



The evolution of Kigumi joinery

Architectural History Thesis

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Abstract

This thesis researches if the traditional Japanese woodworking technique, Kigumi, can offer a solution for a circular and biobased building industry. The construction sector is currently responsible for about 37% of global CO2 emissions. Although wood is a sustainable alternative to concrete and steel, circularity in modern construction is often limited by the use of glue and steel screws. These methods make it difficult to take buildings apart without damaging the wood, which makes reuse difficult. Kigumi offers a unique solution by using complex, pure wooden joints without glue or metal. In this research, five case studies are analyzed from the ancient Hōryū-ji temple to modern projects like the Tamedia office building and the Expo 2025 ring. The research looks at the technical quality, the level of demountability, and the seismic resistance of these joints. An important part of the thesis is the transition from handwork to modern technology. While Kigumi could previously only be made by specialized carpenters (Miya-daiku), 5-axis CNC milling now ensures that these joints can be produced quickly, precisely, and on a large scale. The conclusion of this research is that the combination of old Japanese wisdom and modern robotics is a realistic path toward a sustainable future. It makes buildings fully demountable, allowing wood to be reused at a high level and drastically reducing the impact on the environment.

1 Introduction

1. Introduction

1.1 Background: Timber Construction and the Need for Circularity

The world is currently facing a big sustainability challenge.

According to the 2021 Global Status Report, the building industry is responsible for about 37% of all CO₂ emissions (Wubbo Ockels School for Energy and Climate, 2024). To solve this, we need to move away from materials like concrete and steel and start using biobased materials. Wood is a great solution because it stores carbon and is renewable. However, just using wood is not enough for a circular economy. The way we put wooden buildings together is also very important. Nowadays, most timber structures use a lot of glue or steel bolts and screws. While this works well for building, it is bad for circularity. Glue makes it hard to recycle the wood later, and steel fasteners often damage the wood when you try to take it apart. This means that at the end of a building's life, the wood is often burned or wasted instead of being reused. To make the building industry truly circular, we need joints that allow us to take a building apart without damaging the materials. A perfect historical example of this is Kigumi, a Japanese way of making dry wooden joints.

1.2 Research Theme and Central Question

This thesis researches if Kigumi can be the solution for making bio-based buildings more demountable and circular. Historically, these joints were made by specialized craftsmen called Miya-daiku. They built temples and pagodas that were very strong and could even survive earthquakes, all without using any glue or metal nails.

The goal of this research is to see if we can use these old Kigumi principles in modern buildings. Because traditional Kigumi takes a lot of manual work, I will also look at how modern technology, like 5-axis CNC milling, can make these joints faster and easier to produce for today's building industry. The main research question is: In how far can traditional Kigumi joinery be modernized through digital fabrication to serve as a sustainable and technically viable solution for demountability and material reuse in modern timber construction?

1.3 Sub-questions

To answer this main question, I have divided the research into the following sub-questions:

- What specific types of Kigumi joints are used in the selected case studies?
- What are the technical qualities, like strength and flexibility, of these wooden joints?
- To what extent can these joints be demounted without damaging the wood?
- How can modern CNC technology help to improve these traditional joints for the future?

2 Theory of Kigumi

2.1 What is kigumi joinery

This thesis is focused on wooden Kigumi joinery because it uses only wood as material in the detail. This Kigumi technique is an old Japanese technique dated out 6 centuries. This detailing in the joinery needs to be super precisely, so it is difficult to make this detail by hand. There are around 200 different kinds of Kigumi joinery all the joints are divided in two groups. Tsugite this is kind joinery is in the length of the fragments. Shiguchi is an angle detail to connect most likely beams with columns, in this thesis it is focused on Shiguchi. There are several technical aspects of Kigumi joinery: mechanical properties & force distribution, seismic resistance and material interaction & sustainability.

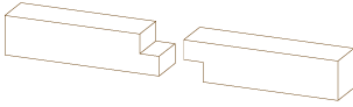
2.2 Mechanical properties & force distribution

The detailing is a 3D puzzle that locks the wooden fragments in different directions. The joint has a big surface resistance that makes the detail strong (Teles, 2026).

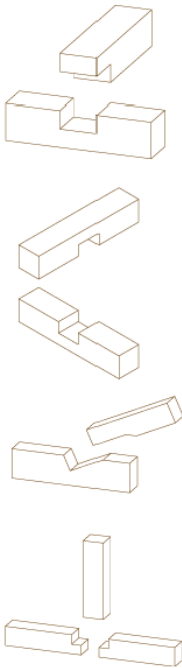
Also, the Joints have a tapered form, this gives a compression preload. If the forces on the joint are bigger the joint gets stronger, because of the tapered form (Shizen-Ya, 2025). For effective joints the pieces need to be exact and less tolerance, about 0,1 – 0,2mm (Reyes, 2025). Currently this is much easier, because there are CNC machines. In the past all this joinery were made by hand.

2.3 Seismic resistance

Seismic resistance is the earthquake resistance of the joinery. The joints have a small movement slack of 2 – 5mm, so the joinery can dissipate the power of the earthquake trough this slack (Shizen-Ya, 2025). The property of wooden elasticity is important to move back to the normal form after the earthquake (Reyes, 2025). So wooden properties ande the slack of movement in the joinery gives this a good seismic resilience.



Tsubite 継手



Shiguchi 仕口

Figure 1 Tsubite and Shiguchi joinery from Horace, 2024

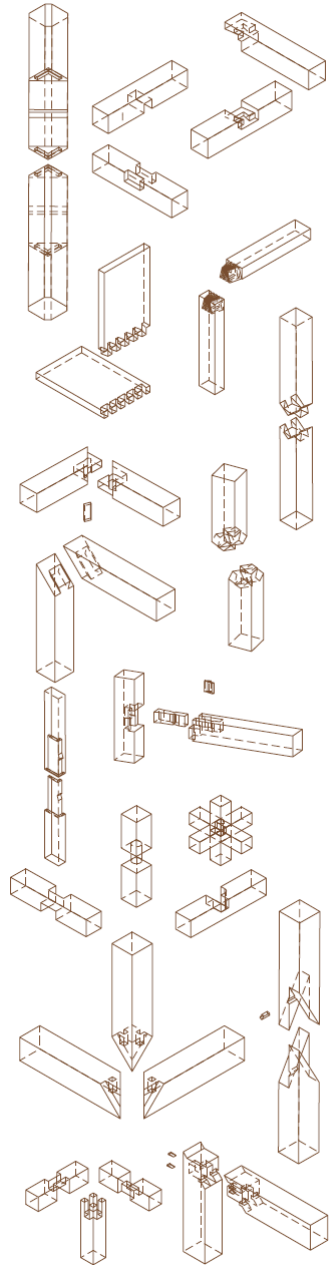


Figure 2 All kind of Kigumi joinery from Horace, 2024 7

2 Theory of Kigumi

2.4 History of Kigumi

The history of Kigumi started in the Jomon period (300 BC) the traditional houses where pit dwellings, made from stone and wood. The connection between the wood was with lianas, there where no tools yet. After this period the iron revolution was a turning point. Tools were produced in Korea and were imported by Japan the first wooden joinery was made; the first joint was mortise and tenon which is used in Tammedia office which has a case study later in the thesis. This innovation made the buildings higher, and the first carpenters 'guild was started. After political unification between Korea and Japan in the Tumulus period (250 – 550 AC) the carpenters migrate to Japan. In this period the Ise Jingu complex was first build. The Buddhism revolution was the start of the Asuka period (550-650 AC). This is when the Horyu-ji temple was build which adopted the Chinese bracket system and the temple is now the oldest wooden building. In the next long golden period (9th-19th century) was the Kigumi joinery refined to art form. There were multiple architectural styles from castles to three rooms. In this period the craftsmanship became more diverse and more complex. At last, we have the current period from 1868 when the Meiji restoration was. This is where steel becomes involved in the joinery. This was to make joints stronger and faster. It also could be the end of traditional Kigumi joinery because it was no longer only wood connections. Later in last 20 years the cnc machine was a solution to fabricate fast and complex joinery. This made the Kigumi joinery more common and easier to use in usual buildings.

2.5 Material Interaction, Demountability, and Circularity

Wood is an organic material that can expand and contract by temperature and humidity, because of the use of only wood this isn't a problem. If there are nails or screws involved the wood can crack over time (Reyes, 2025). Also, metal can have corrosion what attacks the wood (Shizen-Ya, 2025). Wood stabilized over time the form gets more stabilized, so the joints are stronger over time. The Kigumi joinery is a dry connection which is easy to detach. The demountability of the joinery makes it easier to transport or replace the fragments (Reyes, 2025). This is a circular way to maintain the building or give it another destination.

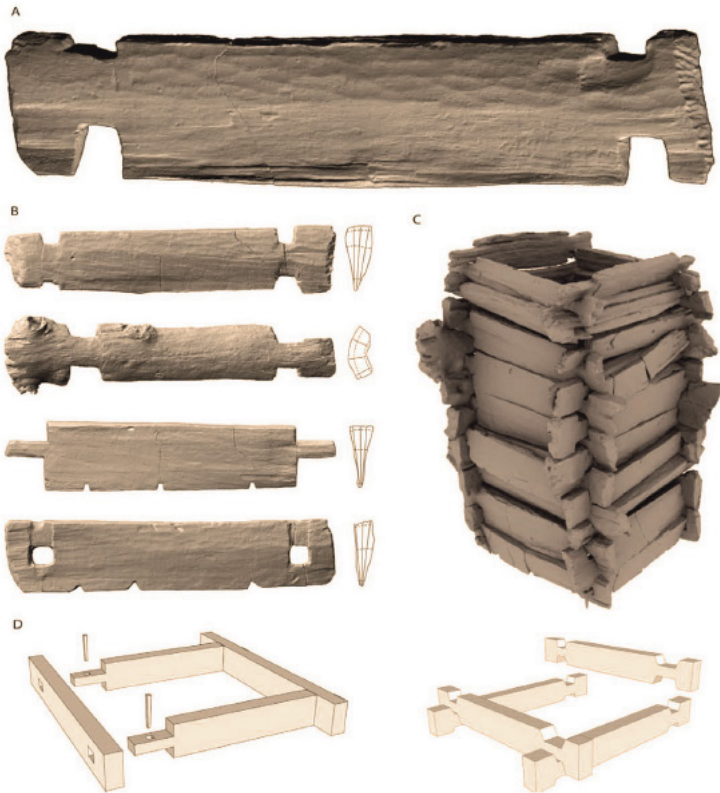


Figure 3 Hemudu marsh area, earliest joints from Traditional Japanese wood joinery and its modern translations, by F. Horace, 2024.



3 Case Studies

3.1 Ise Jingu Complex

3.1 Ise jingu complex

What is the Ise Jingu complex

The Ise Jingu complex is perhaps the most important practice of Japanese timber. It is a symbiosis between structure and environment. The complex is first made in the 4th century and every 20 years it is taken deconstructive to build the new structure near the old site (Foster + Partners, z.d.). The old structure is exported somewhere else in the country to reuse the building. The vision for the rebuild every 20 years is to maintain the Japanese joinery techniques in the generations. The complex is a short of catalogue and exam piece for the new wooden joinery masters.

3.1.1 Wooden joints

There are many kinds of wooden joints in this project, so it is hard to focus on one example. In this case study it is about all the different Kigumi techniques, the beauty of the joinery. The design of the buildings or joints aren't important then the current wooden joinery in architecture. Trough the time in this complex the joinery becomes more complex. The joint is made by hand; this is hard to make because of the little margins on the joints. In Japan it is also now a real craftsmanship (Foster + Partners, z.d.). It is hard to study one of the joints that are used in this complex, because there are many different joints and the craftsmanship is part of the culture, so it is sort of classified information (Potter, 2023).

3.1.2 Sustainability

This project is special because of the age of it; in the beginning of this complex, it wasn't the purpose to make it sustainable. It is the culture and craftsmanship that used the wood and dry joinery without any nails. Also, the design to rebuild it every 20 years was more to contain the craftsmanship then make it demount able for reuse it. In 1920s the builders wants to take the wood local from the forest nearby (Foster + Partners, z.d.). So this is when they become more aware of the sustainability. This project is a good inspiration to make buildings more demount able and sustainable. The techniques that are in this complex are useful to research and implementing it in modern buildings. The building industry had big improvement over the centuries, but this complex is still inspiring architects to use this knowledge.



Figure 4 Architectural picture of the main sanctuary at Ise Jingu showing the thatched roof and gold-capped timber beams (<https://jref.com/articles/ise-grand-shrine-ise-jingu.556/>)

3.1 Ise Jingu Complex

3.1.3 Conclusion

The Ise Jingu complex is sort of the beginning of the Kigumi joinery and for 16 centuries still the masterpiece for this kind of craftsmanship. The joints are getting more complex trough the time but always made by hand. The sustainability started more attached to the culture and tradition. Later it was also part of the solution to make the building industry more circular and sustainable. The building industry grows and evolves; the complex is for 16 centuries almost the same. However, the current architecture is now inspired by the Ise Jingu complex. So, this project is the inspiration for the modern buildings that use Kigumi joinery.

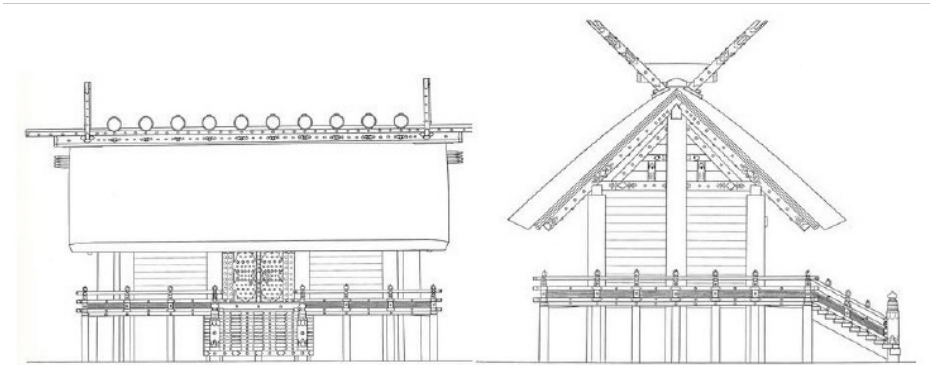


Figure 5 Ise Jingu Temple drawing, front and side view, Naiku from Traditional Japanese wood joinery and its modern translations, by F. Horace, 2024.



Figure 6 Ise Jingu Naiku (<https://www.isejingu.or.jp/en/about/index.html>),
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3.2 Horyuji Temple

3.2 Horyuji temple 604 AC

This temple is the worlds oldest wooden building; it was the first site in Japan on the UNESCO world heritage list. It is a masterpiece of wooden architecture with Kigumi joinery. The temple had survived typhoons, earthquakes and it is still strong today, because of the skilled carpenters. The bracket system is first used in this building from influence of China; this system is to stack multiple beams to get more friction and strength (Horace, 2024). This kind of joinery is mostly used for big roofs and has good seismic resistance which is for earthquakes. The wood they used in this temple is cypruss, the cypruss trees in Japan where huge and over 2.000 years old (Foster + Partners, z.d.). The Japanese aren't only good in the manufacturing from the wood details but also knew which circumstances keep the wood in quality. Take the stronger wood in the columns and prevent rotting through keep the wood dry (Foster + Partners, z.d.).

3.2.1 Wooden joints

There are two main wooden joinery that make the high rise and durability for earthquake and typhoon possible. First the bracket system (the toukyo) this type of joint is imported from China. This joint has a lot of friction surface which is capable for take a lot of weight. Also, this joinery has seismic resistance which make it durable for earthquakes, because the joints are little elastic it could have movement. The second type of joint is central pillar (the sinbashira) which made the height of the temple possible. First this pillar was more a Buddhism symbolic for spirit pillar, later it was the heart of the construction. This strong wooden pillar was the stabilisation of the temple where it has bearing the entire weight of the building and counterbalance during seismic activity (Yoshino). This pillar is in the modern architecture sort of an elevator shaft which gives stability in high rise buildings. And inspired Tokyo Skytree and Yokohama landmark tower.

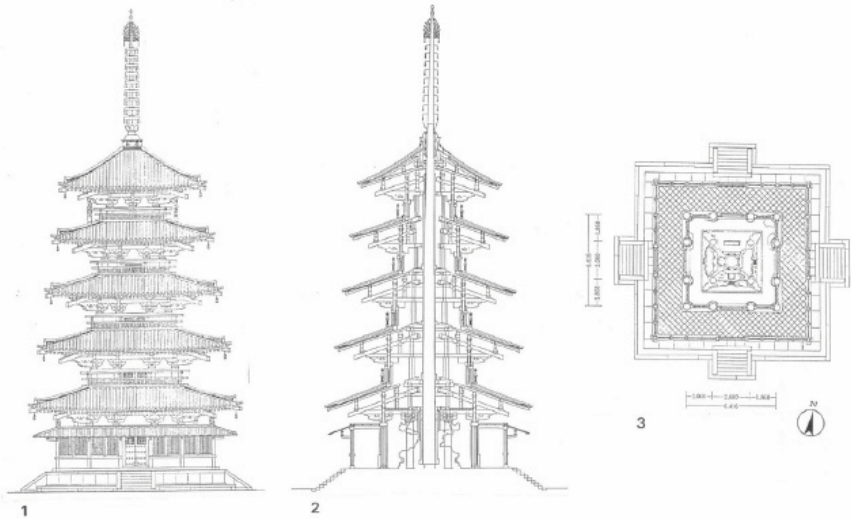


Figure 7 Horyu-ji Temple drawings, front, section and topview from *Traditional Japanese wood joinery and its modern translations*, by F. Horace, 2024.



Figure 8 Bracket joinery detail from *Traditional Japanese wood joinery and its modern translations*, by F. Horace, 2024.

3.2 Horyuji Temple

3.2.2 sustainability

Because the building is the oldest wooden building it can be described as the most sustainable building to. The age of the temple is because the Japanese carpenters are using knowledge to keep the wood in good condition. The joints are dry and demountable this means that it is possible to demount parts without breaking the whole structure down. This make restauration from rotten beams easy and sustainable. the temple is kept so long in good condition, because parts can easily be repaired by replace them and the placement of the wood prevent rotting. So other than the Ise Jingu complex it is also demountable but more for replace broken parts than rebuild the whole building in another site.

3.2.3 conclusion

The bracket system that is used in this project allows movement in the joint which is good agains seismic force. This System can also take a lot of weight by distribute in to different beams. In this project the knowledge of the wood properties is also important. The Japanese carpenters knew that shade results in less efficient drying process, which is important to prevent rooting from wood. Also the central pillar was a new structural column that gives the opportunity to build high. This was first a religion piece in the building what later become inspiration for other high-rise buildings. So, the oldest wooden building is the biggest inspiration of the durability for wooden buildings. Because the parts can be demounted separately it is easy to repair the building which make it circular.



Figure 9 The Five-Story Pagoda of Hōryū-ji, showing the bracket system
Note. From *Fibre to fibre: Japanese timber joinery*, by Foster + Partners, n.d., (<https://www.fosterandpartners.com/insights/plus-journal/fibre-to-fibre-japanese-timber-joinery>).

3.3 Hasley nine bridge golf clubhouse

3.3 Hasley nine bridge golf clubhouse

This project is completed in 2010 and is a golf clubhouse in Yeosu in South Korea. The architect Shigeru Ban is known by the innovative use of material, the roof structure in the clubhouse is the specialty of this project (Viva, 2021). In the roof is also the wooden joinery the main subject of the design. The joinery is not only aesthetic and a tribute to the Japanese craftsmanship, but also that complex organic structure can be solved by modern advanced wooden joints (Viva, 2021). This building has a big contrast with two natural materials but very different. The wooden roof structure is more organic and calmer appearance with a open space for the reception and lounge. Against the natural hard stone where the more closed spaces are.

3.3.1 Wooden joints

The roof structure is a complex grid with many of the same wooden joints that are combined the structure what give is stability and strength. This is the beauty of Kigumi joinery that on many points are surface friction that gives the strength to the structure. The wooden joint detail is not that hard to make, but the complexity of the organic form makes this project special. Therefore needs to be a exact computer model and the joinery needs to be cut in a 5 axle CNC machine (Rondina & Rondina, 2015). The half wood joinery (Aigaki) is a simple joint where half of both wooden beams have half a cut to cross each other (Horace, 2024). The wooden beams in this structure are also laminated and curved to achieve the organic structure. The grid structure gives the opportunity to have big spans with the wooden property.

Type

仕口 Shiguchi - Angle Joints

Name

相欠き Aigaki

Note

Halving joint

Etymology

相 ai - mutual
欠き kaki - notch

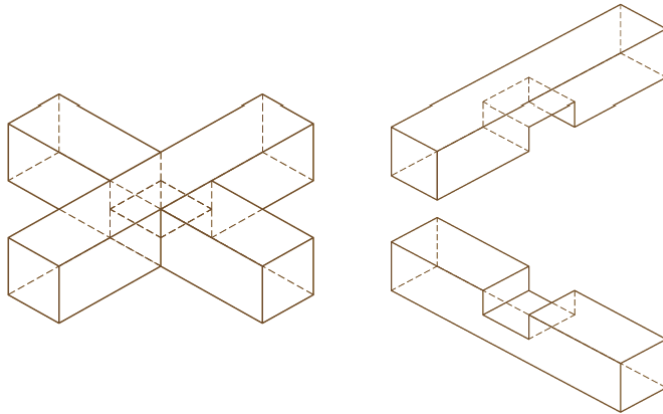


Figure 10 Aigaki joint from Traditional Japanese wood joinery and its modern translations, by F. Horace, 2024.



Figure 11 Detail view of the timber roof nodes at the Haesley Nine Bridges Golf Clubhouse from Haesley Nine Bridges Golf Clubhouse, Yeosu - Shigeru Ban, by Arquitectura Viva, 2021, (<https://arquitecturaviva.com/works/club-de-golf-haesley-nine-bridges-0#>).

3.3 Hasley nine bridge golf clubhouse

3.3.2 Sustainability

The project has four different aspects on the sustainability; material, joint, demount ability and data. First the material wood is the most obvious, wood have CO2 storage and is a renewable material. The use of wood in this kind of project is a risk, because of the fire safety and the big spans in this project. The half-cut joints are important for the strength of the roof structure and connection without steel or glue (worldarchitecture.org, z.d.). Although there are some steel connections in this project where it has to be for safety reasons. So, the philosophy of only wooden joints is mostly not that strong or safe by the building regulation. The dry wooden joints are demounted able, so it could be used after life span in a new environment. Although the structure is unique and have 4500 wooden components which are different, so it cannot be easily assembled in a different configuration (worldarchitecture.org, z.d.). At last in this project the engineers had a programme to simulate the grid shell that calculates the most efficient grid structure. This minimized the material waste and material use of the project. So in this project the old Japanese wooden joinery techniques were used and improved by the modern technology.

3.3.3 Conclusion

This project uses one of the simplest wooden joineries (Aigaki) this is used with a complex structure that makes the project special. Not only aesthetic beauty of Kigumi joinery also the strength of this joinery is visible in this building. Although the Aigaki joint is an old technique with new computer systems this project accomplished a complex organic structure. The joints in this project are not handmade like Ise Jingu complex but with a 5 axle CNC machine. This is needed because of the double curved joints. The philosophy of demount ability of Kigumi joinery is possible but the project can not be reconfigured. But the Kigumi joints gives the wood extra strength to have big spans. So, this project is a good example of combine the modern building techniques and the old Kigumi technique to accomplished stronger and more complex structures.



Figure 12 Haesley Nine Bridges golfclubhouse (<https://www.blumer-lehmann.com/en/references/referencetimber-haesley-nine-bridges-golf-resort.html>)



Figure 13 Vertical column transition into the ceiling grid at the Haesley Nine Bridges Clubhouse from Haesley Nine Bridges Golf Clubhouse, Yeosu - Shigeru Ban, by Architectura Viva, 2021, (<https://arquitecturaviva.com/works/club-de-golf-haesley-nine-bridges-0#>).

3.4 Yusuhara wooden bridge museum

3.4 Yusuhara wooden bridge museum

This building is made in 2011 by the architect Kengo Kuma who is known for the use of the old Japanese techniques (Yusuhara Wooden Bridge Museum, z.d.). For this project Kengo use the Agokaki joint, this made the overhang possible. For this project the overhang is made from many small sections. The building stands on the bridge which has only one column, the roof is the same principle as the bridge. The overlapping system that also is used in brick structure makes the bridge strength. The wooden bridge is symbolic for connection between historic and modern techniques. Also, the bridge between the old and new building.

3.4.1 Wooden joint

The wooden joinery in this project is Agokaki which is similar to the joint in the golf clubhouse. The joint is less then half cut, so the joint does not have that much friction (Horace, 2024). In this project the joint is more to get the wooden beams together and fixed it in place. The strength of the structure is from the cross laying of the beams that are systematic get bigger. So, the Japanese wooden joints are used as a simple fixation between the beams to have a dry wooden connection. The modern part of this project is that with the modern data it is easy to calculate the forces on this project (Yusuhara Wooden Bridge Museum, z.d.). It makes the big overhang possible with wood which is a less strong material than steel. This shows that the modern architecture is solved by old techniques which conducting for the climate goals.

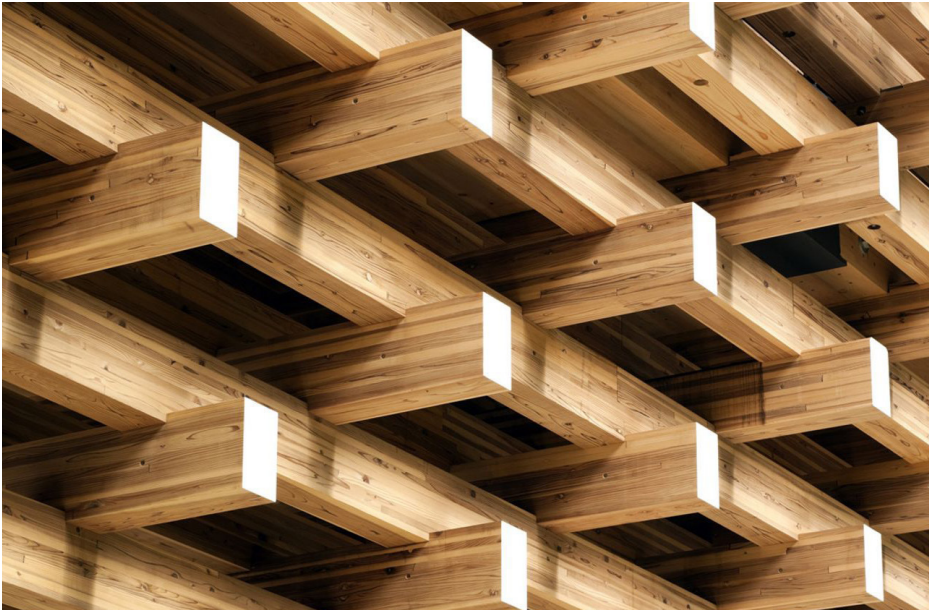


Figure 14 The cantilevered structural system of the Yusuhara Wooden Bridge Museum from Yusuhara Wooden Bridge Museum, by Kengo Kuma and Associates, n.d., (<https://kkaa.co.jp/en/project/yusuhara-wooden-bridge-museum/>).

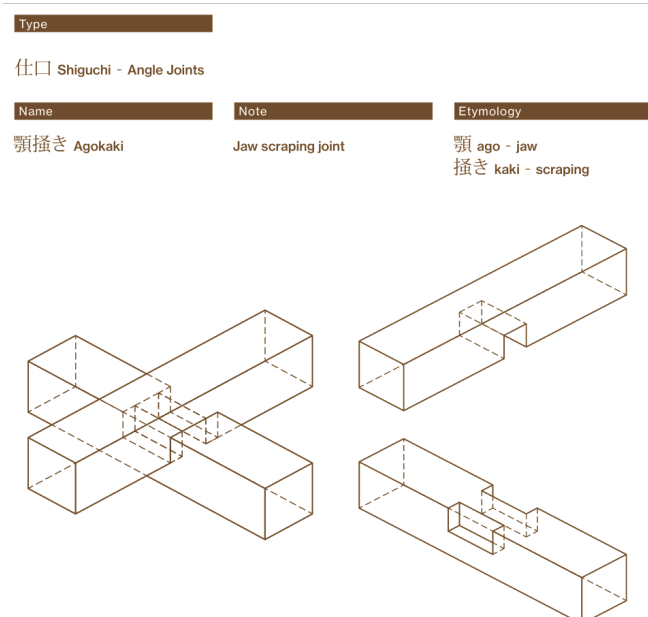


Figure 15 Agokaki joint from Traditional Japanese wood joinery and its modern translations, by F. Horace, 2024.

3.4 Yusuhara wooden bridge museum

3.4.2 Sustainability

In this project there are a couple of sustainable principles; local wood source, demount ability and material efficiency. First the material chois from Kengo Kuma is to harvest it local. Wood is very sustainable the largest amount of CO2 emissions in wood is processing and logistic. So, if it is local wood it is much more sustainable. This project is a good example of demount ability; the connection is simple. Also, the properties of the wooden beams in this structure can easily be reused. Because of the small gaps in the wooden joints and straight lengths of the beams. The small section in the beams are also important for the material efficiency. How smaller there is less waste, and smaller tree could provide the beams. Despite the small section with the cross-laying structure, it gives the strength it needs. In this project there is unfortunately still steel tie rod for the tensile force. This could be improved by a joint that gives more strength.

3.4.3 Conclusion

Yusuhara bridge museum made by Kengo Kuma is a tribute to the Japanese Kigumi joinery. Despite it use a simple and not major carving from the wood it is a strong structure. This is because it uses a cross laying system where the beams get longer in phases. The architect use for this system a simulation to calculate the strength and minimal use of material. This combines with the local wood and demount ability it makes the project sustainable.



Figure 16 Detailed view of Bracket system Yusuhara bridge museum (<https://www.archdaily.com/199906/yusuhara-wooden-bridge-museum-kengo-kuma-associates>)



Figure 17 Detailed view of roof inside Yusuhara bridge museum (<https://divisare.com/projects/310486-kengo-kuma-and-associates-takumi-ota-yusuhara-wooden-bridge-museum>)

3.5 Tamedia office building

3.5 Tamedia office building

This building is made in 2013 by the architect Shigeru Ban; it is an office building in Zürich. This project is an example that wooden Kigumi joinery can be implemented for big commercial buildings. There is one complex joint in this building that characterizes the design of the project. Shigeru Ban makes the design a good combination with the traditional Japanese technique and modern city aesthetics (Yoann, 2023). The wooden joint is a variant on 'Kashigi ooier hozo sashi' joint, which is an angle joinery with wooden dial (Horace, 2024).

3.5.1 Wooden joint

The joint in this project is a good example of the modern variant on Kigumi joinery. It is a simple wooden dial system that has great aesthetic design aspects. Figure X is the original Kigumi design. Because of the big load on the dial is this stronger and denser wood. The beams are pine wood and for the dial the architect used beech wood, to absorb the forces. The oval dial shape is to block any movement in the joint. In this project it is important to have minimal movement in the joint to absorb the forces of seven stories above (Japanese Details & Swiss Precision - Trä Magazine, z.d.). This kind of joint is also used in old Japanese temple building Like Ise Jingu complex. This project use over 3600 pine trees, the trees need to be slow growth to have more dense and strong wood (Japanese Details & Swiss Precision - Trä Magazine, z.d.). This project has also a complicated Cad file that is made by a 5axle CNC machine to minimize the failures in the joint. For bigger buildings and modern building regulations the joints must be the same.



Figure 18 Detail joint Tamedia office building (<https://www.ubm-development.com/magazin/tamedia-building/>)

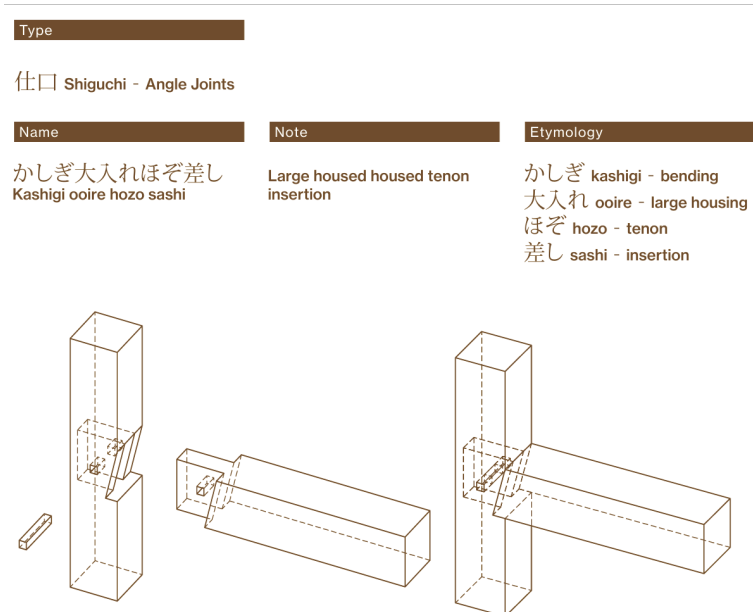


Figure 19 Detail Kashigi ooire hozo sashi from Traditional Japanese wood joinery and its modern translations, by F. Horace, 2024.

3.5 Tamedia office building

3.5.2 Sustainability

This building structure is completely out of wood not extra metal to join or absorb tensile forces. It is also demountable because of the dry connection. The dimensions of the beams are big, so it is easy to reuse or give it another life. The wood is slow grown this means that it is stronger and the forest is more sustainable than the fast trees industry. There is 2.000 cubic meters wood in this project, so there is a lot of CO2 storage (Japanese Details & Swiss Precision - Trä Magazine, z.d.).

3.5.3 Conclusion

This project use for the structure only wood which is impressive for the size. Because of the open floor plan, it can be used in different configurations. The dry wooden joints make the building demountable. The dimensions and single material give the opportunity after life span more variations and easier. The wooden dial joint is an example of the modern Kigumi joinery. The new intelligence for this technique makes the size of the projects bigger.



Figure 20 Interior structure Tamedia office building (<https://www.archdaily.com/478633/tamedia-office-building-shigeru-ban-architects>)



Figure 21 Exterior Tamedia office building (<https://hicarquitectura.com/2014/04/shigeru-ban-architects-tamedia-office-building/>)

4 The historical evolution of Kigumi

4.1 Kigumi in modern architecture

The Ise Jingu complex has the traditional Kigumi joinery techniques. In the other case studies these techniques are implemented in the joinery of the projects. By the clubhouse and bridge museum is also metal implemented in the construction. Only by the Tamedia office building they succeed to need only wood as construction. This means that the Kigumi technique is not so easy to implement in the modern architecture. The building regulations could be the problem. Wood is a great material, but the proportions are not consistent, for metal the strengths are the same. The case studies have implemented the joinery in their own design. The bridge museum has the most traditional joint, the design is not adapted. The other two joinery are modern variants; because of the complex design the joints need to be cut by CNC machine. This is also a big improvement for the joinery techniques. Despite the modern machinery the Ise Jingu complex is new hand made every 20 years. This for contain the knowledge about the traditional joinery. It is for the Japanese more a culture, this is why the modern architects use the Japanese technique as a tribute in the design. So, the old techniques are implemented in the modern architecture with new machinery and complex simulation programs. This makes it possible to have big buildings like Tamedia Office.

4.2 Kigumi in circular economy

The most important feature of the Kigumi joinery for the circular economy is the demount ability. It starts with the Ise Jingu complex which is demount every 20 years for 400 years long. With the modern projects it is possible to demount the structure but the designs is so specific that the configuration possibilities are limited. So, to have a more modular system with common dimensions is more sustainable. Wood is the other big aspect which make it circular. It is a renewable material which storage CO2. To conclude the Kigumi joinery can be one solution for the circular building industry, but it needs more improvement and better implemented.

4.3 Kigumi with CNC machinery

CNC machinery is a good solution to have multiple joints with the exact same cut out and to minimize the margin of error. This way of machinery is expensive, so it depends on the kind of joint and quantity if it is necessary. In the old hand made Japanese technique are the corners mostly 90 degrees. The machine has round drills this means that 90 degrees inner corner is impossible to make. The wall thickness needs to have a certain thickness; this is because the drill has a lot of speed and forces which could break the thin walls of the joint. There are two different type of CNC machines 3-axis and 5-axis. The 3-axis machine has only movement in x, y and z linear axes, this limits the possibilities. The 5-axis machine can move simultaneously while cutting the wood this give more design possibilities. Most Japanese wood could be made in the 3 axis CNC machine. So, the production of the wooden joints is faster and more precise than hand made. The craft of Japanese woodworking has come to an end with this, using CNC machines.



Figure 22 Kigumi joinery (<https://japanculturalexpo.bunka.go.jp/en/hotspots/629/>)

5 Conclusion

5. Conclusion: The Future of Kigumi

In this thesis, I researched if Kigumi joinery can be the solution for a circular and biobased building industry. After studying old temples like the Hōryū-ji and modern projects like the Tamedia building and the Expo 2025 ring, I can conclude that Kigumi is a very strong option for the future. First, Kigumi is technically very good. The Hōryū-ji temple proves that these joints can stand for more than 1000 years and even survive heavy earthquakes. Modern architects like Shigeru Ban show that we can still use this technique today for big buildings, without needing any steel or glue. Second, modern technology like 5-axis CNC milling is the most important factor. In the past, only master carpenters (Miya-daiku) could make these joints by hand. This took too much time and was too expensive. Now, we can use CNC robots to make these complex joints very fast and precisely. This makes Kigumi a realistic choice for the modern building industry. Finally, Kigumi is great for the environment. Because no glue or metal screws are used, the joints are easy to take apart without damaging the wood. This is perfect for the circular economy, because we can reuse the wood directly for something new after a building is demolished, instead of burning it. In short, by combining old Japanese knowledge with modern robots, we can make sustainable and demountable buildings that are ready for the future. It helps us to produce less waste and build better with natural materials.

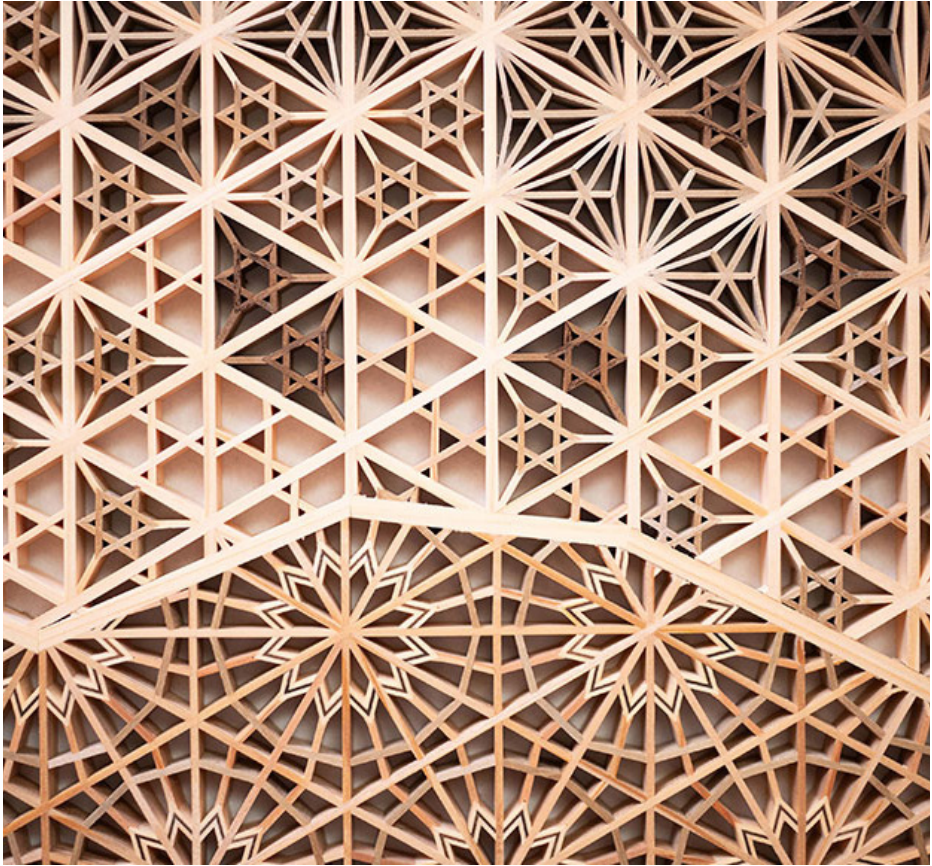


Figure 23 Kigumi joinery (<https://japanculturalexpo.bunka.go.jp/en/hotspots/629/>)

6 Discussion

The results of this thesis show that Kigumi joinery has a lot of potential for a circular building industry. Although the case studies prove that it works, there are still some challenges that need to be solved before Kigumi can be used on a large scale in practice. One of the biggest points is the price and the economics. Even though 5-axis CNC milling makes producing Kigumi much faster than before, it is often still more expensive than using standard steel screws or glue. In the current building industry, speed and low prices are often more important than circularity. To make Kigumi a real standard, the industry needs to look more at the long-term benefits. This means looking at how easy it is to take buildings apart and the high value of the wood that can be reused, instead of only looking at the lowest construction costs. Also, there are the building regulations and safety. Most modern rules, like the Eurocodes, are mostly written for structures made of steel and concrete. There is still not enough official data on how complex wooden joints behave during a fire or under extreme pressure in modern high-rise buildings. Even though the Shinbashira in the Hōryū-ji pagoda works great against earthquakes, we need more modern tests in labs to prove to building authorities that these joints are also safe for modern buildings in Europe.

Another problem is the lack of knowledge among designers. Designing Kigumi joints requires a lot of specific knowledge about wood grain and geometry. Most architects and engineers today are not trained to design these kinds of pure wood-on-wood joints. To implement this more, we need better software tools. Parametric design could help architects to automatically calculate the best joint for a specific part of the building, so you don't have to be a master carpenter to design it. Finally, more research is needed on different types of wood. Traditional Kigumi is mostly based on Japanese wood types like Hinoki (cypress). Future research should focus on how these joints work with European wood types, like oak, pine, or spruce. Every type of wood reacts differently to moisture and pressure. It is important to know which Japanese joints can be translated best to our local materials.

In the end, Kigumi is more than just a beautiful way of building; it is a technical system for the future. By investing more in research on CNC production, software, and updated building rules, we can bridge the gap between old Japanese tradition and the modern need for a circular economy.



Figure 24 Japanese temple (<https://excellent-japanese-wood.com/en/technology/column06/>)

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