature curves (A1, A2, A3, A4 and A5), the deepest feature curve A6 and the central feature curve C1, and the surface of the Akudo part of the winnowing basket was further reproduced by B1 and B2. After each feature curve was sequentially eliminated, the numerical change in the agreement rate was used to compare the magnitude of the influence of each feature curve on the overall morphology: A3 (4.52%) > A4 (3.69%) > A6 (3.09%) > A2 (2.62%). Due to the high overall agreement, no new feature curves were added when reproducing the Echigo winnowing basket.

When the feature curves used to reproduce the morphology of the Tokushima *Ajiro* winnowing basket were arbitrarily deleted, the overall agreement rate became much lower, but when feature curve A7 was added, the reproduction effect on the *Misaki* side of the Tokushima *Ajiro* winnowing basket improved (the green area clearly expanded). Comparing the magnitude of the effect of each feature curve on the overall morphology, A2 (8.75%) > A3 (6.88%) > A4 (4.75%) > A6 (1.35%) Of the three winnowing forms, the feature curve was used most frequently to reproduce the morphology of the Tokushima *Ajiro* winnowing basket, and was relatively considered the most complex form. The feature curve that had the greatest influence on the form of the Tokushima *Ajiro* winnowing basket was A3 in the middle of the *Itami*. Next, A6 was found to influence the morphology near the *Akudo*; the addition of A6 clearly reduced the maximum distance in the normal direction (from 12.3 mm to 9.3 mm). When feature curve A7 was added, A7 was found to have a more important influence on the reproduction of the morphology of the Tokushima *Ajiro* winnowing basket than A2 and A4. 3D-CAD reproduction experiments of the three winnowing baskets morphologies showed that the C series curve (C1) and B series (B1, B2) curves It was found that the morphology of the *Akudo* part could not be reproduced if B2 was removed, although it was not verified how the morphology of the winnowing basket is affected by the increase or decrease of the C series curve (C1) and the B series curve (B1, B2). For classification by simplified form of the winnowing baskets, the measurement item 'vertical length' is considered a simplified model of the C series curve, while the measurement items 'depth', 'height of *Akudo* part' and 'length of *Akudo* part' are simplified models of the B series curve, and both series are considered necessary elements for reproducing the form (If B-series and C-series curves are not used for the reproduction, the form of winnowing basket can't be reproduced. Because there are locations where the thickness of the manual work is not uniform, so sometimes the prototype or the scanned object is not the ideal model when studying the physical properties of the artificial object. The reproduction of the 3D model should take into account the (functional) physical properties and not simply imitate the external shape of the artificial object. This paper reproduces the form of the winnowing basket by means of a curve with elastic characteristics that can be used for physical simulation applications, proving that the form and function of an artificial object such as the winnowing basket are unified, or that the form and composition determine its function).

The reproduction of the 3D model should take into account the (functional) physical properties and not simply imitate the external shape of the artificial object. This paper reproduces the form of the winnowing basket by means of a curve with elastic characteristics that can be used for physical simulation applications, proving that the form and function of an artificial object such as the winnowing basket are unified, or that the form and composition determine its function.

By comparing the reproduced forms of the three winnowing baskets together, the agreement rate between the reproduced forms and the scan data could be significantly improved by increasing the number of feature curves in the A series. Feature curves A2 to A4 reflected more structural changes caused by manual work during manufacture. Feature curves A1, A5, A6 and A7 represent changes in the overall form caused by elasticity changes, influenced by the *Udeki* and folding structure. Feature curve C1 plays an important role in the reproduction of Nara and Tokushima *Ajiro* winnowing basket, partly because the elasticity in the y-direction produced by the *Udeki* is continuously reflected in the x-direction. For example, when *Itami* are fixed to the *Udeki* by pulling strongly on the *Misaki* side, the centre line C1 on the winnowing basket is more curved. Conversely, when *Itami* are gradually fixed to the *Udeki*, the centre line

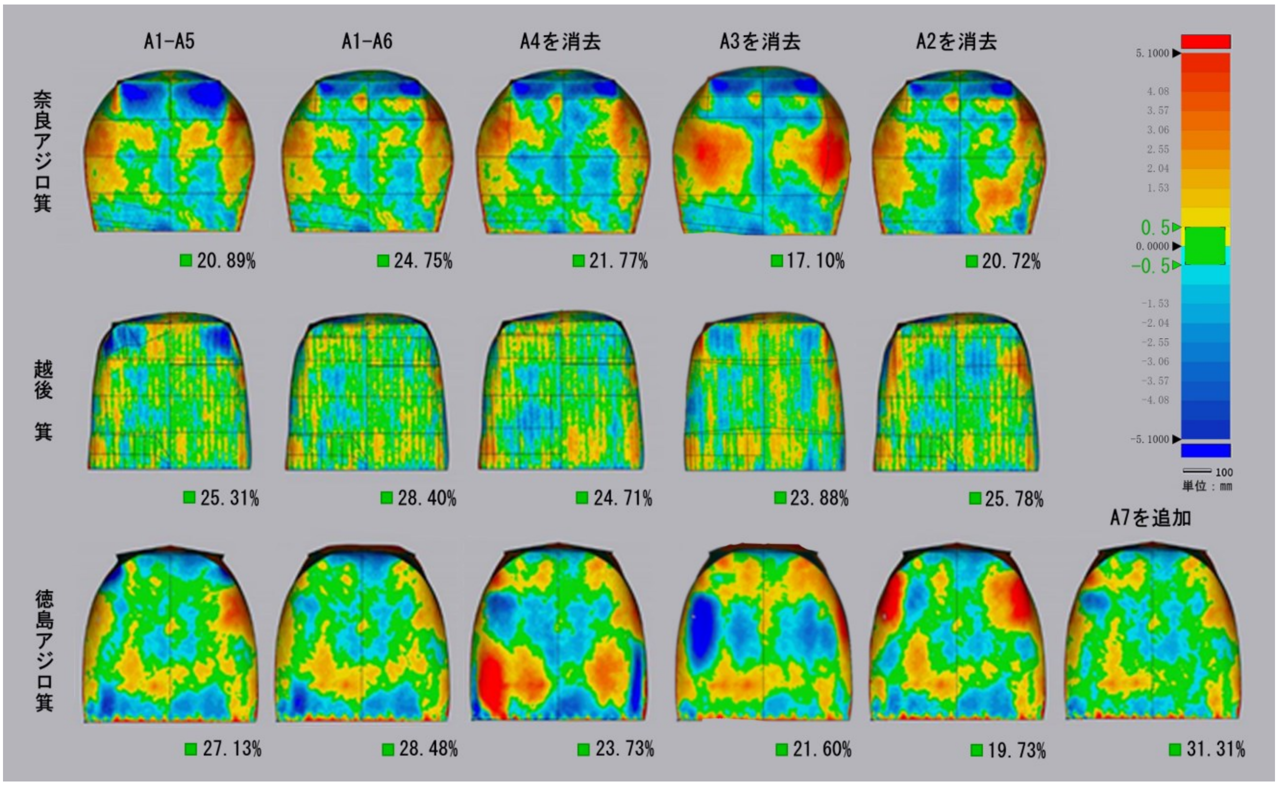


Fig.68 Agreement between digital reproduction models and scan data of the three winnowing basket (for evaluation and comparison of local morphology)

C1 is closer to a straight line. In summary, the form of the *Udeki* affects the centre line C1 when the form of winnowing basket was reproduced on 3DCAD, which consequently affects the depth and capacity of the winnowing basket and the form of the *Misaki* (The form of the winnowing basket is a manual process that uses the elastic characteristics of the material, such as the static elasticity to resist external forces, to create a form that has a physical function (wind selection). The natural material of each part of the winnowing basket is the same, but the static elasticity of each part is different because of the variation in the form of the winnowing basket itself, so we can use the variation in properties (a set of characteristic curves with different curvatures) to reproduce a 3D model with a physical simulation (winnowing function). The nature of form is the embodiment of a new function given to natural materials through artificiality).

3.3.9 Winnowing basket CAD models for morphometric and functional analysis

In order to compare the morphology of the entire winnowing basket form, to analyse the structure of that form and the air flow in the winnowing basket[55] (Fig.69), it is necessary to remove the influence of surface irregularities caused by the weaving method in CAD models.

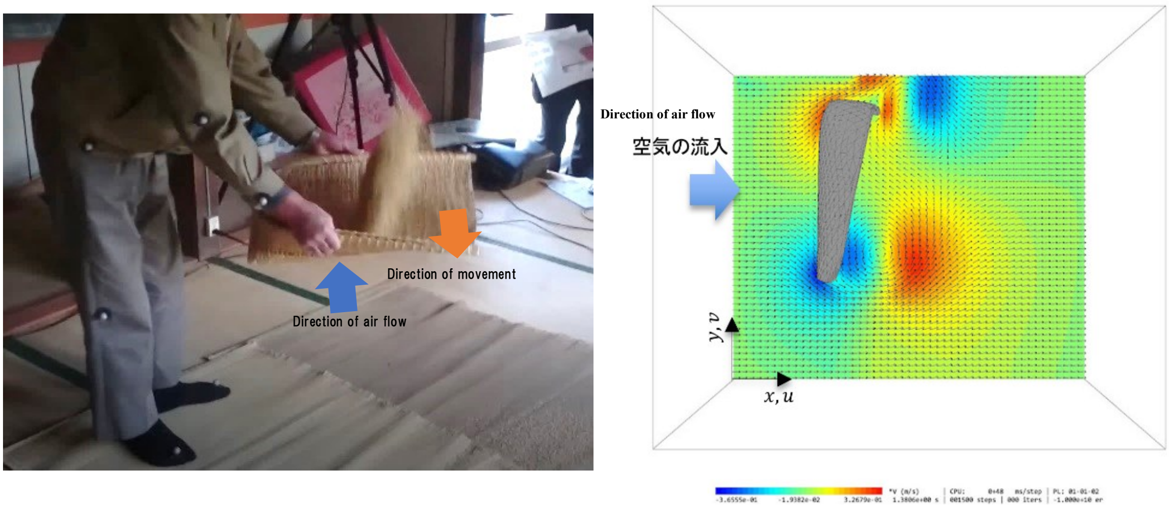


Fig.69 The shape of a winnowing basket that creates its own wind

The surface irregularities were measured in each of the three winnowing baskets (Nara *Ajiro*, Echigo and Tokushima *Ajiro* winnowing basket) for which CAD modelling was carried out, and the allowable range was set using the above-mentioned method. Fig.70 shows the measurement of the surface irregularity (depth) of the Echigo winnowing wheel as an example. For the Nara *Ajiro* winnowing basket, the tolerance range was set to ±2.60 mm and the agreement rate between the reproduced model and the actual winnowing basket shape was 83.91% (Fig.71). For the Echigo winnowing basket, the tolerance was set to ±2.85 mm and the agreement rate was 88.12%(Fig.72). For the Tokushima *Ajiro* winnowing basket, the tolerance range was set to ±2.51 mm and the agreement rate was 84.00% (Fig.73) .

55 M, Kubo., [風を起こす箕の形], 日本デザイン学会 第 69 回研究発表大会, 9A-01,2022

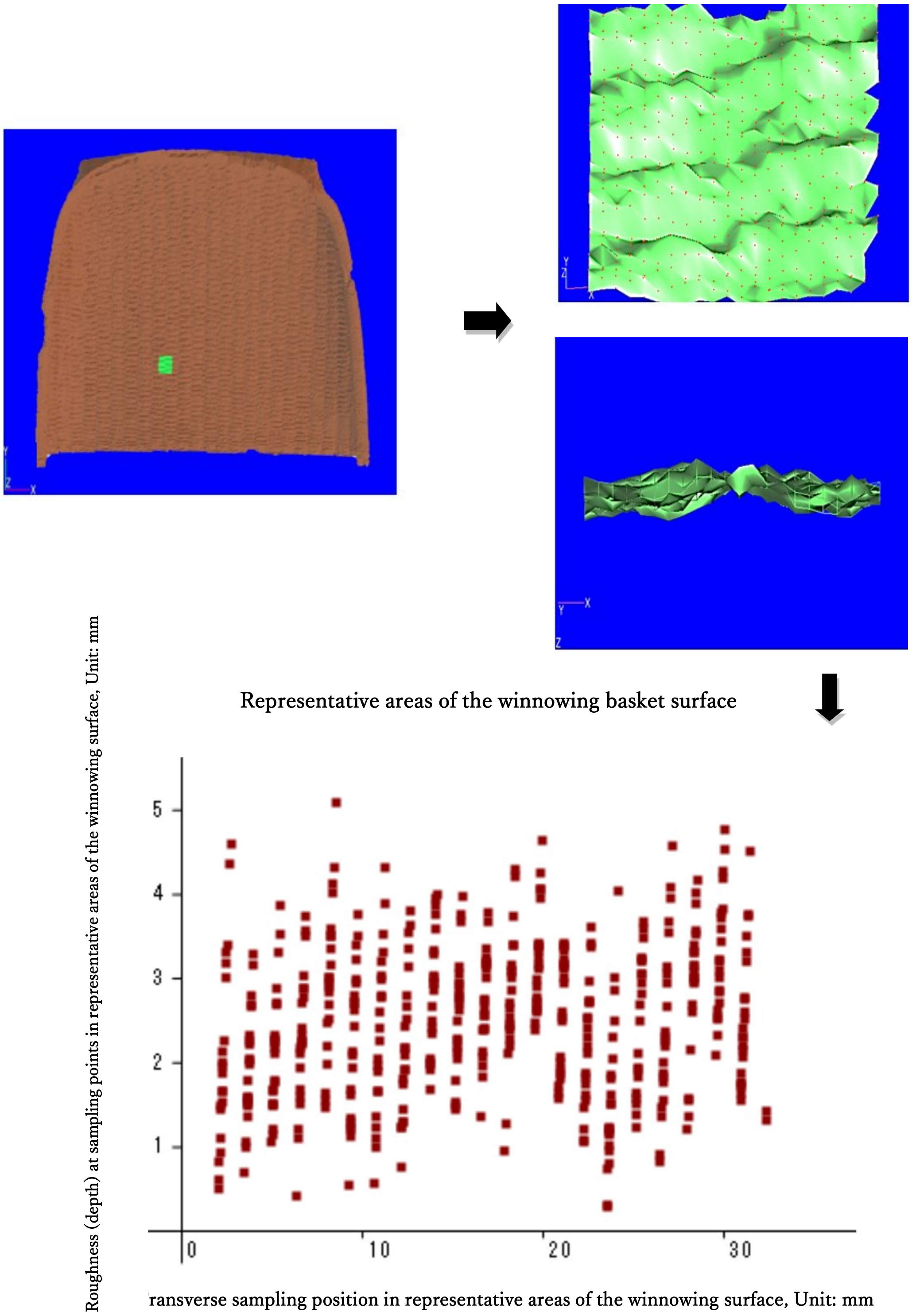


Fig. 70 Measurement of the unevenness of representative areas of surface

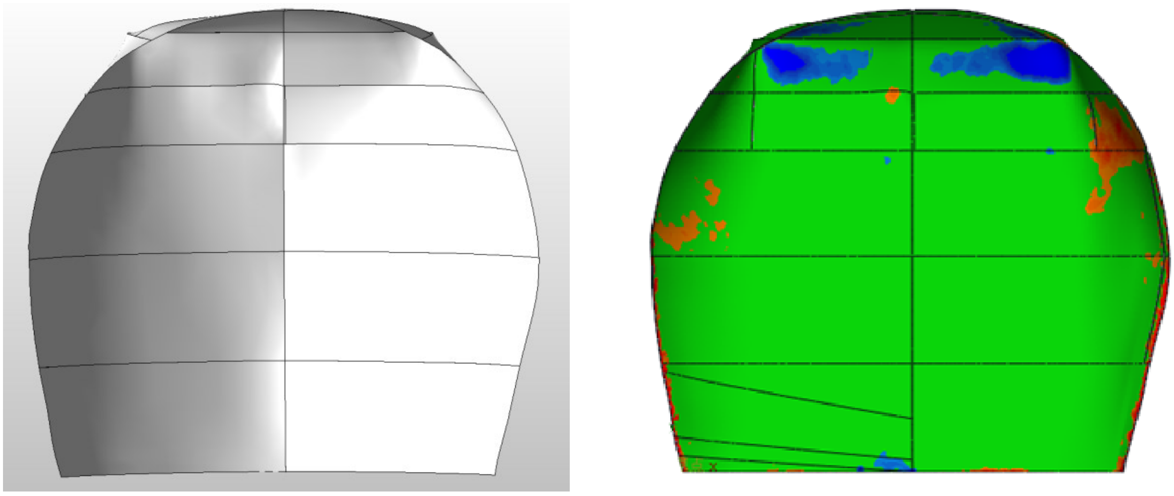


Fig 71 Nara *Ajiro* Winnowing basket (tolerance range: ±2.60, agreement rate :83.91%)

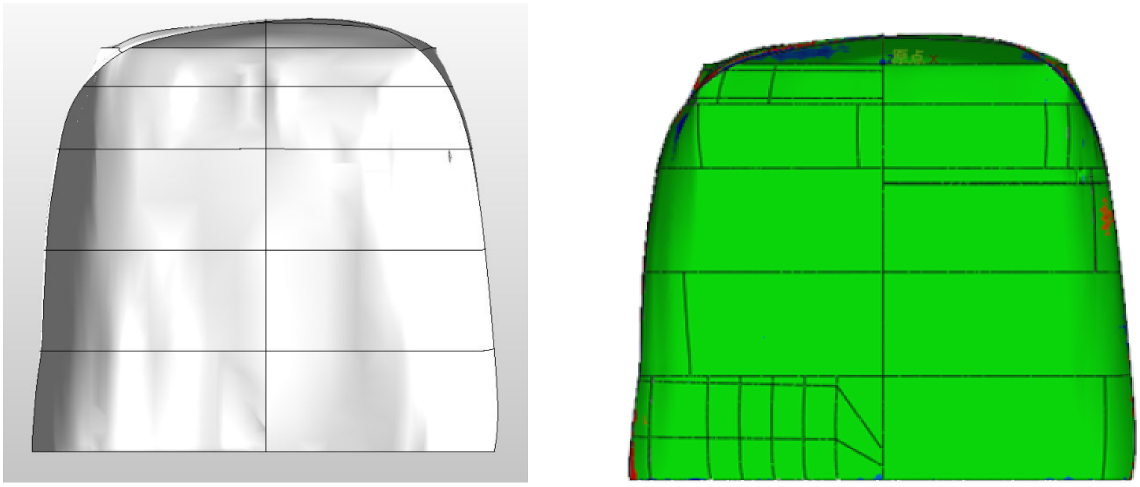


Fig 72 Echigo Winnowing basket (tolerance range: ±2.85, agreement rate :83.91%)

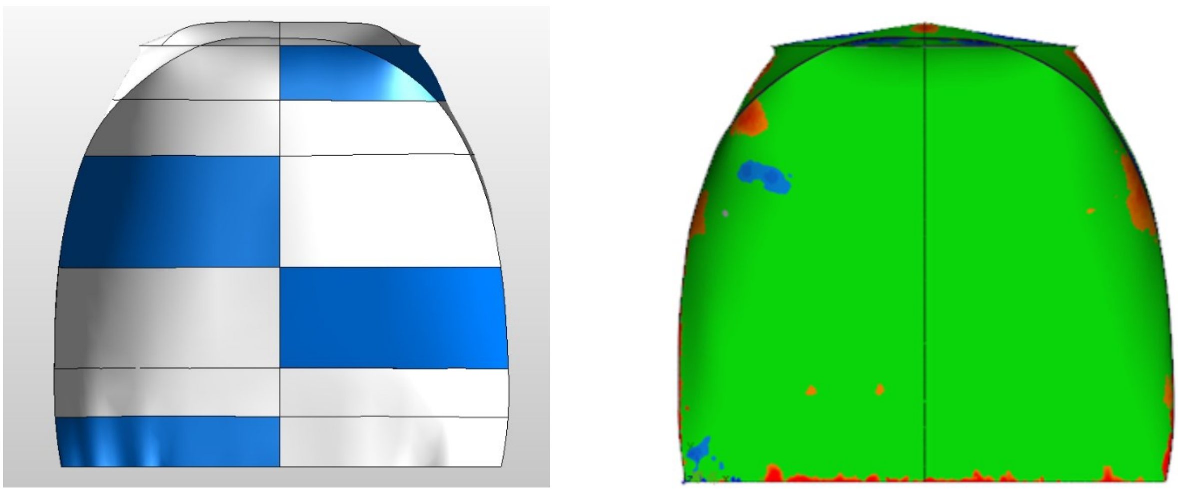


Fig 73 Tokushima *Ajiro* Winnowing basket (tolerance range: ±2.51, agreement rate :84.00%)

3.3.10 The relationship between materials and production methods

The Nara Ajiro winnowing basket is made using the *Amiage* forming method and the Tokushima *Ajiro* winnowing basket is made using the Nui- awase forming method. Both are made from the same material (giant bamboo), but there are two different textures about them (the *Ajiro* form is oriented different: the Nara *Ajiro* winnowing basket is with an oblique ajiro form and the Tokushima *Ajiro* winnowing basket is a with positive Ajiro form), because bamboo wood is a typically anisotropic material[56], the elasticity and hardness of the material surface differs between the two types of *Ajiro* forms (the force used to bend the material by hand is also different).

It is also indirectly reflected in the difficulty of reproducing two 3D forms of winnowing baskets; the Nara *Ajiro* winnowing basket as a whole is reproduced in a more rounded form, with a smaller selection of feature curves and be selected at locations where the morphology is more evenly spaced(Fig. 74-Left) while the Tokushima winnowing basket requires more feature curves for the reproduction of the 3D forms, and the rear of the winnowing basket has a more dramatic change in form(Fig.74-Right). It also corresponds to forming method and the behaviour of the production.

Fig 74. *Ajiro* form orientation of Nara *Ajiro* winnowing basket (Left) and Tokushima *Ajiro* winnowing basket (Right)

[56] Anisotropic materials： Materials with different mechanical properties (e.g. strength and Young's modulus) in each direction are referred to as anisotropic materials. http://kentiku-kouzou.jp/yugenyoso-touhouihou.html, (異方性材料)

The Echigo winnowing basket, has a softer surface and is more suitable for Nui-awase forming(Fig.75) due to the use of the Fuji skin and bamboo material, and the 3D reproduction requires more feature curves. The above-mentioned forming methods imply two different production behaviours(methods and forces for bending materials by hand) by the craftsmen when producing the winnowing basket.

Fig.75 Nui-awase forming method (Left) and Amiage forming method(Right)

(from the official website of Tokyo Institute for Cultural Properties)

3.3.11 The investigation of the relationship between the feature curves and the handcrafting of the winnowing basket

The 3D reproduction of the form of the winnowing basket in this part is inspired by the elastic characteristics of the material of the winnowing basket. The change in the overall form of the winnowing basket is reflected (Fig.76[57]) by the change in the elastic form of the horizontal material during the manufacturing process. Using the feature curves of representative areas of morphological change (where the curvature changes are relatively large), the NURBs surface model is automatically calculated to reproduce the overall form of the winnowing basket.

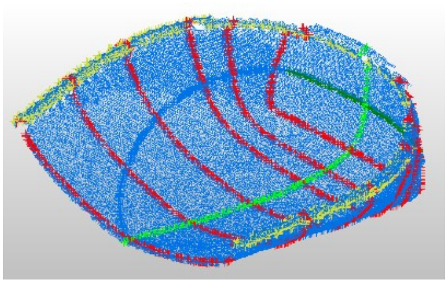
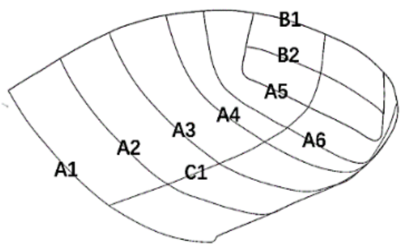
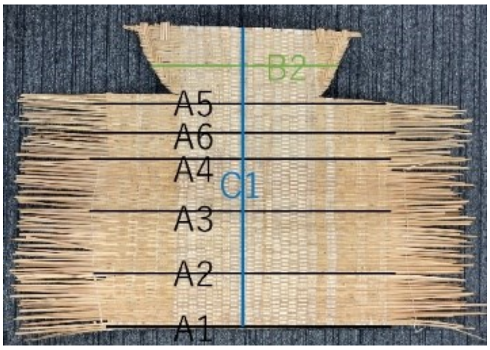
The following table illustrates the relationship between using feature curves

[57]M, Kubo., A, Ueda., [箕に見る自然な曲面のつくり方],
https://jglobal.jst.go.jp/detail?JGLOBAL_ID=201802213950060596

in 3D model reproduction and handmade winnowing basket work (Nara *Ajiro* winnowing basket for a example in Table 6.

Fig.76 The horizontal material of the handmade model of the winnowing basket

Table 6. The relationship between using the feature curves in 3D model reproduction and handmade winnowing basket work (e.g.Nara *Ajiro* winnowing basket)

<table>
<tr><td></td><td>Feature curves used for 3D model reproduction


</td><td>Corresponding hand-crafted meanings and stages

</td></tr>
</table>

Group A curves (A1,A2, A3,A4, A5,A6)	The basic feature lines of NURBs curve modelling (each curve corresponds to an equation) determine the morphology of the winnowing basket's NURBs surface. A6 is an additional feature curve without which the reproduction rate of the winnowing basket would be reduced.	This group curves reflects the change in form of the horizontal material of the 3D winnowing basket form and the extent to various parts of the winnowing basket has been bent after it has been *Shitate* formed(hand-made work). The A6 curve represents the part of winnowing basket depth where is not easily observed from the original form（Hige right cross ヒゲ通し,Fig. 77,78）.
Group B curves (B1,B2)	B1 is the edge line for NURBs curve modelling which determines the overall size and overall form of the winnowing basket. B2 is an additional curve, without which the reproduction rate of the *Akudo* part would be lower.	The B1 curve represents the *Udeki* part of the winnowing basket. The bending of the *Udeki* is also a difficult and important part of the handmade process, as it requires a lot of manual effort and determines the final form and quality of the winnowing basket (Udeki making: 腕木作り,Fig.79 Udeki inset: 腕木嵌める,Fig.80). The B2 curve represents the part where the Mimi of the winnowing basket has overlapping stitches during the *Nui-awase* forming(Fig.81) and therefore the thickness of this part varies unevenly（Shitate: 仕立て Fig. 82）.

<table>
<tr><td>Group C curves (C1)</td><td>The C1 curve represents the direction in NURBs curve modelling, while the extent to which it bends is influenced by the extent to which B1 curve bends.</td><td>The C1 curve, which also represents the direction of the hand weave, determines the curvature of the base of the winnowing basket's three-dimensional form after Shitate formed（The direction of the weave or the centre line of the form）.</td></tr>
<tr><td colspan="3">Because of the heterogeneous variation in the morphology of the winnowing basket, the parts of the feature curve selected for in NURBs modelling are often the most complex parts of its morphology (the parts where the morphology changes dramatically), which reflects the process of manual work that requires a lot of effort to resist the inherent elasticity of the material（bend resistance）.</td></tr>
</table>

Fig. 77 *Hige* right cross（ヒゲ通し 1, 徳島アジロ箕）

Fig. 78 *Hige* right cross（ヒゲ通し 2、木積箕）

Fig.79 *Udeki* making (腕木を曲げる、木積箕)

Fig.80 *Udeki* making (腕木を嵌める、木積箕)

Fig. 81 *Nui-awase* (徳島アジロ箕)

Fig. 82 *Shitate* (奈良アジロ箕)

3.4 Short Summary

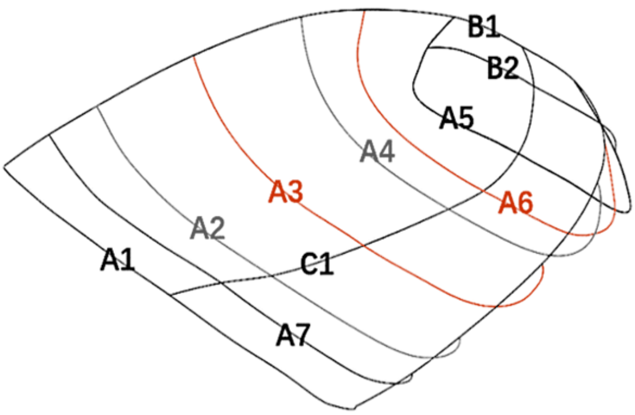


Fig. 83. Extracted feature curves (Tokushima *Ajiro* Winnowing basket).

This study mathematically extracts the characteristics of the natural curved surface form of handmade winnowing baskets and uses the elastic properties of the material to reproduce a simplified 3D model of the winnowing baskets, explaining to some extent the elastic properties of the winnowing basket and giving a new perspective on thinking about the reproduction of the 3D form (the morphological features and function).

The 22 *Kataguchi* winnowing baskets in the collection of the National Research Institute for Cultural Properties, Tokyo, were modelled in 3D, and six items representing the characteristics were measured: length of the *Misaki,* vertical length, depth, height of the *Akudo* part, length of the *Akudo* part and opening angle, and the winnowing basket forms were classified according to principal component analysis. As a result, it was found that the main components of the extracted winnowing baskets form were the winnowing method (*Amiage*, *Nui-awase*) and winnowing depth, and that these two factors could explain 88.3% of the characteristics of the winnowing basket forms. As the influence relationship between the feature curves governing the overall form of the winnowing basket and the partial forms of *Akudo* and *Misaki*, three winnowing basket were reproduced: Echigo winnowing basket, Nara *Ajiro* winnowing basket and Tokushima *Ajiro* winnowing basket, which represent the "*Nui-awase* Gozame", "*Amiage Ajiro*" and "*Nui-awase Ajiro*" of forming styles, have been identified. The influence of each feature curve on the reproduction of the simplified model was examined from the change trend of the agreement rate between the CAD model and the actual winnowing baskets.

A total of nine feature curves were extracted to reproduce the simplified form of the winnowing basket. Feature curve B1, which directly reflects the form of the *Udeki*, and feature curve C1, which reflects the symmetrical form of a single sided winnowing basket and degree of surface curvature, were extracted, while the other seven A-series feature curves were extracted along the horizontal direction (Fig. 83). Since the aim of this study was to effectively reproduce the 3D model, the feature curves of the A series were extracted separately from the surface reproduction process (model construction) to construct the model and the change trends in agreement with the actual winnowing baskets were compared and investigated.

As a result, it was found that feature curve A3 shown in Fig 86. had the greatest influence on the reproduced form. It was also found that feature curve A6, which passes through the deepest position, has a significant influence on the form near the Akudo. The influence of feature curves A2 and A4 on the winnowing basket morphology was relatively small, and it was understood that the changes in the surface affected by these two feature curves were smooth, confirming that one of the representative features of the winnowing basket morphology was reproduced.

The study presents a simplified and effective 3D form of the winnowing basket form that enables a parametric mathematical analysis of the physical functions of winnowing basket, such as 'winnowing' for sorting grains and tea leaves, through the extraction of feature curves, and the influence of its morphological and material characteristics. Using 3D technology, the process of reproducing the winnowing basket, enables a better explain some of the key points and difficulties in the crafting process that are difficult to be spot and be understood.

And it would better illustrate some relationship between human hand and natural materials in manual production.

4. Visualization and Quantification of Body (Hand) movement during the Use and Production of Winnowing Basket by a simplified movement model with artificial intelligence (Mechanical Learning)

4.1 Background

The production technique of Kizumi winnowing basket in Chiba Prefecture, Japan is rated as a national intangible cultural heritage of the country[58]. With a delicate production process, the winnowing basket are exquisite and of high artistic value and practical value. Most producers and users of winnowing basket are elderly craftsmen who, however, are skilled in using and producing winnowing basket.

To protect the inheritance of traditional culture, some operations and tricks failing to be explained by craftsmen easily in words or observe during the use and production of winnowing baskets, existing Deep Neural Networks, Body Recognition Technologies have been applied to visualize the craftsman's movements recorded by using videos, especially the wrist action as a numerical model.

In this section, it has been tried to validate that the human movement recognition technique, such as OpenPose could reduce the learning time and increase the enjoyment of the beginners who would make the winnowing basket, and the 3d-pose-baseline algorithm combined with mathematical simulation could numerically observe the nature of certain body movements of craftsmen with vibrational models of relevant physical quantities.

4.1.1 About AI app OpenPose(Fig.84)

OpenPose[59] is software developed at the Centre for Technology Transfer and Enterprise Creation (CTTEC) at Carnegie Mellon University. OpenPose is a realtime, multi-person key point detection and realtime system that can detect a total of 130 key points, including human bodies, hands and faces, from an

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[58] The technique of producing Kizumi winnowing basket, Important Intangible Folk Cultural Asset, 11 March 2009, Sosa City, Kisaku, Chiba, Japan (Kisaku winnowing basket preservation committee)

[59] Z Cao, G Hidalgo, T Simon, S-E Wei, Y Sheikh, OpenPose: Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields, *Computer Science_Computer Vision and Pattern Recognition*, 2018-2019

image using OpenCV and Caffebased C ++ libraries that can be multithreaded. The line time is constant regardless of the number of people in the image. It is a flexible, easy to configure., multithreaded module that saves and loads in a variety of formats, including JSON, XML, PNG and JPG. It also uses Caffe, but the code can be ported to other frameworks such as Tensorflow and Torch.

Fig. 84 2D skeletal parsing of human and humanoid forms using OpenPose.

Detecting all the key points and then composing different people is one of the more popular algorithms for human pose evaluation today. The success reason of OpenPose is that it has open sourced its implementation code on GitHub[60], with detailed documentation. As with many bottom up approaches, OpenPose first detects the joints (key points) of everyone in the image, and then assigns the detected key points to each corresponding person. The diagram below illustrates the architecture of the OpenPose model.

OpenPose algorithm (Fig.85).

1. input an image, after VGG19 convolutional network to extract features, to get a set of feature maps, then divided into two forks Branch1&2, using CNN

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[60] GitHub, a free website for programing and code, https://github.com/CMUPerceptualComputingLab/openpose,

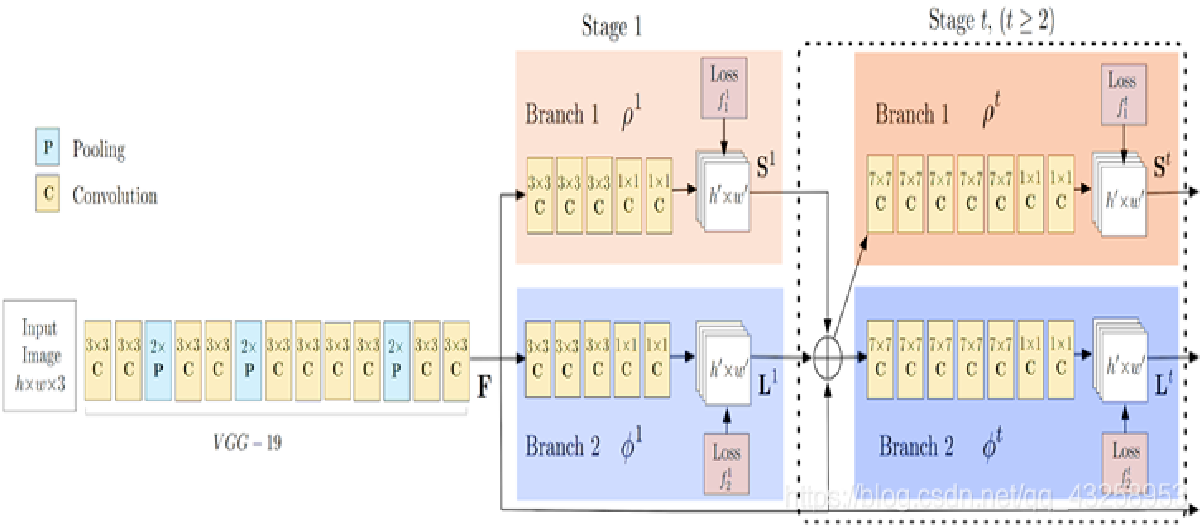

Fig. 85 Algorithm for OpenPose (from the paper by Z Cao.)

network to extract Part Confidence Maps (confidence degree) and Part Affinity Fields (association degree), respectively.

2. after obtaining these two pieces of information, we use Bipartite Matching in graph theory to find Part Association, which connects the joints of the same person. due to the vectorial nature of PAFs themselves, the resulting even matches are correct and eventually merge into the overall skeleton of a person.

3. finally find Multi-Person Parsing based on PAFs > convert the Multi-person parsing problem into a graphs problem > Hungarian Algorithm (Hungarian Algorithm is the most common algorithm for part graph matching) . The core of the algorithm is to find augmented paths, which is an algorithm that uses augmented paths to find the maximum match for a bipartite graph).

Heatmap and vectormap of key points for Openpose(Fig.86,87)

For example, a total of 19 key points, will generate 19 channels of heat map, each channel for a certain joint of the heat map distribution (that is, probability map). A vectmap of 192 channels will also be generated, why 192? Because the vector map is divided into two directions, one for the X direction and one for the Y direction.

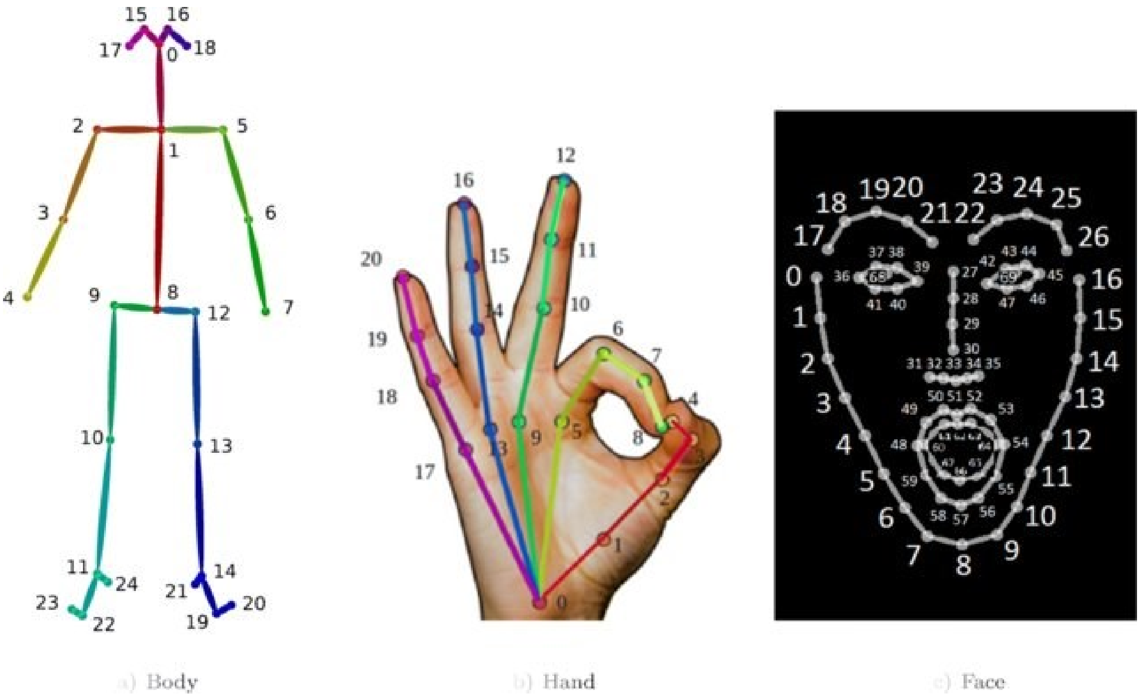

Fig. 86 The key points for Openpose

The heatmap generates a heatmap of key points, with all values of 0 for key points not in the map and not labelled. 19 heatmaps are generated, the last of which represents the background.

Vectormap vector forking: vectormap is twice as many as heatmap at 38 (19*2), as there are 19 key points connecting the lines, each line is represented as a vector with a map of the x-axis, and a map of the y-axis, respectively.

4.1.2 About 3D human skeleton recognition technology 3d-pose-baseline[61](Fig. 88)

3d-pose-baseline is a library implemented in the paper "A simple yet effective baseline for 3D human pose estimation" presented at ICCV2017 by Julieta Martinez et al. The 3d-pose-baseline uses the 3D pose data from the dataset "Human3.6M" as the teacher data, and learns and estimates the pose using a

[61] J Martinez, R Hossain, J Romero, J J. Little, A simple yet effective baseline for 3d human pose estimation, *Computer Science > Computer Vision and Pattern Recognition*, 2017

Fig. 87 Heatmap and vectmap of key points for Openpose

neural network. The model can be realised with a lightweight model. In the 3d-pose-baseline pose estimation method, the number of joint

using a neural network. The model can be realised with a lightweight model. In t he 3d − pose − baseline pose estimation method , the number of joint points is N, the input 2D joint coordinate points are $\boldsymbol{xi} \in \boldsymbol{R2n}$, the output 3D joint coordinate points as $\boldsymbol{yi} \in \boldsymbol{R3n}$ and the function $\boldsymbol{f*}$: to minimise the error function shown in equation below $\boldsymbol{R2n} \rightarrow \boldsymbol{R3n}$.

$$f* = min\, f \, \frac{i}{N} \sum_{i=1}^{N} L(f(Xi) - Yi)$$

The function f is approximated by a neural network as shown in Fig. below. Sixteen 2D joint coordinate points are input to the neural net and sixteen 3D joint coordinate points are output.

According to the experimental results of the above paper, using the 3d-pose-baseline algorithm, the inference of 3D key points from the 2D key points of OpenPose depends mainly on the 2D resolution accuracy of OpenPose rather than the 3D inference accuracy.

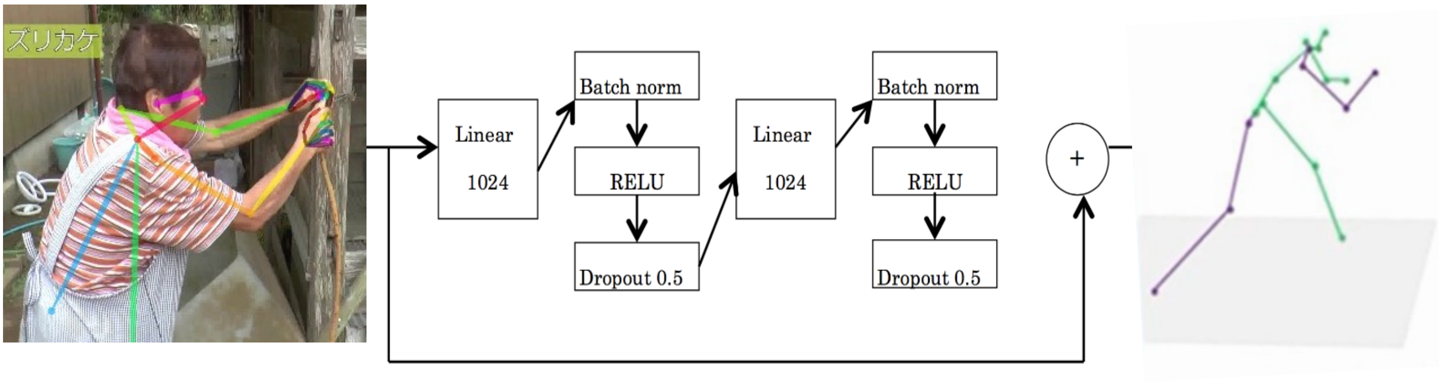

Fig. 88 Algorithm for converting 2D pose to 3D skeletons

4.1.3 Purpose and Method

The first two chapters of this paper are devoted to an indirect study of the relationship with the human hand through the simplification of historical forms, and this part is a direct study of the movements of the hand(wrist) of craftsman in the production and use of historical artefacts-winnowing baskets through artificial intelligence.

Using AI to simplify or transform body movement models, and to perform quantitative and qualitative analysis, the limitations of human vision are extended to some extent. The aim is to demonstrate the possibilities of AI technology in the field of traditional craft transmission, for example to improve the efficiency and enjoyment of learning and to complement some difficulties and details of use and production processes which cannot be verbalized or ignored by some craftsmen when teaching a craft to beginners. This paper also attempts to use AI to explain the nature of certain engineering aspects of human movement, such as the physical quantities associated with vibration, from the perspective of mathematical simulation and physics.

This part of the study helps to explain some interdependence and coordination relationship between human hands and historical artefact forms, and helps the transmission of certain traditional crafts (use and production of winnowing basket).

4.2 Recognition and application of human skeletal movements in the production and use of winnowing basket

4.2.1. Visualization of Hand skeletal movement during the Production of Winnowing Basket

Backgroud

Body movement habits or subtle movements are the hardest to be perceived during the process of inheritance of a traditional technique because these kinds of body movements cannot be clearly expressed in words and vary from person to person. It is also true, however, that there are some common or similar body movement details when the same movement is completed. In this paper, Application OpenPose is used to analyze the existing video data, visualize the hand movements and wrist trajectory when making the winnowing basket (Kizumi) with the tool (*Kitachi*) in hand, and make some importance of the production process easier to observe and understand, so as to facilitate the learning by the successors to the technique. In this way, they can master the technique in less time and find the production process more interesting, and perhaps make it possible spread more widely.

Existing Inheritance Methods

The production technique of Kizumi winnowing basket in Chiba Prefecture was listed as Japan's national intangible cultural heritage in 2009. Now, such a technique is still passed down from the older generation. But fortunately, the

Tokyo National Research Institute for Cultural Properties made video and handbooks of handicraftsmen's production process of winnowing basket, allowing the successors to have a comprehensive understanding of the technique.

Field Visits

The wisteria winnowing basket in Kizumi, Sosa-shi, Chiba Prefecture are taken as an example. A Kizumi Winnow Making Preservation Association was established in Kizumi, Sosa, Chiba Prefecture, offering the winnowing basket making course in the Inheritance Classroom once a month and teaching learners all over the years. From July to November 2018, we participated in the course in the Inheritance Classroom several times, shot the video on the craftsman's production of winnowing basket, and experienced the production and use of the winnowing basket. A great many key points and problems during the process of inheriting the existing winnowing basket making technique were found in the field visits.

(1) From the collection and processing of materials to the forming of winnowing basket, they are all done manually. The flexible use of hands and implements is the key to making Kizumi winnowing basket.

(2) The Inheritance Classroom is small and has a poor production environment, so it is not suitable for a large camera to work there. Furthermore, most handicraftsmen are elderly people who resistant body setting devices, such as motion capture equipment.

(3) The talent skilled in the production technique of Kizumi winnowing basket is rare in Japan. Most handicraftsmen are elderly people, and there are few opportunities to inherit the protection technique. For this reason, such a technique desperately needs successors.

(4) It is difficult to teach the production process of winnowing basket only in words and by demonstration because there are many details of production actions, which are the bodily sensations and work habits of the handicraftsmen.

(5) It is very difficult for a beginner to master the production technique of

Kizumi winnowing basket for the complexity and uniqueness of the production process, especially the process of separating and weaving the two layers of the winnowing basket (Naka weaving) with implements, which become the key and difficult points in learning this technique.

Preparation of Experiments Based on the Results of Field Visits

Based on the conclusions of the above visits, the existing video of the Tokyo National Research Institute for Cultural Properties are analyzed to study the movement trajectory and bodily sensations of the handicraftsmen when making winnowing basket. However, the video materials are still insufficient, so small cameras are used for photography in the Inheritance Classroom in this research. The arrangement of photographic site is as follow Figs (89, 90):

Fig. 89 A site visit to the Kizumi Winnowing basket Heritage Classroom

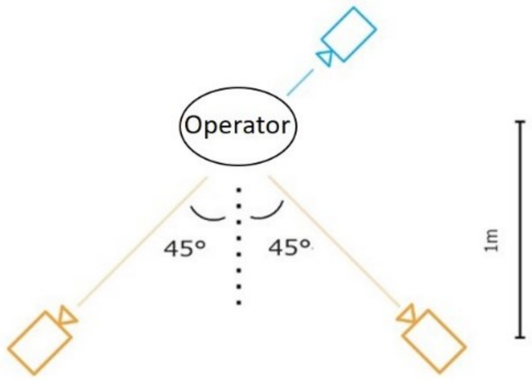

Fig. 90 Equipment configuration for on-site photography

Obtainment of Research Objects and Attempts of Multiple Methods

A case of the difficulties in the process of winnowing basket making is selected for key analysis. During the process of winnowing basket weaving, *Kitachi* is used to separate the two layers of materials of the winnowing basket. According to the suggestions of the handicraftsmen, hand movement, especially wrist movement in this process, is very critical (Fig. 93) and is a key and difficult point in the process of winnowing basket making.

It is difficult to clearly observe the movement of wrists and fingers only through the video from the Tokyo National Research Institute for Cultural Properties. Therefore, it is necessary to use such means as video taken on the site and AI for analysis. Before that, we tried several other analytical methods.

(1) Motion Capture: In addition to the relatively high cost, it takes plenty of time to set and commission the Motion Capture [62](Fig. 89), and a large space is required. The main reason is that a maker has to be set around the wrist of the handicraftsmen to map winnowing basket weaving.

(2) Although 2D animation of the human body can be converted by such APPs as Dense Pose[63] and RADiCAL[64] Motion AI into 3D animation through video data, generating merely 3D motion of the human body surface mapping. However, the motion analysis without key points of the human skeleton and low accuracy (which may be related to the deep learning data used) are not conducive to observation.

(3) OpenPose is finally selected to make up for the shortcomings of the above AI human body recognition APPs. Despite its mere 2D analysis of hands, OpenPose has the most comprehensive deep learning database (being continuously updated), and the data is extracted by using the Convolutional Neural Networks. In addition, the most popular Hungarian Algorithm, combined with the heatmap and vectmap (vector map) of the video, is used, and the precision is high. In this way, the relatively difficult body actions of winnowing basket weaving, especially the hand movements, can be analyzed.

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[62] Motion capture, from Wikipedia, The technology of digitally records the movements of real people and objects. https://ja.wikipedia.org/wiki/motion capture.

[63] Dense Pose, Dense Human Pose Estimation In The Wild, http://densepose.org.

[64] RADiCAL, AI-powered 3D animation, https://getrad.co.

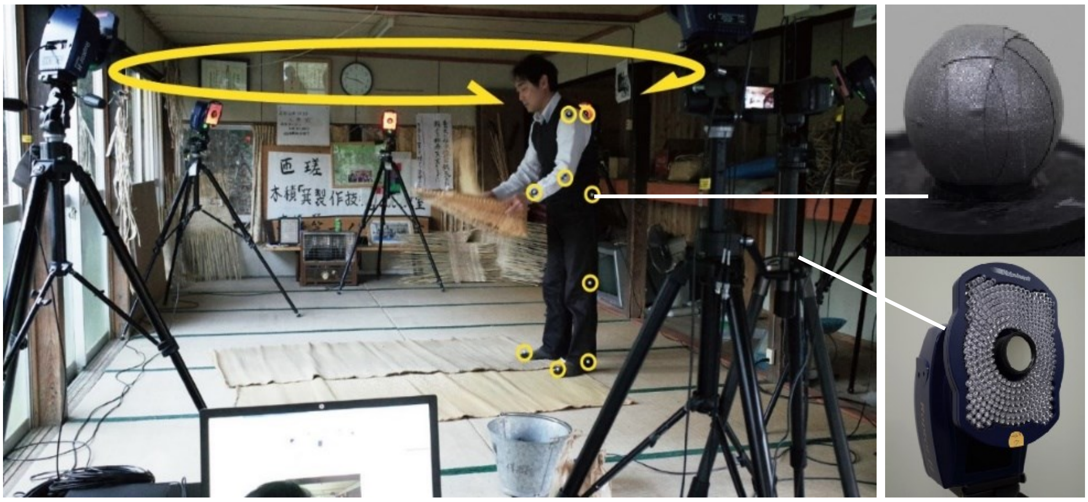

Fig. 91 Captured on location using motion capture in Heritage Classroom

Analytical Environment and Precision Description of OpenPose

There are many versions of OpenPose, with different debugging methods, configuration environments and analytical precision, and the official website and relevant papers can be referred to for details. After repeated verifications, the configuration environment used in this paper is described below to reflect the hand movements in a better manner, simplify the hand movement of the handicraftsmen, and facilitate the observation.

(1) Openpose master

(2) Openpose 1.3.0 win64 gpu binaries

(3) 3d-pose-baseline

(4) Visual studio 2015 professional[65]

(5) Windows 10 professional

The detection sensitivity of OpenPose is inversely proportional to the detection speed. In this paper, the detection sensitivity value is set to be 0.03 (recommended by the official website), and the detection result can be obtained through the confidence files (results of coordinate comparison between actual

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[65] Visual studio 2015 professional, Programming software in C++ , https://learn.microsoft.com/ja-jp/visualstudio/releases/2015/vs2015-sysrequirements-vs

key points and deep learning data) of JSON file[66] (key point coordinates) generated by application. According to credibility report automatically generated based on OpenPose, in this experiment, the confidence level of most analytical results can hit more than 80%.

Analytical Process and Analysis of Results

First, editing the video clips on the use of *Kitachi* in Naka weaving. Then, use OpenPose (with setting and debugging done) to identify all joints of the whole body except for the face to obtain a complete video of the whole body motion trajectory. After that, we use the app's heatmap to identify the wrists separately (Fig. 93), locate the key points, track them, find their motion trajectories (white lines), and make an analytical video. A complete analytical video includes:

(1) the motion trajectory of the wrist;

(2) the motion trajectory of the body frame and fingers;

(3) the motion trajectory of the implement end (Fig. 93).

Through watching the analytical video and the opinions of the handicraftsmen, we can draw the following conclusions:

(1) During Naka weaving process, the weaving materials of winnowing basket are used as a fixed plane, and a handicraftsman sits in the middle of the plane for operation.

(2) *Kitachi* is an important tool in the production of the winnowing basket with a special three-sided structure (Fig. 92). Slight rotation or tilt may change the function of *Kitachi*, which, however, will not do damage to the materials of winnowing baskets and operators' hands. For this reason, such an implement can be used for the separation of two layers of the materials of winnowing baskets and the fixation of one layer of materials. *Kitachi*, a function extension of hands and can be considered as one with the hands, so the trajectory of the

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[66] JSON: JSON stands for JavaScript Object Notation, JSON is one of the object notations defined in JavaScript and is expressed in text format, allowing easy data exchange. It is therefore used by all major programming languages, not just JavaScript. *And Engineer*

craftsman's wrist can to some extent reflect the trajectory of the *Kitachi*.

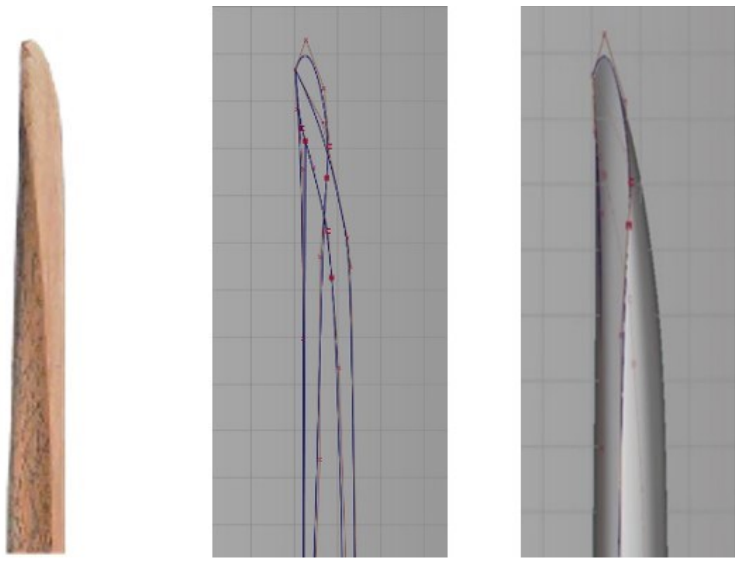

Fig. 92 The form of Tool *Kitachi* tip

(3) In the process of Naka weaving, the left hand plays the role of fixing materials, and the shape of the fingers of the left and right hands is basically unchanged.

(4) During the weaving process, *Kitachi* is obliquely inserted into the middle of the two layers of materials. The tip structure of *Kitachi* is important (Fig. 92,93). It can effectively fix the materials tightly without scratching the hands.

Fig. 93 Skeletal analysis of the body and wrist of craftsman by OpenPose

The Actual Experiment of Allowing Beginners Between Watching Original Video and Watching Teaching Video (Fig.94: Investigation data from Furukawa Yuka's paper, common research)

Subject: 14 design studies students (5 males and 9 females, Average age 25 years old) who were beginners in winnowing basket production, were randomly divided into two groups (7 for each): Group A (3 males and 4 females) and Group B (2 males and 4 females).

Experimental materials and tools: wisteria bark, bamboo strips, *Kitachi* (the special tool in Naka weaving), water (keep hands and materials wet during production), cameras for taking video, computers for teaching, sheet etc..

Experimental procedure: Group A only watches the original video taken, and Group B watches the teaching video of the wrist motion trajectory to use *Kitachi* in Naka weaving of winnowing basket, which is an important part of Winnowing Basket production process. They were asked to stack three sheets of wisteria bark between the bamboo strips. Only the analytical video featuring the wrist motion trajectory is used in this experiment to control the experimental variable.

Experimental method: The working processes of the subjects were taken the video from a distance of 1m diagonally in front of the camera. The body skeleton, especially the wrist motion trajectory was analyzed with OpenPose. Comparing and Evaluating the forms of the woven products completed by the two groups. An interview questionnaire on the production was administered after the experiment.

Experimental result: According to the results of the analysis video by OpenPose, the wrist movement of the subjects in Group B was smoother than the subjects in Group A. The group A subjects had a dotted or curved wrist trajectory and difficult to manipulate significantly in operation, while the group B subjects had a circular wrist trajectory and the large range of arm movements in operation. The subjects in Group A showed that spent a longer time on average than those in Group B in mastering this technique.

According to the completed product, the group A subject's woven products were rough and untidy, with untight connections between materials, However the Group B' s woven products were relatively neat, with a relatively straight arrangement of the concave and convex surfaces.

According to the results of the interview questionnaire, by watching the analytical video, most subjects in Group B found the weaving process interesting. Although only a part of the winnowing basket was made, they preferred to complete the whole winnowing basket and use the it they had made by themselves. Some subjects in Group A thought it is difficult to master the technique of Naka knitting with the *Kitachi*. because they need to be taken very seriously to understand the wrist movement. They had only observed the original video, and thought the operation time consuming and easy to abandon.

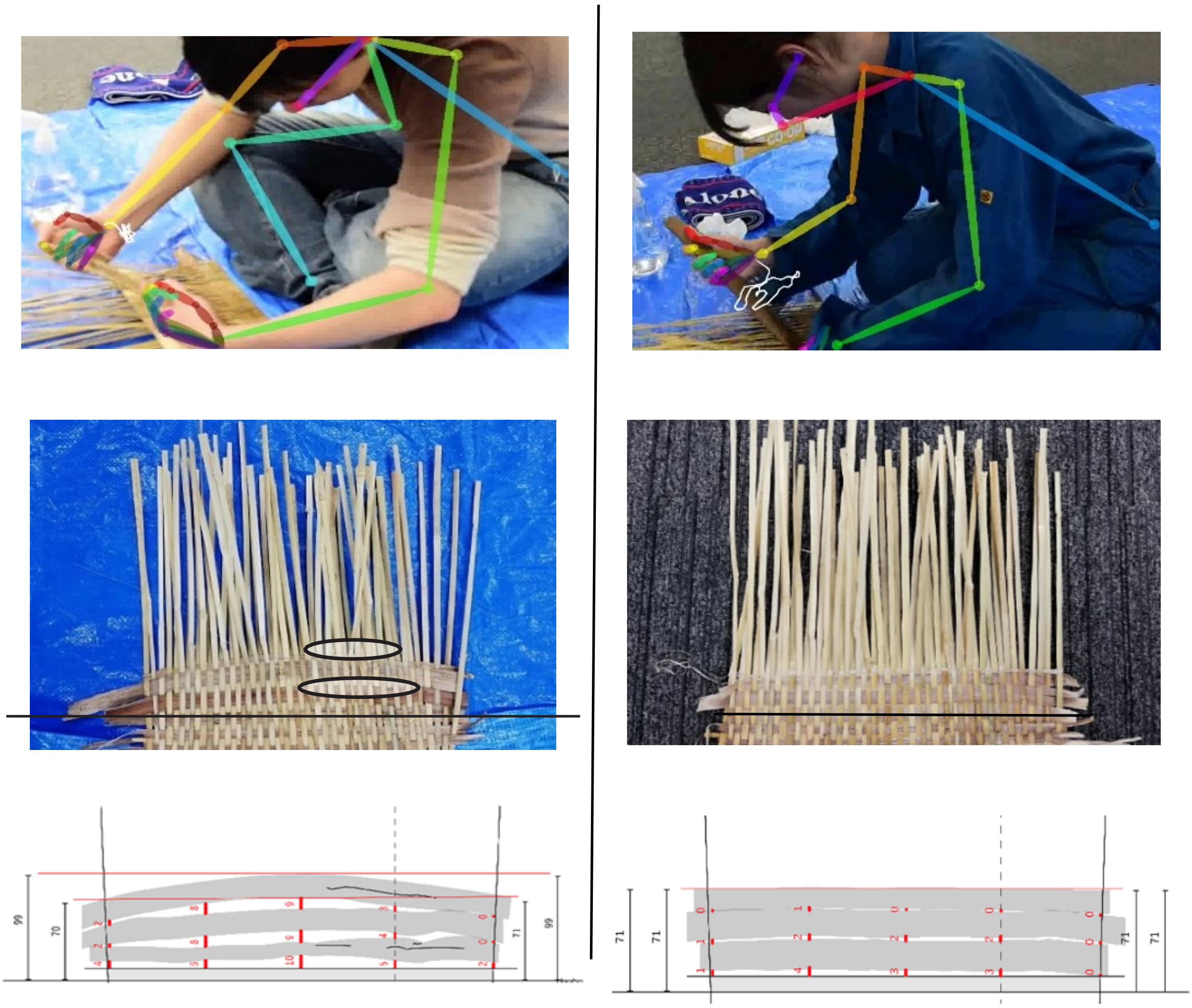

Fig. 94 Analysis of the hand skeleton of the students in group A, weaving the finished product and finished product form (Left: A group, Right: B group)

Short Summary of common research

According to the experimental results, the subjects who have watched the teaching video on analysis of wrist motions are more likely to get the skill of *Kitachi* in Naka weaving quickly than those who have watched the ordinary video, and the finished woven products are of better quality. By using OpenPose, we can analyze the motion trajectory of the subjects' wrists and body posture, and the difference of body movements between the two groups of beginners. This proves the possibility of the application of deep learning data app in the inheritance of the traditional handicraft Naka weaving in winnowing basket production, which can improve the efficiency and quality of making and to stimulate the interest of beginners.

4.2.2 Simplification of Hand skeletal movement during the Use of Winnowing Basket

Research Purpose

For the comparison of winnowing baskets making, it seems relatively simple to use a winnowing basket, but its main function selection by winnowing (vibratory screening of grains) can be used in many ways, some of which are easy but some are difficult for observing and understand. For beginners, however, they may not grasp them easily even by observing the original videos and practicing. This part provides handicraftsmen's two methods of use of Kizumi winnowing baskets, which are called Type A vibration and Type S vibration in this paper. A quantitative analysis is made on the process of the winnowing, and the datasets from Human3.6 and Human skeleton recognition technology are used to presume the two dimensional motion of the operators in the original video to be three dimensional motion. The three dimensional motion trajectory model and coordinates of human motion are extracted and simplified. Quantitative analysis and comparison of the differences between the two vibration models make observers more intuitive and accurately grasp the body movement rule when a winnowing basket is used, and understand the important operation details which fail to be explained in words or unable to be observed in the original video.

Research Methods and Principles

First, it is still necessary to use OpenPose to analyze the video (Fig.95,99) on the processes of use of winnowing baskets with two methods recorded on the site, and extract dynamic bones and the JSON files containing two dimensional trajectory coordinates. After that, sort out the coordinates in the JSON files and delete the coordinates with low reliability through the generated reliability report and by observing the analysed videos. 3d-pose-baseline (an algorithm) is used in the process. With TensorFlow running, Human3.6M

Dataset are employed for AI extrapolation on the processed JSON files to calculate the three dimensional trajectory charts and coordinates. And descriptions are provided here on use of Human3.6m to extrapolate the three dimensional coordinates and the principle and algorithm of human motion trajectory:

(1) Human3.6M[67] is the world's largest dataset on the three dimensional motion of humans. It is comprehensive and the best data for the main bones of the body besides the 3D data of hands and faces. Through observation of analysed videos and comparison with popular human skeletal databases in the world. It is reasonable to use Human3.6M Dataset when the detailed 3D data of human body corresponding to the vibration of winnowing baskets are not obtained.

(2) The principle of 3D morphology extrapolation in this paper is to generate a number of 2D images from the Human3.6M Dataset and compare the 2D images with the 2D motion trajectory of OpenPose to find the most similar motion trajectories which will be then used to generate the 3D trajectory and coordinates of human body. As there is a threshold value for the degree of freedom of human joints which cannot be infinitely extended and bent (for example, elbows can only be bent inwards, but not outwards) and there is a certain proportional relationship between human joints, it is feasible in principle to generate data that can be used for tests through the training of artificial intelligence. And the paper of "A simple yet effective baseline for 3D human pose estimation"[57] confirms that the accuracy of the 3D human skeleton resolution depends on the accuracy of the results of the 2D-dimensional resolution using Openpose.

Results Obtained after Observation of the 3D Skeletal Motion Analysis Animation

The screenshots of GIF generating the extracted data for Type S vibration

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[67] Human 3.6M, a dataset by Catalin Lonescu, Dragos Papava, Vlad Olaru and Cristian Sminchisescu, http://vision.imar.ro/human3.6m/description.php

and Type A vibration of winnowing baskets are as follows:

(1) The 360° rotation of the 3D analytical animation on the use of winnowing baskets by handicraftsmen allows the use of winnowing baskets and the vibration trajectory of human body, especially the overall posture and balance of the body, to be observed more clearly.

(2) For Type A vibration model, upward and downward vibration with alternation of left and right hands could be observed obviously through the 3D analytical simplified skeleton animation. For Type S vibration model, the upward and downward vibration of both hands together could be observed. That is also one of the key differences between the two vibration models.

Table 7 Three-dimensional coordinates of the wrist for completing one complete up and down wind-selection vibration (3.3 seconds) when using winnowing basket by a craftsman.

Time	X	Y	Z
0.00s	502.2725	-77.2019	806.9324
0.33s	501.3541	-84.0467	840.1149
0.66s	500.1188	-95.7721	866.1406
0.99s	501.2683	-73.7126	872.1885
1.32s	492.0424	-65.2822	872.2656
1.65s	476.3840	-40.7621	862.1339
1.98s	483.0375	-20.8809	840.9021
2.31s	471.9212	-3.4402	783.2864
2.64s	449.6372	12.9418	757.7809
2.97s	458.2844	37.1131	748.9083
3.30s	467.4631	36.1716	733.5417
...	...	...	...

Extraction of Motion Coordinates of Handicraftsmen's Wrists

Coordinates (Table 7) are extracted from the 3D human skeleton motion animation generated by 3d-pose-baseline and Human3.6m, with an interval of 0.33s (system default), to study the main differences between the two vibration rules. For Type A vibration, since the left and right hands move up and down alternately, the motion trajectory is quite different, making it necessary to extract the 3D coordinates of the left and right wrists respectively. For Type S vibration, both hands move up and down simultaneously, and the motion trajectory is similar in the longitudinal plane where the direction of gravity is located, so only the 3D coordinates of one wrist (left hand) are extracted in this research. The extracted 3D coordinate point cloud of the wrist is drawn with the B spline curve in the MATLAB to generate a 3D motion trajectory animation for easy observation. After that, the difference between the wrist motion of the two types of vibration is figured out. In Type A vibration model, the animation of the left and right wrists is generated at the same time, and finally the complete 3D coordinate cloud map and static trajectory charts are drawn respectively. In Type B vibration model, the 3D coordinate point cloud and motion trajectory of the left wrist are drawn.

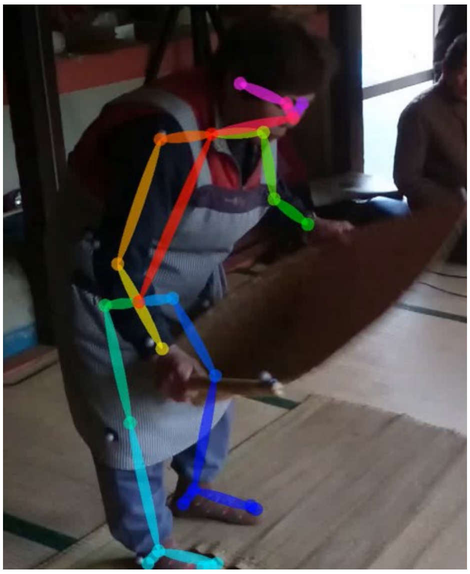
Extraction of Vibration Model (Fig.95-105)

Although the motion trajectory of the wrist of the handicraftsmen can be seen from the dynamic GIF image, it is Fig. 97 Subject A a complete static trajectory chart, and the trajectories of the up and down motion of the wrist are overlapped. In this context, it is not very easy to figure out the vibration rules of the two models. Accordingly, MATLAB is used to convert the 3D motion trajectory into a 2D waveform. The horizontal axis of the wave represents motion time, and the vertical axis symbolizes the amplitude (the projection of the wrist trajectory onto the gravity direction line, Y-axis) of the upper and lower motion of the wrist when the handicraftsmen use the winnowing baskets. Because no obvious periodic pattern can be observed in the waveform of the projection of the wrist trajectory on the direction line perpendicular to gravity (Fig. 103), which is not the focus of analysis in this paper.

(1) According to the waveform, we can see that the trajectory of handicraftsmen's wrists of Type A vibration is not a simple up and down reciprocating motion of the left and right hands. There is a small vibration between the peak and the trough during the up and down motion, which cannot be observed merely through the original video. This phenomenon is especially obvious in the trajectory (red) of the left wrist, which is called the small

vibration of the Type A vibration in this paper. It is speculated that the small vibration may be caused unconsciously by the handicraftsmen in completing the whole action, the large primary vibrations of one hand occurs at the same time or later, these small vibrations occur in the other hand, which may indicate small vibrations caused by major large vibrations. Nevertheless, it cannot be denied that it is a part of the complete vibration process.

(2) By observing the 3D trajectory and vibration waveform of wrist motion, we can see that for Type S vibration for screening, the time of both hands in the lower part (trough position) is a little longer than that in the upper part. According to the original animation video, during the Type S vibration, the bran of the grain is not removed at the time when both hands reach the peak and trough of the vibration wave, but at the time when approaching the trough of the vibration wave. On the waveform, it can be observed that there are also some small fluctuations in the middle of the large amplitude of both wrists, which are called the tiny vibrations of Type S vibration. Because this kind of tiny vibrations has the characteristics of small and many times, it is likely to be formed to buffer the downward inertia of the hands. This kind of tiny vibrations may have no practical significance, but its vibration time and vibration intensity undoubtedly affect the efficiency of the whole vibration. Since there is no clear language and written record of these vibrations, it may be the spontaneous and unconscious behavior of the handicraftsman’s body, the result of the joint action of the hands and the elastic material of the winnowing baskets.



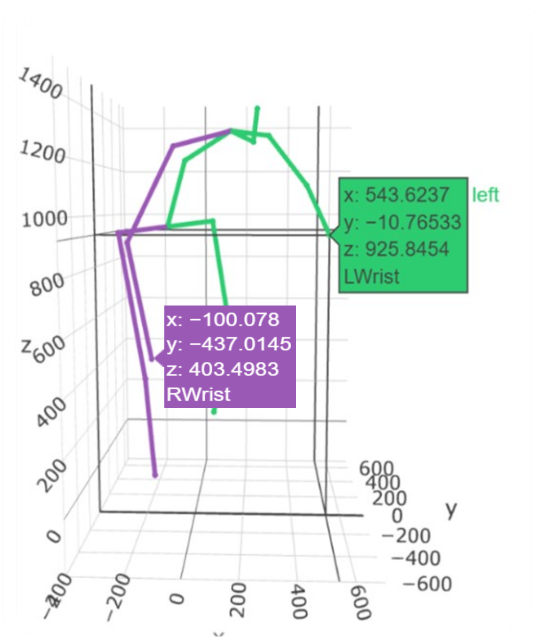
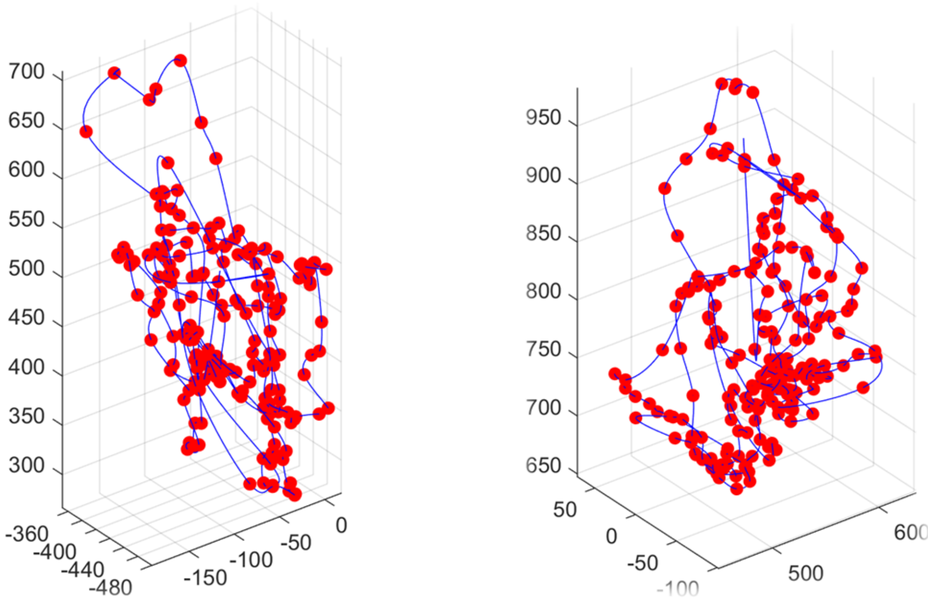


Fig. 95 Type A, 2-dimensional analysis of skeletal movements of the body during winnowing basket use by the craftsman

Fig. 96 Type A, 3-dimensional prediction of the body skeletal movement of the body during winnowing basket use by craftsman.



left wrist

right wrist

Fig.97 Type A, 3D trajectory of the wrist during using the dustpan by the craftsman

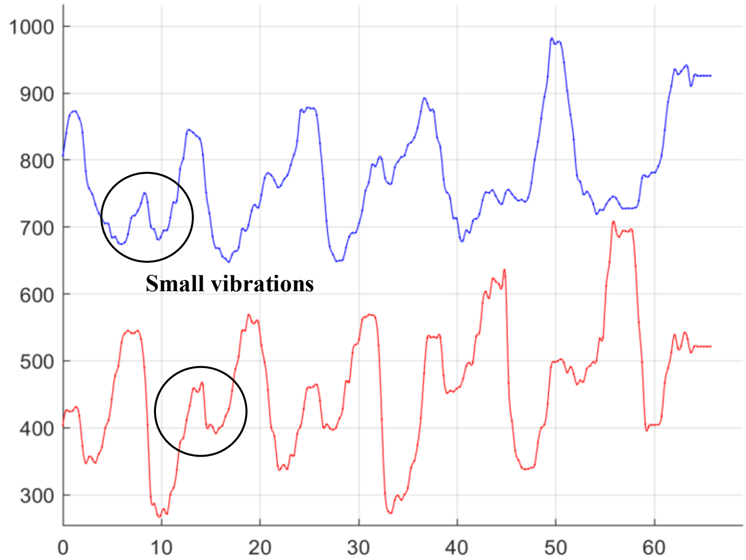


Fig.98 Type A, Waveform diagram of the movement of craftsman's wrist in the plane of gravity (horizontal axis is time) during the winnowing basket use (blue: left wrist, red: right wrist).

Fig.99 Type S, 2-dimensional analysis of skeletal movements of the body during winnowing basket use by the craftsman.

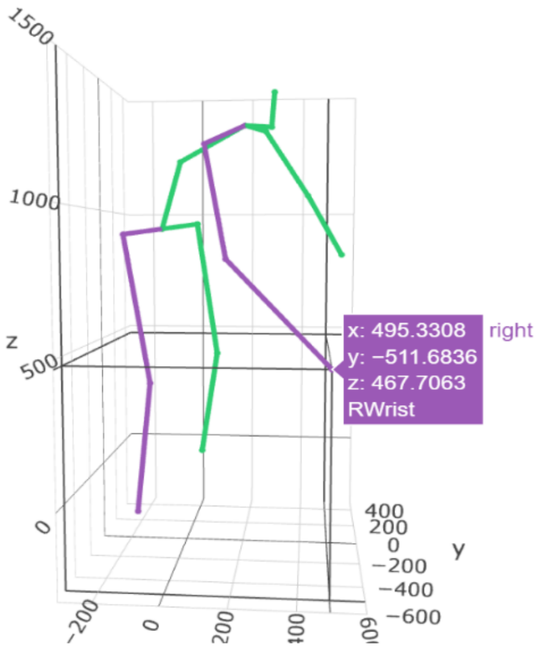


Fig. 100 Type S, 3-dimensional prediction of the body skeletal movement of the body during winnowing basket use by craftsman.

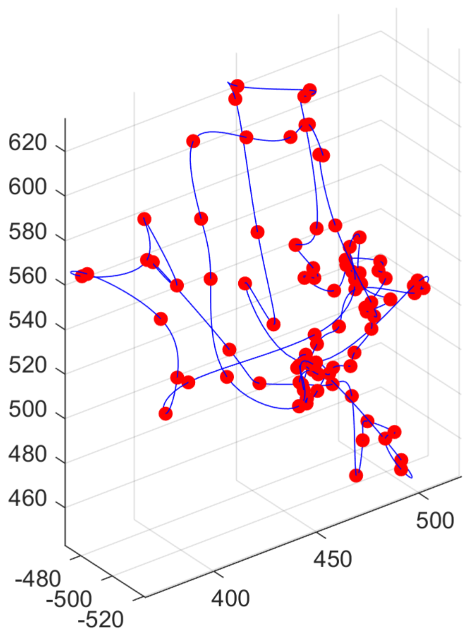


Fig.101 Type S, 3D trajectory of the wrist during using the dustpan by the craftsman (single-sided wrist).

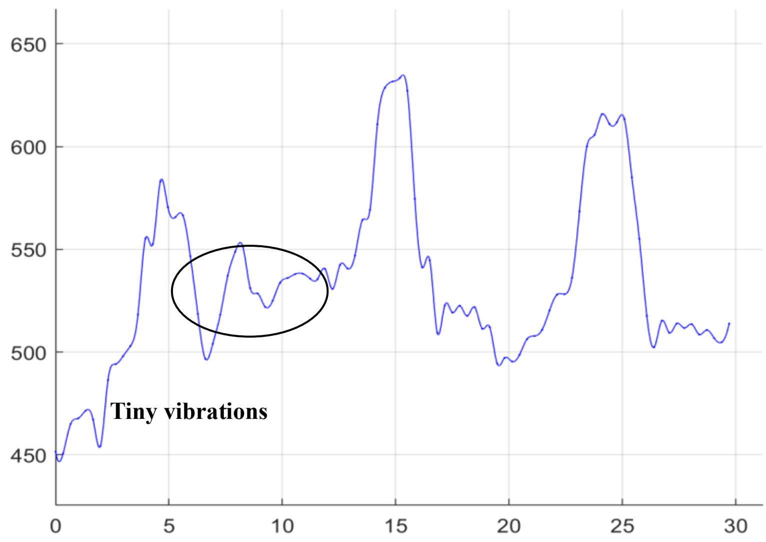


Fig.102 Type S, Waveform diagram of the movement of craftsman's wrist in the plane of gravity (horizontal axis is time) during the winnowing basket use (single-sided wrist).

vibrations may have no practical significance, but its vibration time and vibration intensity undoubtedly affect the efficiency of the whole vibration. Since there is no clear language and written record of these vibrations, it may be the spontaneous and unconscious behavior of the handicraftsman's body, the result of the joint action of the hands and the elastic material of the winnowing baskets.

(3) The small vibration of Type A does not seem to affect the efficiency of the entire vibration, because when a small vibration occurs in one hand, the other hand is producing an effective main vibration, and all the overall effective vibration occurs continuously between the left and right hands. However, the tiny vibrations of the Type S affect the efficiency of the entire screening due to its long duration, and these tiny vibrations seem to have no practical function, just to buffer the inertia of the downward movement of the hands.

(4) By comparing the waveforms of the two type vibrations, the Type A vibration alternately vibrates up and down between the left and right hands, and two effective vibrations are completed within 10 units of time (3.3 seconds), while the Type S vibration vibrates up and down with both hands at the same time, and one effective vibration is completed 10 units of time (3.3 seconds). Because the frequency of the Type A effective vibration is higher than that of the Type S, if the effective winnowing amount of each vibration is the same, the screening efficiency of the A type vibration is higher. However, it is not enough to evaluate the entire screening efficiency only from the vibration frequency, because the actual screening efficiency is also related to various factors such as the amplitude of vibration, the shape and capacity of the winnowing basket, the effective screening amount of grains, human energy consumption, the working habits of craftsmen and so on.

(5) The two types of vibration appear to be similar according to the original video merely. However, by observing the waveform of the wrist trajectory, especially tiny vibrational waves of two types, shows that the properties of the two vibrations are different. This is an important operational detail which unable to be observed by looking at the original video. The above only shows the motion rule of the handicraftsmen's wrists observed and a simplified analysis of mathematical simulations during the use of winnowing baskets. And many handicraftsmen cannot accurately express their bodily sensations in

words or the parts that they do not think are important, or the procedural memory of their body, muscles, and skeleton when teaching the technique of winnowing basket use or important details which unable to be learned by merely observing the original video when studying the pattern of human movement. In this part, Human skeletal recognition techniques and mathematical simulations are used for simplification and quantification to reduce irrelevant factors to express the human body's movement in mathematical models, so that the beginner and researcher can grasp the essence of this technique more quickly and clearly.

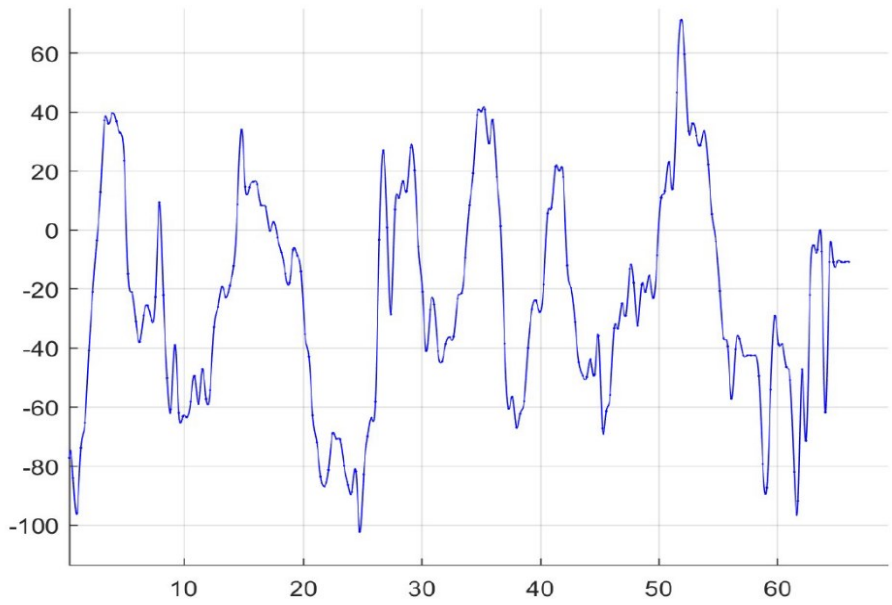


Fig.103 Type S, Irregular waveform diagram of the movement of craftsman's wrist in Horizontal plane (horizontal axis is time) during the winnowing basket use (single-sided wrist).

4.3 Short Summary

In this part, AI app such as OpenPose is used to extract the motion trajectories of the hands of the handicraftsmen during the process of application of the difficult touse *Kitachi* and *Naka* weaving to make a 2D analytical video to visualize the motion of wrist bones. Through the comparative experiment of making beginners watch the original video and analytical video, it is proved that artificial intelligence means can be used in the teaching of winnowing baskets production to enhance quality of completed products and fun at work. Furthermore, that can also allow the beginners to grasp this technique more accurately and quickly.

At the same time, the two vibration models for winnowing baskets are quantitatively Human3.6M. Through the 3D coordinates inferred by AI, the motion trajectory and vibration waveform of the wrists during the use of winnowing baskets are made, enabling the detection of the difference between the two vibration models and the small fluctuation (details of body movement) that fails to be detected only by watching the original video. It is also speculated that such a small vibration may be an unconscious human behavior (spontaneous behavior of the body) of the handicraftsmen but it affects the efficiency of screening to a certain extent.

By simplifying and transforming the winnowing basket production and use with human movement, the limitations of human vision are extended to some extent, and some important details and simplified models of the operation process can be summarised to explore the nature of human behaviors, which are expected to be of help in the process of the inheritance and protection of the traditional technique.

(1) Regarding the 2D and 3D data base sand algorithms of human skeletal movement used in this paper, which are only the most popular and widespread in the world now, there may still be some prediction errors in certain details of body movement when applied to Use and Production of Winnowing Basket of this unique skill.

(2) Although no assessment of learning efficiency for beginners involved in winnowing basket use with or without the 3D human skeleton videos and simplified the model GIF images, so the content and conclusions of Chapter 4 in this paper are primarily to provide a scientific basis for researchers and enthusiasts of winnowing basket use principles.

5. Conclusion

This paper cited two historical artefacts as objects (the Kuhon handprint and the winnowing basket) and three events related to them (the transmission of the religious meaning of the simplified 3D model of the Kuhon handprints , the 3D reproduction of the winnowing basket form, and the trajectory of the wrist movement when making and using the winnowing basket) to explain the function and morphological characteristics of historical artefacts and human responses during the making and use of them in terms of message transmission with forms, production of forms, and use of forms.

The original form of historical artefacts often tend to be not the ideal model for observation, so that scientific modelling methods such as simplification, transformation and transfer are needed to remove some excessive decorative and distracting elements. It was implemented to extract and enhance the core parts of its form (engineering components) and the simplified functional models that could make us understand easily the engineering properties, nature of the artefacts and the relationship between historical artefacts and people in productive life have been proposed.

(1) Message transmission of hand-related form-Kuhon handprints

In order to verify whether the form of *Kuhon* handprints can reflect their religious significance as described in the classics of Buddhist *Jodo* Buddhism, where 2D photographs cannot be evaluated, removing the effects of colour, texture, light, etc., and synthesizing and simplifying the 3D model of the nine handprints of the Joshin temple, and evaluating them with an impression with SD method and Quantification Type III , it was demonstrated that the refined and simplified 3D form of the Buddhist *Kuhon* handprints can indeed reflect to some extent the religious meanings of stability, teaching, and welcoming as described in the classics. It is verified that the simplified 3D model of the human hand-related form - the handprint form - can indeed be used as a visual medium to convey certain specific meanings and that the morphological features and sensual engineering nature can be observed and understood more easily than the prototype. According to the results of this paper, a different view of the naming of the *Kuhon* handprints at the site of the prototype (Joshin Temple) is also offered, the assessment of this paper is closer to the generally accepted naming and religious interpretation than the naming and interpretation currently in use of the Joshin temple, which also demonstrates that the modelling approach used in this part is reasonable and the results obtained seem to explain some of the general nature of Buddhist handprint forms, such as the Buddhist handprint form as an embodiment of religious meaning, which is associated with human abstract senses.

(2) Production of hand-related form-winnowing basket form

In order to apply a simplified model of the winnowing basket for engineering field (imitating the winnowing process by hand), the *Katakuchi* winnowing baskets collected by the Cultural Properties Research Institute of Tokyo was subjected to 3D measurements, 3D synthesis and morphological classification. The feature curves (curves presented by the winnowing basket shape of the section) were used to reproduce 3D simplified model by NURBs curve modeling, which are Echigo winnowing basket, Tokushima *Ajiro* winnowing basket, Nara *Ajiro* winnowing basket, represented three forming methods (*Nui-awase Gozame*, *Amiage Ajiro*). The results of this paper examined the effect of each feature curve selected on its local morphology and overall morphological reproduction, and demonstrated the possibilities of using a fewer feature curves to generate a 3D simplified model of winnowing basket by NURBS curve modelling. The process of 3D form reproduction some extent indirectly explains some details, priorities and difficulties which are difficult to explain or overlooked when manually making winnowing baskets, as well as some of the engineering characteristics of winnowing basket form. This section also attempts to correspond the process of 3D form reproduction with the handcrafting process, explaining the reasons for the formation of the overall and partial form of the winnowing basket, and examining the production of winnowing basket form multiple viewpoints.

(3) Use of hand-related form-winnowing basket

In order to directly investigate the relationship between the human hand and the production and use of the historical artefact, the winnowing basket, the 2D motion model of the human hand's skeleton during the production of the winnowing basket was extracted and trajectories were simplified using existing deep learning data of AI technology, and an AI analysis video was produced. A comparative experiment was conducted with and without observing the AI analysis videos by winnowing basket hobbyists, confirming that using AI analysis videos can improve the efficiency and enjoyment of winnowing basket making. OpenPose's parsed data combined with 3d-pose-baseline algorithms and mathematical analysis have revealed some small vibrations in the use of the winnowing basket, explaining some characteristic quantities and nature of the physics of human movement during the use of the winnowing basket. The modeling methods such as AI, mathematical simulation are used in this section to examine human responses in the context of use of hand-related form, which helps to explore the properties of historical forms and the nature of human movement and contribute to the transmission of traditional culture.

This paper investigated the morphological characteristics, material properties, engineering properties, and human physiological and psychological responses to the production and use of historical artefacts from three different perspectives: the message transmission, the production of form, and the use of form. I think that the modelling methods used in this paper may be scalable on simplifying, emphasizing and recomposing various historical forms, which contain a large amount of information and are complex, in order to capture features and explain phenomena which are difficult to be observed, understood or described with language. As the examples and perspectives cited in this paper are relatively few, the results are somewhat limited, but it is hoped that the methods and conclusions used in this paper will have wider application in the investigation of artefacts and human responses and the theme of the investigation of forms related to human (hands) will be continued.

Acknowledgments

First of all, I would like to express my gratitude to the handicraftsmen of the Inheritance Classroom in Chiba for their guidance and opinions and permission of me to join the Inheritance in Classroom several times and to have site visits and carry out the experimental operations of the production and use of winnowing baskets. At the same time, I would like to thank the Tokyo National Research Institute for Cultural Properties and Design culture Lab in Chiba University for their provision of the video materials and collaboration, which enrich the arguments of this paper. To conclude, I would like to thank all the students of Chiba University who participated in the experiment, Thanks for your careful and patient cooperation in completing the experiment of this paper. And this paper has been funded by the grant-in-aid for scientific research: (1) basic research (B) "Modularization of ideas accumulated in historical artifacts for design implementation" (Research Project / Area Number 18H03481). (2) basic research (C)“Elucidation of the artistic characteristics of local historical artifacts Towards attribution and identification of ’style’ ”(Research Project/Area Number 21K12541).

Publications

Conference presentations:

「浄真寺九品印相の形態分析及び印象評価」(和文)

日本デザイン学会第 65 回春季発表大会　2018 年

「箕の制作過程における身体知の可視化」(和文)

日本デザイン学会第 68 回春季発表大会　2021 年

「風を起こす箕の形」(和文)

日本デザイン学会第 69 回春季発表大会　2022 年

Academic periodicals：

「MORPHOLOGICAL ANALYSIS AND IMPRESSION EVALUATION FOR THE HANDPRINTS OF THE KUHON BUDDHA STATUES IN JOSHIN TEMPLE」(英文)

「Journal of the Science of Design」2021 Volume 5 Issue 1 Pages 1_77-1_86

「箕を構成する形態要素の抽出と 3D モデルによる再現」(和文)

「デザイン学研究」　2022 年 69 巻 1 号 p. 1_35-1_44

Reference

[1] J Jia., *Introduction to Functional Hand Rehabilitation*, China Electronic Industry Press, Chapter 1 Section 1, 2019

[2] Scientific Modelling, 科学的モデリング, from Wikipedia, https://ja.wikipedia.org/wiki/モデリング_(科学的),

[3] Point cloud modelling, from SGS, https://www.df-sgs.co.jp/3d-modeling-of-point-cloud-data point- cloud-data-3d-modeling/

[4] Q. Wang., W. Zhou., et al., NURBS-enhanced line integration boundary element method for 2D elasticity problems with body forces, *Computers & Mathematics with Applications*, 77(7), Pages 2006-2028, 2019,

[5] K. HuaChang, *Computer-Aided Engineering Design*, Pages 125-167, 2015

[6] Ergonomics guide: *How to science sensibility,* Human Performance Laboratory (HPL), 153-155, 2014

[7] YK, Amano., *Multivariate analysis in practice*, 50-55, 2018 (in Japanese)

[8] YK Amano., *Multivariate analysis in practice*, 65-86, 2018 (in Japanese)

[9] Z. Cao, G. Hidalgo, T, Simon, S-E. Wei, Y. Sheikh., *Computer Vision and Pattern Recognitio*,2019

[10] Julieta Martinez, Rayat Hossain, Javier Romero, James J. Little, *A simple yet effective baseline for 3d human pose estimation*, ICCV 2017

[11] Parameter Estimation,from mathwork, https://jp.mathworks.com/discovery/parameter-estimation.html, form MATLAB & Simulink

[12] Finite element method, from Wikipedia, https://en.wikipedia.org/wiki/Finite_element_method

[13] Akiyama, SK., *Buddha Handprint Encyclopedia*,127-131, 255-259,1985.

[14] *The Sutra of Measurements for the Construction of Statues*, Chinese Buddhist Electronic Text Association(CBETA),18-19, 2002, http://buddhism.lib.ntu.edu.tw/BDLM/sutra/chi_pdf/su tra10/T21n1419.pdf(Accessed 2 November 2019) Original work published GongBu, 1742.

[15] Buddhist Tantra: It refers to the Eastern Tantra of Shingon Buddhism and the Tai Tantra of Tendai Buddhism in Japan, Including the same type of Buddhist thought in India and Tibet, From Wikipedia, https://ja.wikipedia.org/wiki/%E5%AF%86%E6%95%99.

[16] *The Sutra On Contemplation Of Amitayus*, Chinese Culture Lecture Hall, 2013, (in Chinese), Original work published JiangLiang's translation ,YS,424

[17] The Three Pure Land Sutras, including *[The Sutra on the Amitabha]* - also known as *[the Little Amitabha Sutra]*. *[The Sutra on the Contemplation of Immeasurable Life Buddha]* - also known as the Sutra of *[Kuan Amitabha]*, or *[simply the Kuan Sutra]*. *[The Sutra on the Immeasurable Life]* - also known as the Great Amitabha Sutra.

[18] SK, Akiyama., *Buddha Handprint, Encyclopedia*,127-131, 255-259,1985 (in Japanese)
[19] [當麻曼荼羅 3 -九品来迎図], 2013/07/05, http://avantdoublier.blogspot.com/2013/07/blog-post_5.html.
[20] Hyeun, the Ansho temple's founding monk, from the Tang dynasty, is said to have brought the *Kuhon* Mandala to Japan.
[21] Ansho Temple, is located in Goryo Hirabayashi-cho, Yamashina-ku, Kyoto, belonging to the Shingon sect, the main shrine is the eleven-faced Avalokitesvara.
[22] Tm Ito, *Collection of Buddhist images*, Pages35-37, Yawata Shoten,2005,12
[23] *Kuhon Buddha origin*, The brochure of Joshin Temple, 201X
[24] Kaiseki Shonin, https://ja.wikipedia.org/wiki/珂碩上人
[25] Joshin Temple, *Comprehensive survey report on cultural heritage*, Tsuda Photo Printing,1986, 浄真寺
[26] Yosegi zukuri, from ニッポニカ, https://kotobank.jp/word/寄木造
[27] Teicho period, from Wikipedia, https://ja.wikipedia.org/wiki/定朝様
[28] Agisoft metashape, from Agisoft Company, Photogrammetric processing of digital images and 3D spatial data generation software.
[29] Autodesk recap photo, from Agisoft Compnay, Digitalisation of objects into digital data software.
[30] J Noguchi, 3D measurement of stone tools, disclosure of results and common use, 1st Data Science Salon for Archaeology and Cultural Heritage, 2019.
[31] Freecad, A software of 3D parametric model, from Freecad Company.
[32] YK,Arita., Art Appreciation Lessons though Verbalization of Styles in Japanese Arts: Using Catch Phrases in Appreciation of Buddhist Sculptures, *Art Education: Journal of Art Education* of JSSD, 34, 33-37,2013 (in Japanese); SD-Method Research on Reactions of Observers of All Ages to Buddhist Sculpture Styles 35,45-59,2014 (in Japanese)
[33] Ergonomics guide: *How to science sensibility*, Human Performance Laboratory (HPL), 153-155, 2014(in Japanese)
[34] Eisuke Shimizu, 17th abbot of Joshin Temple(清水英碩).
[35] The height of the Buddha's statue：The Buddha’s statue is generally required to be viewed at an angle of 10 degrees above the line of vision, from Baidu.
[36] YK,Amino., Multivariate analysis in practice, 50-55, 2018
[37] Fukui M, A software for social system analysis education: College Analysis, Annual Meeting (19), Japan Society of. Educational Information, 148-151, 2003
[38] Statistical Analysis Laboratory Ice Tat Co., Ltd.:
https://istat.co.jp/ta_commentary/method3_03 (Accessed 2 November 2019)
[39] FB, Ding , *Buddhist Dictionary*, Explanation of Buddha three secrets, 2011
[40] Y,Tanino., Stability from Standpoint of Dynamics and Kinematics, [関西理学], 59-62, 2003.
[41] *Kuhon Buddha origin,* The brochure of Joshin Temple, 2018(九品仏縁起)
[42] Ushiku Daibutsu, Guinness World Records for the largest statue of the Great Buddha,

Bronze Standing Statue of Amitabha, in Ibaraki of Japan, 1995.
[43] Winnowing basket(箕), Containers for removing husks and dust during the sorting of rice and other grains. from Wikipedia.
[44] Mitsukuri(箕作り), Minaoshi（箕直）, https://ja.wikipedia.org/wiki/Mitsukuri, form Wikipedia
[45] M,Imaiashi, conveying the art of winnowing, *Tokyo Institute for Cultural Properties*, 2017
[46] Shape of a winnowing basket- Document collection, from the Document collection From the Department of Intangible Cultural Heritage of Tokyo National Research Institute for Culture Properties, https://www.tobunken.go.jp/ich/research/mi/
[47] Konica Minolta： Polygon Editing Tool, Polygon editing software dedicated to VIVID., https://www.konicaminolta.jp/ins rumentst/support/discontinued_products/vivid910
[48] Kubotek 3D: KeyCreator 2019 SP2, a 3D CAD Software, https://www.kubotek3d.com.

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[49] Autodesk: Alias, An Industrial Design And 3D Surface Modeling Software, from alias.design.
[50] Q. Wang., W. Zhou., et al., NURBS-enhanced line integration boundary element method for 2D elasticity problems with body forces, *Computers & Mathematics with Applications*, 77(7), 2006-2028, 2019,
[51] NS, Imai., 分かりやすい NURBS 解説, *UNISYS 技報*, 32(3), 173-186, 2012
[52] Kruth. JP., Kerstens. A., Reverse engineering modelling of free-form surfaces from point clouds subject to boundary conditions, Journal of Materials Processing Technology, 76(1-3), 120-127,1998
[53] XF. Zhang., P. Hu., et al., A new surface parameterization method based on one-step inverse forming for isogeometric analysis-suited geometry, *International Journal of Advanced Manufacturing Technology*, 65(9-12), 1215-1227, 2013
[54] 3D Systerm: Geomagic ControlX, A 3D Inspection and MetrologySoftware, https://jA.3Dsystems.com/software/geomagic-control-x
[55] M, Kubo., [風を起こす箕の形], 日本デザイン学会 第 69 回研究発表大会, 9A-01,2022
[56] Anisotropic materials： Materials with different mechanical properties (e.g. strength and Young's modulus) in each direction are referred to as anisotropic materials. http://kentiku-kouzou.jp/yugenyoso-touhouihou.html, (異方性材料)
[56] M, Kubo., A, Ueda., [箕に見る自然な曲面のつくり方], https://jglobal.jst.go.jp/detail?JGLOBAL_ID=201802213950060596
[57] The technique of producing Kizumi winnowing basket, Important Intangible Folk Cultural Asset, 11 March 2009, Sosa City, Kisaku, Chiba, Japan (Kisaku winnowing basket preservation committee)
[58] Z Cao, G Hidalgo, T Simon, S-E Wei, Y Sheikh, OpenPose: Realtime Multi-Person 2D Pose Estimation using Part Affinity Fields, *Computer Science _ Computer Vision and Pattern Recognition*, 2018-2019
[59] GitHub, a free website for programing and code,

https://github.com/CMUPerceptualComputingLab/openpose,
[60] J Martinez, R Hossain, J Romero, J J. Little, A simple yet effective baseline for 3d human pose estimation, *Computer Science > Computer Vision and Pattern Recognition*, 2017
[61] Motion capture, from Wikipedia, The technology of digitally records the movements of real people and objects. https://ja.wikipedia.org/wiki/motion capture.
[62] Dense Pose, Dense Human Pose Estimation In The Wild, http://densepose.org.
[63] RADiCAL, AI-powered 3D animation, https://getrad.co.
[64] Visual studio 2015 professional, Programming software in C++ , https://learn.microsoft.com/ja-jp/visualstudio/releases/2015/vs2015-sysrequirements-vs
[65] JSON: JSON stands for JavaScript Object Notation, JSON is one of the object notations defined in JavaScript and is expressed in text format, allowing easy data exchange. It is therefore used by all major programming languages, not just JavaScript. *And Engineer*
[66] Human 3.6M, a dataset by Catalin Lonescu, Dragos Papava, Vlad Olaru and Cristian Sminchisescu, http://vision.imar.ro/human3.6m/description.php
[67] Buddhist Stutrast・Bilingual Reading, from Library of Manifestation and Tantra[顕密文庫], http://read.goodweb.net.cn/news/news_view.asp?newsid=110855
[68] [當麻曼荼羅－九品来迎図], http://avantdoublier.blogspot.com/2013/07/blog-post_5.html

Appendix

The original source [The Sutra on the Contemplation of Immeasurable Life Buddha] of the nine grades of birth is as follows[68]:

1) the highest level of the highest grade(Jobon Josho)

The Buddha said to Ananda and Vaidehi, "Those born in the Western Land are of nine grades. Those who attain birth on the highest level of the highest grade are sentient beings who resolve to be born in that land, awaken the three kinds of faith and so are born there. What are the three? They are, first, the sincere faith; second, the deep faith; and third, the faith that seeks birth there by transferring one's merit. Those who have these three kinds of faith will certainly be born there.

There are three other kinds of sentient beings who also attain birth. Who are the three? They are, first, those who have a compassionate heart, abstain from killing and observe the precepts; second, those who chant the Mahayana sutras of greater scope; and third, those who practice the six forms of mindfulness. They aspire to be born in that Buddhaland by transferring there the merit of practice. With the merit acquired from doing these acts for one to seven days, they attain birth.

When an aspirant is about to be born in that land through dedicated and undaunted practices, the Tathagata Amitayus arrives together with Avalokiteshvara, Mahasthamaprapta, innumerable transformed Buddhas, a great assembly of a hundred thousand monks and shravakas and innumerable devas in sevenjewelled palaces. The Bodhisattva Avalokiteshvara, carrying a vajraseat, together with the Bodhisattva Mahasthamaprapta, approaches the aspirant. Amitayus releases a great flood of light which illuminates the aspirant's body and, along with the bodhisattvas, extends his hands in welcome. Avalokiteshvara and Mahasthamaprapta, together with innumerable

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68 Buddhist Stutrast・Bilingual Reading, from Library of Manifestation and Tantra[顕密文庫], http://read.goodweb.net.cn/news/news_view.asp?newsid=110855

bodhisattvas, praise and encourage the aspirant. Seeing this, the aspirant rejoices so greatly as to dance. Then he sees himself sitting on the vajraseat, and following the Buddha, is born into that land in the time it takes to snap one's fingers.

After being born in that land, he sees the Buddha's body complete with all its physical characteristics and also the bodies of the bodhisattvas equally complete with all their physical characteristics. Hearing the discourse on the wonderful Dharma sent forth by the light and the jewelled trees, he then reaches the insight into the nonarising of all dharmas. In a single moment, he visits and worships all the Buddhas of the ten quarters and receives from each of them the prediction of his future Buddhahood. Returning to the Pure Land, he is endowed with innumerable hundreds of thousands of dharanis. Such a person is called one who attains birth on the highest level of the highest grade.

2) the middle level of the highest grade(Jonbon Chusho)

Those who attain birth on the middle level of the highest grade, do not necessarily uphold and chant the sutras of greater scope, but comprehend the teachings of the Buddha so well that when they hear the supreme truths, they are not dismayed. They have deep faith in the law of karmic causes and effects and do not speak slightingly of the Mahayana. They transfer the merit acquired to the Land of Utmost Bliss, aspiring to be born there.

When such an aspirant is about to die, Amitayus appears before him, surrounded by Avalokiteshvara, Mahasthamaprapta and innumerable sages and attendants, carrying a purplegold lotusseat. The Buddha praises him, saying, 'Son of the Dharma, because you have practiced the Mahayana and appreciate the supreme truths, I have come to welcome you.' So saying, he and a thousand transformed Buddhas extend their hands all at once towards the aspirant, who, seeing himself sitting on the purplegold seat, joins his palms and praises the Buddhas. In an instant, he is born in a sevenjewelled pond of that land.

The purplegold seat has become like a great jewelled flower, which opens *after one night. The body of the aspirant has become the color of purplegold, and beneath his feet are sevenjewelled lotusflowers. The Buddha and bodhisattvas together release a flood of light which illuminates the aspirant's body. His eyes open, and because of the store of merit from his previous life, he hears voices everywhere expounding only the most profound and supreme truths. Descending from his golden seat, he bows with joined palms and praises the Buddha, the WorldHonored One. After seven days, he immediately reaches the Stage of Nonretrogression for realizing the highest, perfect Enlightenment. He is also able to fly in the ten quarters, as he wishes, to revere all the Buddhas and learn various samadhis from them. After the lapse of a smaller kalpa, he attains the insight into the nonarising of all dharmas and receives from each Buddha the prediction of his future Buddhahood. Such a person is called one who attains birth on the middle level of the highest grade.*

3) the lowest level of the highest grade(Jonbon Gesho)

Those who attain birth on the lowest level of the highest grade likewise accept the law of karmic causes and effects, do not speak slightingly of the Mahayana and awaken aspiraten for the highest Enlig, htenment. They transfer the merit acquired to the Land of Utmost Bliss, aspiring to be born there.

When such an aspirant is about to die, Amitayus, together with Avalokiteshvara, Mahasthamaprapta and a host of attendants, come to welcome him, bringing a golden lotusflower and manifesting five hundred transformed Buddhas. Those transformed Buddhas extend their hands all at once and praise the aspirant, saying, 'Son of the Dharma, since you have awakened pure aspiraten for the highest Enlightenment, we have come to welcome you.'

When he has viewed all this, the aspirant finds himself seated upon a golden lotusflower, which then closes. Following the WorldHonored One, he immediately attains birth on a sevenjewelled pond. After a day and night, the lotusflower opens and, within seven days, the aspirant beholds the Buddha. Although he sees the Buddha's body, he is still unable to discern his physical *characteristics and marks clearly. But after three weeks he sees them distinctly, and also hears all the sounds and voices proclaiming the wonderful Dharma. Then he can travel in all the ten quarters to make offerings to the Buddhas and hear their profound teachings. After three smaller kalpas he acquires clear understanding of the one hundred dharmas and dwells in the Stage of Joy. Such a person is called one who attains birth on the lowest level of the highest grade. These three together are known as the contemplation of the highest grade of aspirants, and the fourteenth contemplation. To practice in this way is called the correct contemplation, and to practice otherwise is incorrect.*

4) the highest level of the middle grade(Chubon Josho)

The Buddha said to Ananda and Vaidehi, "Those who attain birth on the highest level of the middle grade are the sentient beings who keep the five precepts, observe the eight abstinences, practice in compliance with various precepts, and abstain from committing the five gravest offenses and other transgressions. They transfer the merit acquired to the Western Land of Utmost Bliss, aspiring to be born there.

When such a person is about to die, Amitayus appears before him, surrounded by a host of monks and radiating a golden light. He then expounds the truth of suffering, emptiness, impermanence and noself, and praises renunciation of the world as the way to escape from suffering.

Seeing this, the aspirant greatly rejoices and finds himself seated upon a lotusflower. He kneels down, joins his palms and worships the Buddha. Before he raises his head, he attains birth in the Land of Utmost Bliss, where his lotusbud soon opens. When the flower opens, he hears various sounds and voices extolling the Four Noble Truths. He immediately attains Arhatship, acquires the three kinds of transcendent knowledge and the six supernatural powers, and realizes the eight samadhis of emancipation. Such a person is called one who attains birth on the highest level of the middle grade.

5) the middle level of the middle grade(Chubon Chusho)

Those who attain birth on the middle level of the middle grade are the *sentient beings who observe for at least a day and night the eight abstinences, the precepts for a novice or the complete precepts of a monk or a nun, and do not violate any of the rules of conduct. They transfer the merit acquired to the Land of Utmost Bliss, aspiring to be born there.*

When such an aspirant, perfumed by the virtue of observing the precepts, is about to die, he sees Amitayus coming towards him with his attendants, radiating a golden light and carrying a sevenjewelled lotusflower. He hears a voice in the sky above praising him, saying 'Man of good deeds, since you are virtuous and have followed the teachings of the Buddhas of the three periods, I have come to welcome you.' The aspirant finds himself seated upon the lotusflower. The flower having closed, the aspirant is born on a jewelled pond of the Western Land of Utmost Bliss. After seven days the lotusbud unfolds, and then he opens his eyes. With joined palms he pays homage to the WorldHonored One, rejoices at hearing the Dharma and reaches the Stage of a StreamWinner. After half a kalpa, he becomes an Arhat. Such a person is called one who attains birth on the middle level of the middle grade.

6) the lowest level of the middle grade(Chubon Gesho)

Those who attain birth on the lowest level of the middle grade are good men and women who are dutiful to and care for their parents and do benevolent deeds for others. When such a person is about to die, he may meet a good teacher, who fully explains to him the bliss of the land of Amitayus and the Fortyeight Great Vows of the Bhiksu Dharmakara. Having heard this, he dies and in the short time it takes a strong man to bend and straighten his arm, he attains birth in the Western Land of Utmost Bliss. Seven days after his birth there, he meets Avalokiteshvara and Mahasthamaprapta, rejoices at hearing the Dharma from them and so reaches the Stage of a StreamWinner. After one smaller kalpa, he becomes an Arhat. Such a person is called one who attains birth on the lowest level of the middle grade. These three together are known as the contemplation of the middle grade of aspirants and the fifteenth contemplation. To practice in this way is called the correct contemplation, and *to practice otherwise is incorrect.*

7) the highest level of the lowest grade(Gebon Josho)

The Buddha said to Ananda and Vaidehi, "Those who attain birth on the highest level of the lowest grade are the sentient beings who commit various evil acts but do not slander the Mahayana sutras of greater scope. When a foolish person such as this, who has committed much evil but feels no remorse, is about to die, he may meet a good teacher, who praises the titles of the twelve divisions of the Mahayana scriptures. By hearing these sutratitles, he is released from the burden of evil karma which he has accumulated during a thousand kalpas. Furthermore, this wise teacher advises him to join his palms and call, 'Homage to Amitayus Buddha' [Namoomit'ofo].' Calling the name of the Buddha extinguishes the evil karma that the dying person has committed during fifty kotis of kalpas of Samsara.

The Buddha then sends his transformed body and those of Avalokiteshvara and Mahasthamaprapta to the aspirant; they praise him, saying, 'Well done, man of good deeds! By calling the Name of the Buddha your evil karma has been extinguished, and so we have come to welcome you.' When these words are uttered, the aspirant sees a flood of light from that transformed Buddha fill his room. Having seen this, he rejoices and dies. Seated on a jewelled lotusflower, he follows the transformed Buddha and is born on a jewelled pond. In seven weeks the lotusbud opens and Avalokiteshvara, the Bodhisattva of Great Compassion, and Mahasthamaprapta appear before him, releasing great floods of light, and explain to him the extremely profound teachings of the twelve divisions of the scriptures. Having heard these, the aspirant accepts them in faith, and awakens aspiraten for the highest Enlightenment. After ten smaller kalpas, he acquires clear understanding of the one hundred dharmas and enters the First Stage of Bodhisattvahood. Such a person is called one who attains birth on the highest level of the lowest grade. Thus he is born by hearing the Name of the Buddha, the Dharma and the Sangha that is, the Three Treasures.

8) the middle level of the lowest grade(Gebon Chusho)

The Buddha said to Ananda and Vaidehi, "Those who attain birth on the middle level of the lowest grade are the sentient beings who violate the five precepts, the eight precepts or the complete precepts of a monk or a nun. A foolish person such as these steals from the Sangha or takes the personal belongings of monks, or preaches the Dharma with impure motives but feels no remorse. Thus he defiles himself by evil karma, and because of this he will fall into hell.

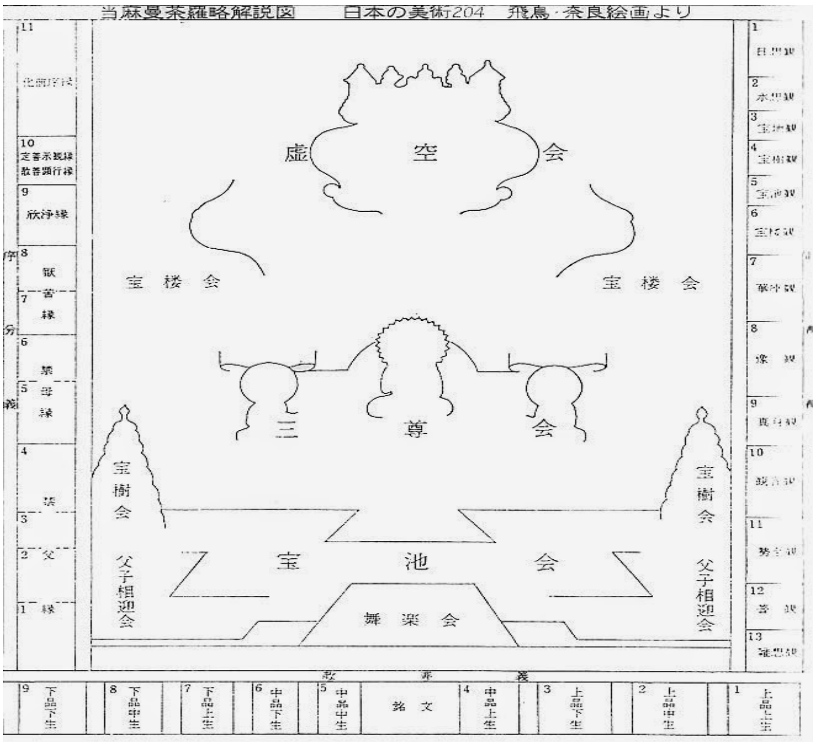
When he is about to die and the flames of hell suddenly close in on him, he may meet a good teacher, who compassionately explains to him the ten supernal powers of Amitayus, fully describing the majestic power of the light of that Buddha, his virtues in the observance of the precepts, meditation, wisdom, emancipation and knowledge of emancipation. When he has heard this, the evil karma which he has committed during eighty kotis of kalpas of Samsara are extinguished; thus, the fierce flames of hell turn into cool and refreshing breezes, wafting heavenly flowers. On each flower is a transformed Buddha accompanied by bodhisattvas welcoming him.

In an instant, he attains birth within a lotusbud on a sevenjewelled pond. After six kalpas the lotusbud opens, and then Avalokiteshvara and Mahasthamaprapta comfort him with their noble voices and teach him profound Mahayana sutras. Upon hearing these, he immediately awakens aspiraten for the highest Enlightenment. Such a person is called one who attains birth on the middle level of the lowest grade.

9) the lowest level of the lowest grade(Gebon Gesho)

The Buddha said to Ananda and Vaidehi, "Those who attain birth on the lowest level of the lowest grade are the sentient beings who commit such evils as the five gravest offenses, the ten evil acts and all kinds of immorality. Owing to such evil karma, the fool like this will fall into evil realms and suffer endless agony for many kalpas. When he is about to die, he may meet a good teacher, who consoles him in various ways, teaching him the wonderful Dharma and *urging him to be mindful of the Buddha; but he is too tormented by pain to do so. The good teacher then advises him, 'If you cannot concentrate on the Buddha, then you should say instead, Homage to Amitayus Buddha.' In this way, he sincerely and continuously says 'Homage to Amitayus Buddha' [Namoomit'ofo] ten times. Because he calls the Buddha's Name, with each repetition, the evil karma which he has committed during eighty kotis of kalpas of Samsara is extinguished. When he comes to die, he sees before him a golden lotusflower like the disk of the sun, and in an instant he is born within a lotusbud in the Land of Utmost Bliss. After twelve great kalpas the lotusbud opens. When the flower opens, Avalokiteshvara and Mahasthamaprapta teach him with voices of great compassion the method of extinguishing evil karma through the realization of Suchness of all dharmas. Hearing this, he rejoices and immediately awakens aspiraten for Enlightenment. Such a person is called one who attains birth on the lowest level of the lowest grade. These three together are known as the contemplation of the lowest grade of aspirants and the sixteenth contemplation.*

Dangma Mandala－The Nine Pins[69]



[69] [當麻曼荼羅－九品来迎図], http://avantdoublier.blogspot.com/2013/07/blog-post_5.html

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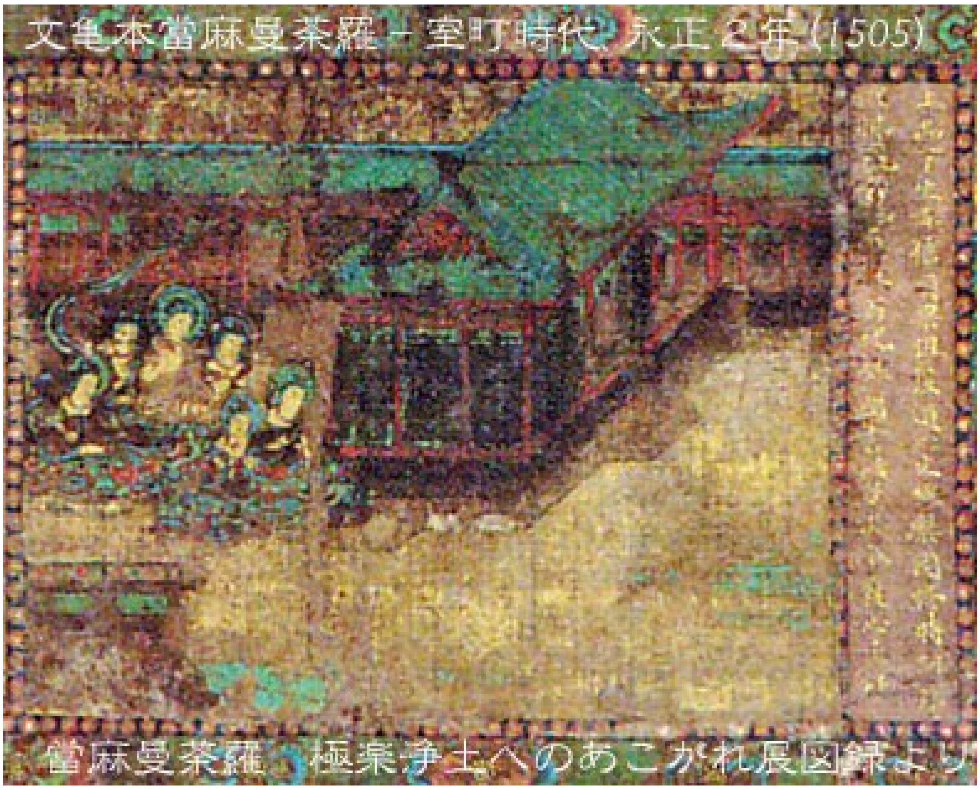
Mandala’s Jobon chusho enlarge image



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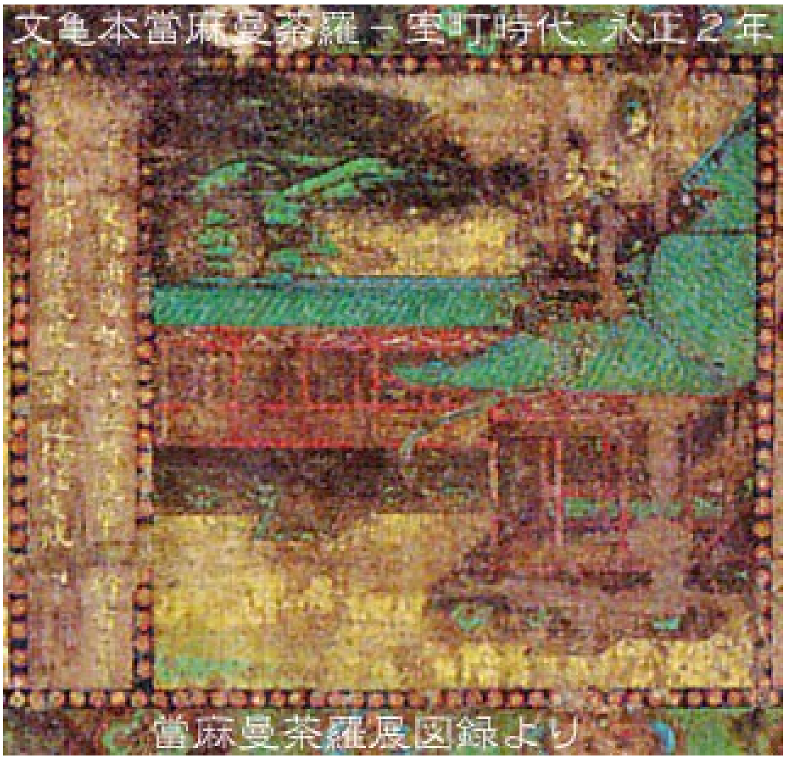
Mandala's Chubon josho enlarge image



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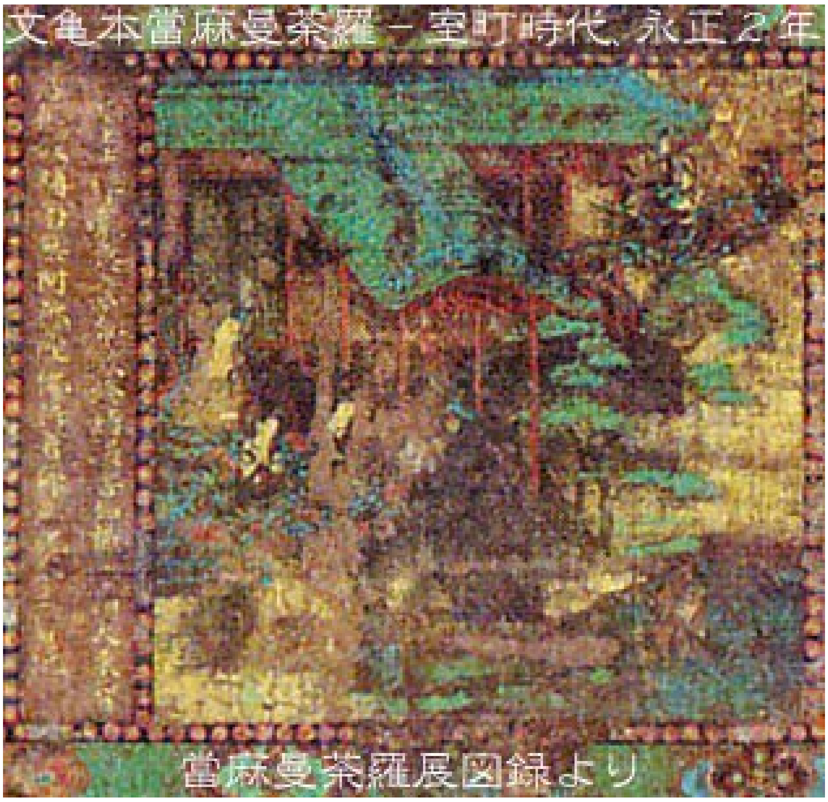

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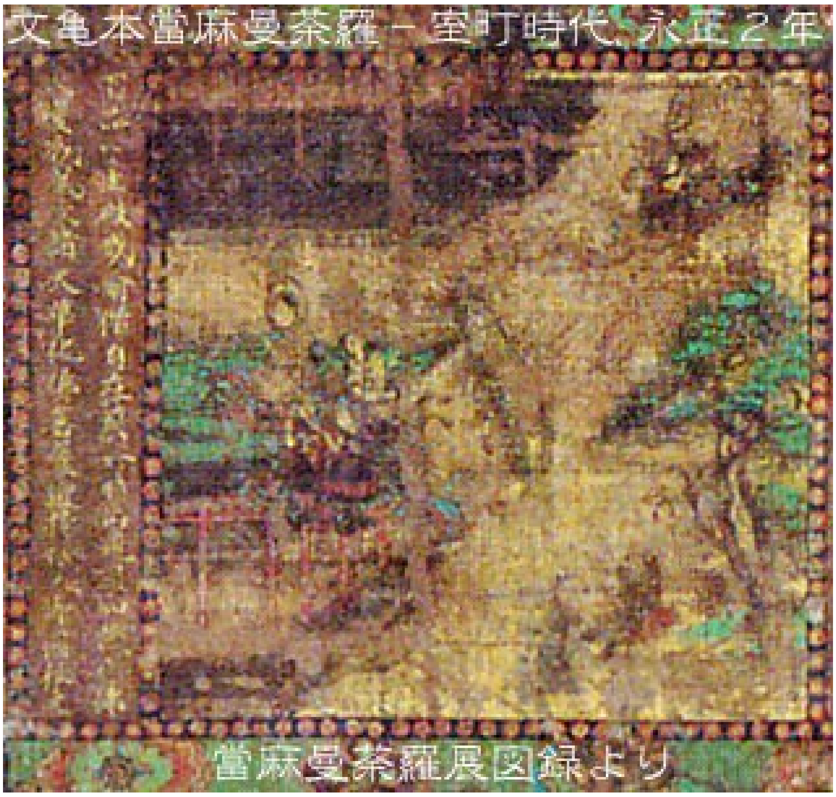

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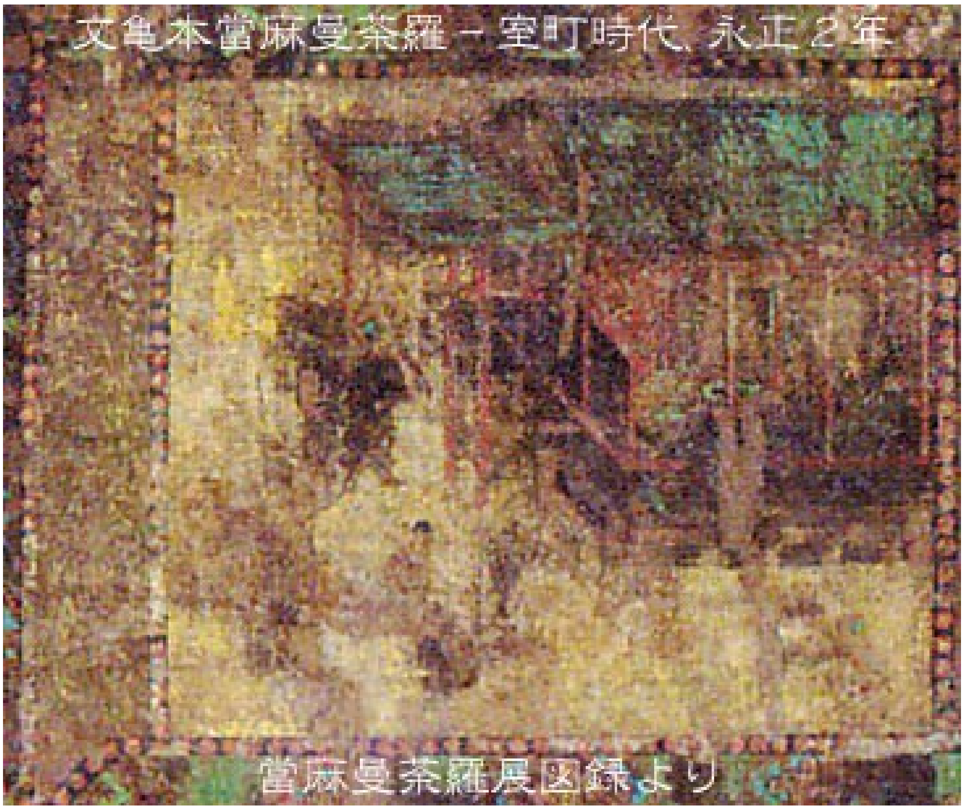

Mandala's Gebon gesho enlarge image

Cross-reference between English and Japanese for proprietary words used in the paper

Joshin Temple：浄真寺

Kuhon Buddha：九品仏

Jobon josho：上品上生

Jobon chusho：上品中生

Jobon gesho：上品下生

Chubon josho：中品上生

Chubon chusho：中品中生

Chubon gesho：中品下生

Gebon josho：下品上生

Gebon chusho：下品中生

Gebon gesho：下品下生

Meditation handprint：定印

Teaching handprint：説法印

Welcoing handprint：来迎印

Winnowing basket：箕

Winnowing：風選

Single-sided winnowing basket：片口箕

Shitate：仕立て

Amiage：編み上げ

Nui-awase：縫い合わせ

Itami：イタミ

Misaki：箕先

Akudo：アクド

Udeki：腕木

Hige right cross：ヒゲ通し

Kitachi：キタチ

Mitsukuri：箕づくり

Minaoshi: 箕直

Nara Ajiro: 奈良アジロ

Tokushima Ajiro: 徳島アジロ

Echigo: 越後

Gozame:ゴザ目