Potential of 3D-CAD use for passing on of traditional carpentry techniques of Kintai Bridge

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***ABSTRACT*:** Kintai Bridge is the historical wooden arch bridge structure in Iwakuni City, Yamaguchi Prefecture in Japan. The completion of this bridge was in 1673, spanning the Nishiki river in a series of five wooden arches. The second, third and fourth bridges are 35.10m in span, while the first and fifth bridges are 34.80m in span, and total length is 193.33m, 4.60m in width. More than 20,000 parts combined construct this bridge. Repairs of the wooden members and reconstruction of the whole bridge take place every few decades. In Japan, the wooden arch bridge is like no other Kintai Bridge. This bridge is rare in the world. So, now, for the registration of World Heritage is promoting a variety of surveys. In this study, we focus on carpentry techniques for such an unusual bridge. For example, the features of the carpentry techniques applied in Kintai Bridge, the problems when passing on carpentry techniques, and for future carpenters, how to communicate carpentry techniques. Present Kintai Bridge also maintains a similar structure when it was built. From now on, the following systematization is important to maintain the structure of Kintai Bridge. (1) Personnel training on the ordering party's side (Iwakuni City), (2) Passing down of carpentry techniques (training of junior carpenters) and (3) Retention of the supply system. In this study, using 3D-CAD to traditional carpentry techniques is proposed. As a result, it is possible to visualize of the construction process, output of specialized knowledge, and also bring up the successor, disseminate of information to the public. Then, reading from drawing and process of making 3D-CAD with the specialist (carpenter) are formed.

KEYWORDS: wooden arch bridge, passing on of traditional carpentry techniques, 3D-CAD

1. INTRODUCTION

1.1 Background

Currently the Kintai Bridge in Iwakuni City, Yamaguchi is preparing for application for inscription on the World Heritage List. The Kintai Bridge, as a wooden arch bridge structure, is rare in the world, and the original appearance has been kept in almost perfect condition since its construction in 1673. However, being a wooden artifact, corrosion and wearing of the wooden members are conspicuous, and repairs of the wooden members and reconstruction of the whole bridge take place every few decades. Therefore none of the original wooden members still exist. Even in recent years, the first to fifth bridge spans were replaced between 2001 and 2004. (Hereafter described as the Heisei reconstruction.) When it comes to inscription on the World Heritage List, either 'Authenticity' or 'Integrity' is important. However, as none of the original construction parts are still in existence, it does not match the criterion of 'Authenticity'. Having said that, ICOMOS advisors from France and the United States commented at the 'Kintai Bridge Symposium' held in January 2008 that: 'It is not entirely negative in terms of Integrity'. In order to maintain long-term Integrity for the future, it would be important to set a frame for preserving the

structure, use, and carpentry techniques that have been inherited from the original construction time that are relevant to its 'Outstanding Universal Value'.
So, for the purpose of being able to pass on the carpentry techniques, video and photographic records of the carpentry work were recorded on DVD during the Heisei reconstruction. However in the case of an arbitrary seeking of visual reference to the inner structure and wooden members, pre-existing videos and photographs, and the bridge itself do not fully correspond to the requirements, and that is a problem.

1.2 Purpose

The purpose of this study is to convert the 2D drawings of the Kintai Bridge drawn at the time of the Heisei reconstruction into 3D-CAD, and preserve the carpentry techniques and construction order. Of course, nothing could be better than an oral passing on of traditional carpentry techniques, but hopefully the 3D-CAD will be helpful.
Also, the results of this study would be useful for purposes other than just the passing on of traditional carpentry techniques. Therefore, more practical uses were considered in discussions with the carpenters and local authorities who were actually involved in the Heisei reconstruction.

2. OUTLINE OF THE KINTAI BRIDGE

2.1 Specifications of the Kintai Bridge

The Kintai Bridge is situated in Iwakuni City, Yamaguchi Prefecture (Figure 2.1) in western Japan, and is a wooden arch bridge with 5 spans bridging the R. Nishiki. (Total length of 193.33m) (Photo 2.1) Structurally, the first and fifth bridge spans on either side are called 'Hashirabashi,' that is a girder bridge structure with bridge pillars (Photo 2.2), and the second to fourth bridge spans in the middle are called 'Soribashi', an arch structure bridge (Photo 2.3). Wooden arch bridges with such a structural type are rare in the world, even in comparison with other Japanese wooden bridges (Kobayashi, 2010, 1), Chinese wooden arch bridges (Watanabe, Kobayashi, Ito and Jojima, 2010, 15), and European wooden arch bridges (Honda, Watanabe and Kobayashi, 2011, 85), no wooden arch bridge of the same kind exists at present.
The dimensions of each part is, as shown in Figure 2.2: Hashirabashi (the first and fifth bridge spans) is 34.80m in span, 4.60m in width, and the height from the riverbed is 9.42m, and Soribashi is 35.10m in span, 4.60m in width, and the height from the riverbed is 12.46m (the second bridge), 13.03m (the third bridge), and 12.90m (the fourth bridge).
The timbers for the structural members are mainly pine (156.4m3, 38.0%) and cypress (151.8m3, 37.0%), and others, Japanese zelkova (66.0m3, 16.1%), false arborvitae (29.8m3, 7.3%), Japanese Chestnut (5.9m3, 1.4%), and Oak (0.8m3, 0.2%) are used in places suitable for their particular characteristics. (The Japanese Association for Conservation of Architectural Monuments, 2005, 36). The pine is used for lightweight bridge girders and crossbeams, and the cypress is for ornamental parts like the bridge boards and railings as it is a plain wood with a beautiful surface. Japanese zelkova is used for both ends and the middle part of the heavy load bearing members. (Figure 2.3).

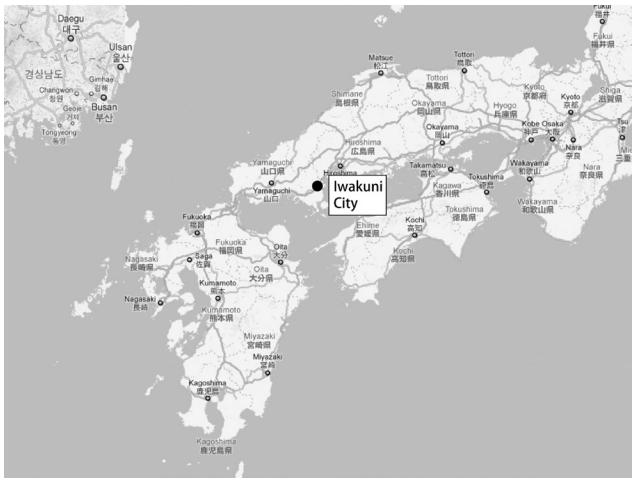

Figure 2.1 Location of Iwakuni City

Photo 2.1 The whole of Kintai Bridge

Photo 2.2 'Hashirabashi' (the first bridge)

Photo 2.3 'Soribashi' (right: the third bridge, left: the fourth bridge)

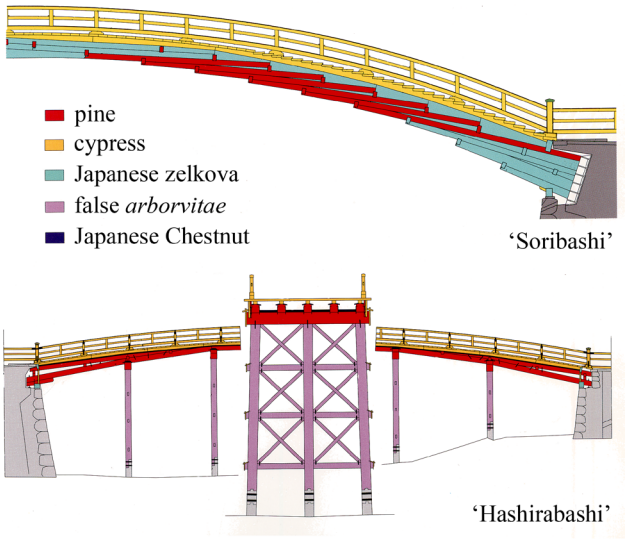

Figure 2.3 Timbers for structural members

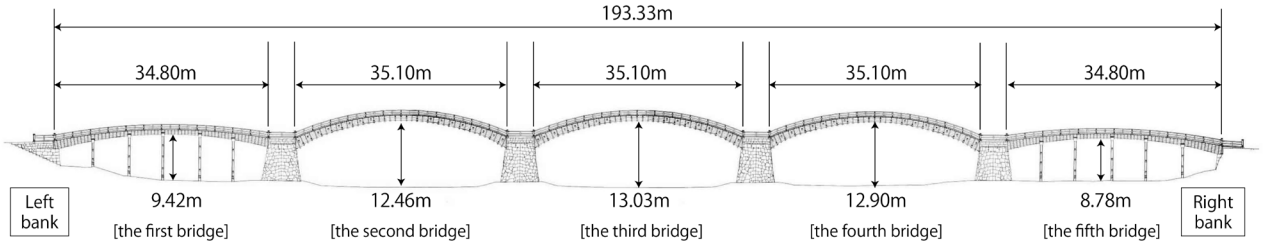

Figure 2.2 Dimensions of each part

2.2 The history of the Kintai Bridge

The completion of the Kintai Bridge was in September 1673. After that date, by way of several reconstruction and repair works, it came under the protection of the Law for the Preservation of Historic Spots, Scenic Beauties and Natural Monuments and was designated as a historical landmark and scenic beauty spot in March 1922. Later, due to the commencement of the 1950 Law for the Protection of Cultural Properties, it was designated as a scenic beauty again. Table 2.1 shows the chronological table of reconstruction and repair works of the Kintai Bridge from the completion date to the present time. Taking a look at this chronological table, reconstruction and repair works took place frequently. The number of times of span

reconstruction is especially great: the first bridge, 11 times; the second bridge, 14 times; the third bridge, 15 times; the fourth bridge, 18 times; and the fifth bridge, 10 times. Even in recent years, the full bridge was rebuilt in the Heisei reconstruction from 2001 to 2004. When reconstructing the bridge, some components can be treated and reused, but in the case of corrosion and wearing of the wooden member, brand new members are supplied. In short, after repeated reconstruction and repair works, none of the original wooden members from the time of completion exist at all at the present date.

3. PROPOSAL FOR THE ISSUE OF THE PASSING ON OF THE TRADITIONAL CARPENTRY TECHNIQUES

3.1 The problem of the passing on of the traditional carpentry techniques

A carpentry technique called 'Shikuchi' (Figure 3.1) is used for joints of the wooden members in Kintai Bridge. However, outstandingly difficult and complicated carpentry techniques used for example in temple building, are not used for the Kintai Bridge. Only the general carpentry techniques for traditional Japanese house building are used in the construction. Therefore, since the time of completion, the Kintai Bridge has been a common site for the daily training of carpenters (especially junior ones).

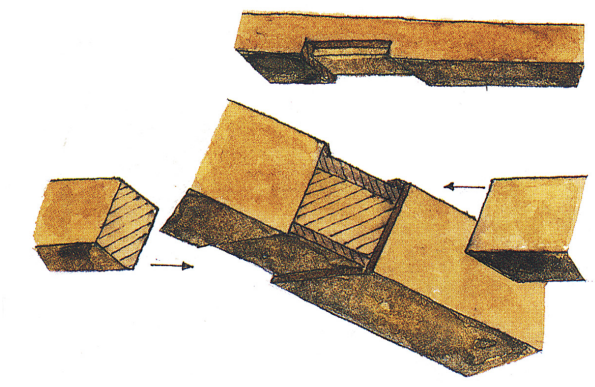

Figure 3.1 'Shikuchi' called 'Watari-ago-kake'

Table 2.1 Chronological table of reconstruction and repair works

Year	Type of works (each bridge)					Execution date		Completion date		Construction period
	first	second	third	fourth	fifth	month	day	month	day	
1673	○	○	○	○	○	6	28	9	30	93
1674	○	○	○	○	○	6	1	10	25	145
1676										
1677										
1683		○	○	○		7	17	10	1	75
1685										
1693		●	●	●						
1694	○				○					
1699		○	○	○		6	28	8	28	61
1703	○				○	7	4	-		
1707		●	●	●						
1711	●				●					
1714		○	○	○		9	26	11	28	63
1722	●				●	2	10	3	1	22
1725		●	●	●		12	12	2	8	57
1737	○				○	11	2	11	4	33
1740				○		10	16	12	20	65
1741		○	○			7	2	8	25	54
1744	○					8	28	9	21	24
1756					○	11	26	11	26	31
1760				○		2	23	4	28	66
1763	○					10	24	12	3	40
1764		○				2	5	3	10	66
1765			○			12	5	2	4	60
1769					●	1	16	2	17	32
1778	○	△		○		1	15	2	27	43
1779		○				12	20	2	12	53
1780			△			8	26	9	15	20
1782			○			11	1	12	17	47
1783					●					
1788					△					
1796				○		9	30	12	20	81
1801		○				11	15	12	-	
1806			○			-		12	23	
1811				○	○	2	21	4	8	48
1826			○			10	17	1	25	99
1827	●	○				10	27	2	28	92
1828				○		10	21	12	19	59
1830			△			2	11	2	12	2
1837			△							
1838					△	2	22			
1839					●	8	8			
1841	○	●				1	26	2	12	47
1845				○		11	7	12	18	42
1848			○		●	10	16	12	18	63
1853	△	●				12	18	2	13	56
1858				○		11	20	2	2	73
1859		○			●	10	15	12	20	66
1861			△			9	16	-		
1868			○							
1870		●		△						
1871				○						
1884	●	●	●	●	●	2	27	4	5	39
1889										
1891	△	△	△	△	△			3	28	
1895			○					12	23	
1897	△	○						6	3	
1898				○	○	12	-	2	1	
1910	●				●			2	7	
1915				●						
1919	●	●	●	●	●					
1922										
1929				○	○					
1934	○	○	○							
1950										
1952	○	○	○	○	○			12	6	
1968	●					2	8	2	28	21
1969		●	●	●	●	1	14	3	5	51
1979	△				△	11	1	12	10	40
1985	△					1	26	3	25	59
1993	△		△	△		12	25	3	5	71
〃					△	6	1	7	21	51
1994	△				△	6	3	7	30	58
1996	△	△	△	△	△	1	4	3	20	77
2001			○							
2002				○	○					
2003	○	○								

Legend: ○ reconstruction ● repair only steps △ repair works

Having said that, along with the rapid growth of the Japanese economy after WWII, the old traditional Japanese houses started to decrease in number and were replaced by modern architecture. The carpenters are more involved in the construction of the modern buildings, and as a consequence, opportunities for learning traditional carpentry techniques have decreased. The carpenters who were involved in the Heisei reconstruction were all local carpenters from Iwakuni City. However, due to the decline in places for them to practice, problems with the technical skills of the young carpenters were revealed in the early stages of the reconstruction work.

In March 2007, the Kintai Bridge Future Plan Consideration Committee of Iwakuni-shi made a plan for regular bridge reconstruction every 20 years. As a result, the following issues arose:

(1) Personnel training on the ordering party's side (Iwakuni City)

(2) Passing down of carpentry techniques (training of junior carpenters)

(3) Retention of the supply system

In short, the systematic problems of passing down the carpentry techniques were resolved, but quite a few specific methodological problems still remain.

3.2 The methods of passing on the carpentry techniques during the Heisei reconstruction

During the Heisei reconstruction, the total construction process was recorded, even the manufacturing of the metal parts and processing of the wooden members, by taking photographs, filming by video camera, drawing by 2D-CAD, and detailed hand drawings in addition to the carpenters' oral transmissions to each other. However, it seems that the following three points are difficult to record by these methods.

(1) It is impossible to view the structure of Kintai Bridge from an angle or cross-section of one's own choice, for example, a view with only the bridgeboards removed or looking straight up from under the girders.

(2) It is difficult to get a detailed view of the joint shapes and how the members are assembled from one's chosen angle.

(3) It is impossible to forward and rewind time while keeping the angle and objects fixed.

3.3 Proposal for the use of 3D-CAD

This study proposes the use of 3D-CAD for Kintai Bridge, as one option for transmission of the carpentry techniques. Compared to 2D-CAD, 3D-CAD has a high degree of reproducibility in terms of dimensions and three-dimensional shapes, and it is more suitable and useful for complicated structures such as the Kintai Bridge. In short, it is not only useful for the passing on of the carpentry techniques, but can also be made useful in the following two ways.

(1) Collective preservation of specialized knowledge and techniques

By drawing up 3D-CAD models based on the actual drawings, the full scale information can be preserved as a whole. Furthermore, with the aim of inscription on the World Heritage List, it is useful for sharing knowledge about the techniques, and for submitting information to the Agency of Cultural Affairs and ICOMOS.

(2) Provide information for academic use

Not only for children's education, but it can also be used as learning material for lifelong learning for adults. It creates a great opportunity for local residents to learn about the detailed structure and manufacturing carpentry techniques, which they would generally never have the chance to learn. Moreover, it may bring about awareness on the part of the local people and encourage them to seize the initiative to protect the precious asset for the future. Also, as the contents of an Internet digital museum,

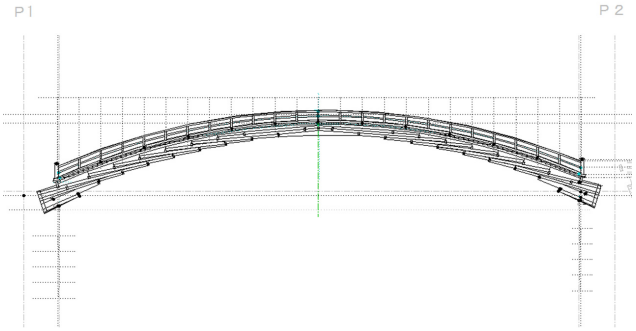

Figure 4.1 2D-CAD drawings

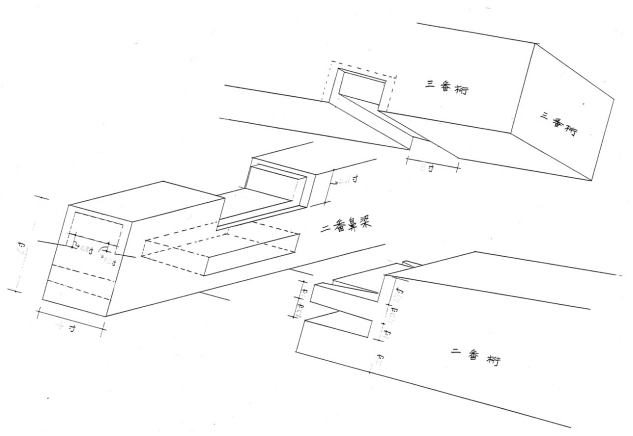

Figure 4.2 Derailed Hand drawing

it could be opened up to people in Japan and even all over the world.

4. A CONSIDERATION OF THE USES OF THE 3D-CAD OF THE KINTAI BRIDGE

4.1 Making the 3D-CAD Kintai Bridge model

4.1.1 Drawing references

The 3D-CAD drawings are drawn based on the official drawings of the Kintai Bridge at the time of the Heisei reconstruction. A carpenter on active duty who was also the former senior managing director of the Traditional Architecture of Iwakuni Cooperative (present chairman of the board of directors) drew the drawings. The drawings referred to are of the following two kinds, and each exists in considerable amounts.

(1) The plans of the first to the fifth bridges and working drawings such as elevations. (Have partly been drawn by 2D-CAD) (Figure 4.1)

(2) Detailed hand drawings of the member dimensions and joint shapes. (Figure 4.2)

4.1.2 Software used and points to consider on creation

SketchUp 8 from Google, Inc. was used for drawing up the 3D-CAD drawings. The following three points were the reasons for using SketchUp 8:

(1) It is free software, accessible to everybody.

(2) Operation is intuitive and easy to understand.

(3) It is a complete package of drawing, viewing, and animation making.

Great effort was made at the time of creation to determine the shape based on precise information. If by any chance, at that time, the shape of a member could not be determined from the drawings, photographs from the construction process were referred to. Even so, in hard-to-decide cases, the working drawings of the 3D-CAD were shown to the carpenter who drew the illustrations, and their opinion was asked for in order to clarify the parts in question and any errors.

4.1.3 The completed 3D-CAD of the Kintai Bridge

Figures 4.3, 4.4, 4.5, 4.6 are captures of the 3D-CAD drawings.

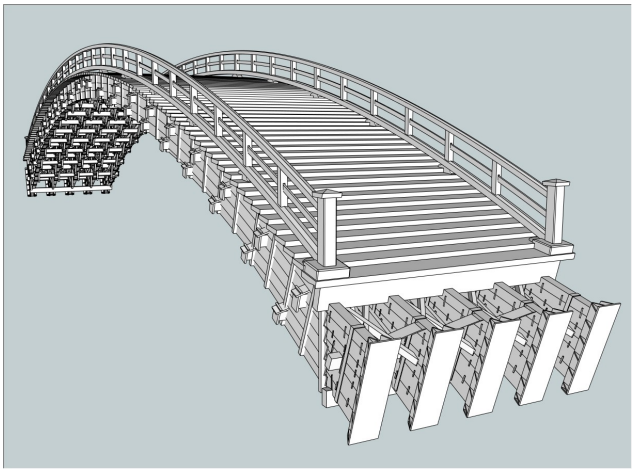

Figure 4.3 The whole of 'Soribashi'

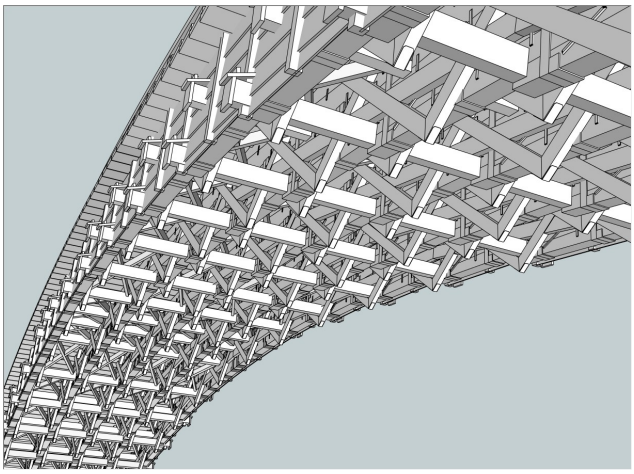

Figure 4.4 Detail of 'Soribashi'

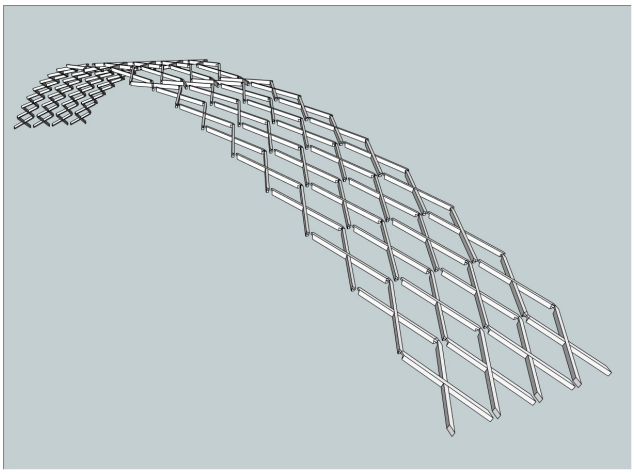

Figure 4.7 Illustration with only 'Furedome'

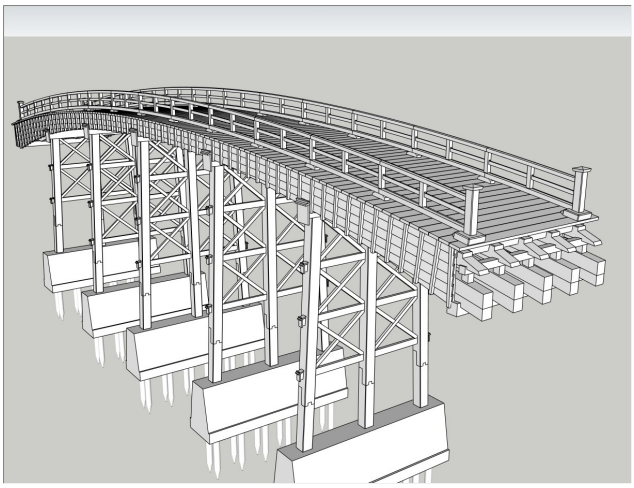

Figure 4.5 The whole of 'Hashirabashi'

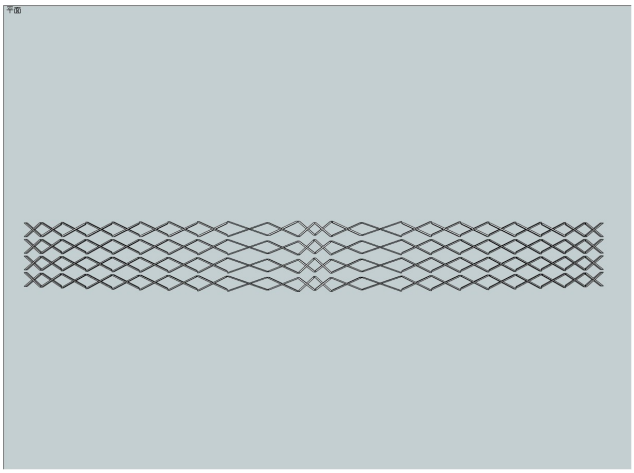

Figure 4.8 Plan of 'Furedome'

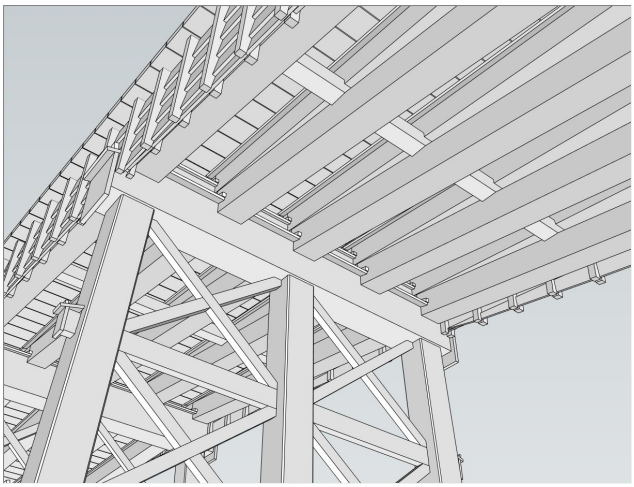

Figure 4.6 Detail of 'Hashirabashi'

4.2 Recommended usage of the Kintai Bridge in 3D-CAD

4.2.1 How to make the most of its use in passing on the carpentry techniques

As a result of showing the 3D-CAD drawings to the carpenters who drew the illustrations, the following usage was found useful for training junior carpenters:

(1) Drawing members which are difficult to draw by hand.

In practice, plans and elevation drawings are essential. However, for the complicated structure of Kintai Bridge, even a drawing can be too difficult to draw at times. The member called 'Furedome,' illustrated in Figure 4.7, is a good example. The Furedome reduces the horizontal

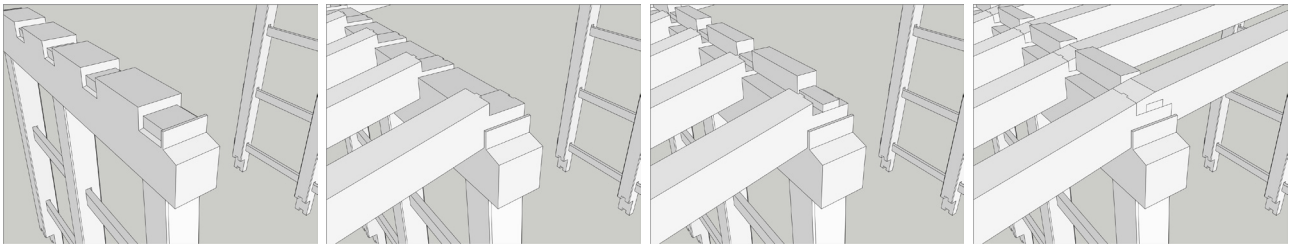

Figure 4.9 Process of assembly ('Hashirabashi')

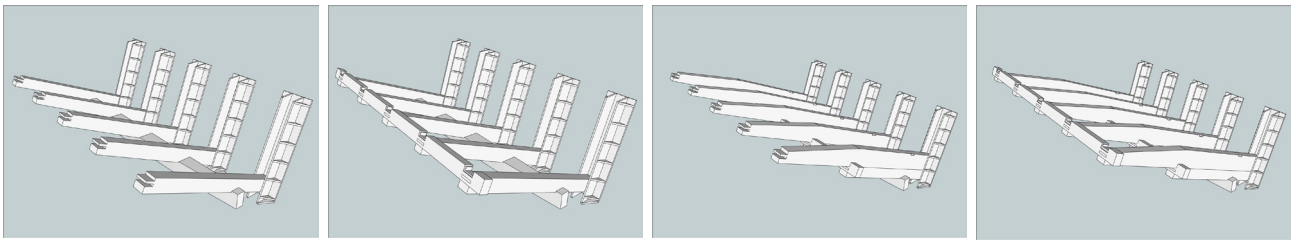

Figure 4.10 Reproduction of the bridge construction process ('Soribashi')

swing against the bridge axial direction. The plan of this member (Figure 4.8), which is positioned on the arch of the Soribashi, can also be easily and precisely drawn in 3D-CAD.

(2) Expression of the assembly of any member; process of assembly.

Although there are many parts assembled in complicated ways by joints, 3D-CAD has the advantage of making it easy to present detailed views and specific images in the actual working situation. (Figure 4.9)

(3) Offering the opportunity to consider one line.

3D-CAD includes all the relevant drawings. So, by looking at it, the junior carpenters who would be in charge of the next bridge reconstruction may wonder about the angle and length of a line and the process from which the shape was derived, and may come up with a question like 'Why does this member need to be shaped like this?'

4.2.2 Recommended uses other than for carpenters

Specific uses other than passing on carpentry techniques were considered in discussions with the relevant administrative agencies that are considering using 3D-CAD for the general public. As a result, it was found to be useful in the following ways. Presently, the materials are under production in cooperation with those administrative agencies.

(1) Saving the 3D-CAD data of Kintai Bridge at the time of completion.

A complete view of the bridge can be shown from a bird's-eye view or by making it seem as though you can actually walk through areas that are in reality not accessible, the whole or the details of the structure can be shown. Thus, not only supplying information to local residents and specialists, but also making use of it to appeal to those outside Japan.

(2) Reproduction of the bridge construction process

It becomes a valuable reference by reproducing the assembly of the members precisely from both macro and micro viewpoints. In addition to that, the characteristics of the structure of the Kintai Bridge can be more clearly illustrated. (Figure 4.10)

(3) Making educational materials

(a) For the education of students and young children

Use to start teaching about the Kintai Bridge in the local schools. Previously, photographs from the building site were used to make materials, but 3D-CAD would make it easier to show clearer illustrations by showing only the required wooden members. It is also likely to help promote the

understanding of both teachers and students.

(b) Use for lifelong learning for the general public.

To be used to spread interest in Kintai Bridge. For that purpose, in addition to (a) above, 3D-CAD is useful for the illustration of the comparison of member shapes, and the equilibrium and transmission of power.

5. CONCLUSION

The following are the results of this study.

(1) The passing on of the carpentry techniques is itself in danger and at this moment in time various measures have been taken to deal with it, such as video recording and photographs. However, this is not limited to the Kintai Bridge.

(2) Use of 3D-CAD would make it possible to record images more detailed than videos and photographs for the passing on of carpentry techniques.

(3) Not only the passing on of the carpentry techniques, but also various other usages are conceivable, such as educational materials for young children, students and the general public, and for presentation to the outside world.

In the future, I would like to search for further possibilities for applying 3D-CAD to the passing on of carpentry techniques and educational use, paying particular attention to the following two points:

(1) Teaching materials for young children, school students and the general public: investigation and improvement

Actually work with schools and instructors of lifelong learning. I would use 3D-CAD itself and the captures as teaching materials and find suggestions for improving it by fixing any issues that crop up.

(2) Consider differentiating with other recording media

In order to capture the real construction situation, the video records and photographs are more suitable. As each media has its own merits and demerits, it is important to indicate the suitability of each recording medium through their comparison.

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