

Design Guidelines to Moisture-Responsive Wood Veneer



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Designer guidelines - moisture responsive wood veneer

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A close-up photograph of a stack of light-colored wooden planks, showing their natural grain and texture. The planks are stacked in a slightly overlapping manner, creating a sense of depth. In the top right corner, there is a large, white, sans-serif number '1'.

1

INTRODUCTION

These guidelines introduce a shape-morphing wood veneer developed for responsive design applications. The material is an oak veneer that bends back and forth in response to environmental moisture changes. The bending response is created by using the wood's natural response to moisture and enhancing it through a specific manufacturing process.

The guidelines are intended as a design tool, making this material performance accessible and usable for designers. By translating experimental findings into design-oriented knowledge about the material, the guidelines act as a bridge between material research and design practice.

The guidelines are written based on the outcomes of a material research leading to a singular performance of oak wood veneer. Different variables are described that can be adjusted to influence the performance, primarily in terms of design outcomes. Although the scope of the guidelines is relatively focused, the underlying principles are relevant for understanding how wood veneer in general reacts to moisture and can be used as a starting point for further research with other wood species or applications.

Chapter 2, *Wood and curvature*, explains the relevant background information on the basics of wood structure, wood veneer and wood species. It then explains how curvature in wood can be designed through the creation of bilayer structures and the application of hot water treatments. Chapter 3, *About the material*, introduces the moisture-responsive wood veneer that forms the basis of these guidelines. It describes in detail what the material is, how it performs, how it is manufactured and how its performance can be controlled. Chapter 4, *Material limitations & opportunities*, outlines the constraints of the material that should be considered when working with it, possible material exploration opportunities, and scaling of the material and manufacturing stages. Chapter 5, *Sample structures*, applies the described material in several examples of sample structures. Each example has its own unique design and manufacturing method. Finally, Chapter 6, *Inspiration*, presents possible applications of the moisture-responsive wood veneer in an indoor architectural context, providing an impression of its potential possibilities.



2

2.1 The basics of wood structure

2.2 Designing curvature

WOOD AND CURVATURE

2.1 The basics of wood structure

What is wood veneer

Wood veneer is made by thinly slicing a log into sheets and is commonly used for decorative and surface applications. The orientation in which the wood is cut influences the material properties and the resulting visual appearance of the veneer. Common veneer cutting methods include rotary cut, flat sawn, and quarter cut, each resulting in a different grain pattern (figure 1). As can be seen in the figure, quarter cut veneer provides the most uniform appearance and fiber pattern.

Wood structure

Wood consists of an ordered structure, with annual growth rings in the radial direction and long fibers in the longitudinal direction (figure 2). Wood is a hygroscopic material, meaning it interacts with moisture from its environment. When moisture enters the wood, swelling occurs in multiple directions due to the material structure defined by fiber orientation and growth ring direction. This swelling is not equal in all directions, with the largest amount of swelling occurring in the tangential direction. The uneven swelling causes the wood to bend. This bending response always occurs perpendicular to the fiber direction.

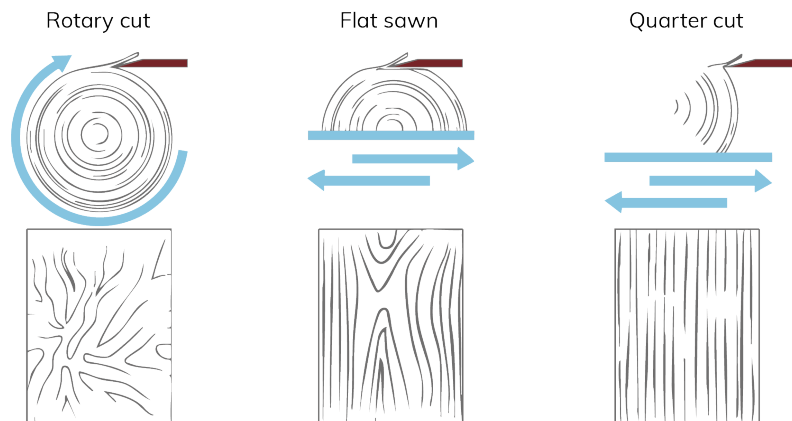


Fig 1. Wood veneer cutting directions.

Wood species

There are many different species of wood. While all wood species respond to moisture in the same way in principle, the specific properties of each species influence how strong and how fast this response is. Zooming in on the structure of wood, each annual growth ring consists of a matrix of cells oriented in the longitudinal direction. Each cell contains a central open space, called the lumen, surrounded by the cell walls. The ratio between cell wall thickness and lumen size varies significantly between wood species. This variation affects properties such as density and porosity, which influence the amount of water absorption and the rate. These factors directly affect the natural bending response of wood when exposed to moisture. Because of these variations between wood species, the response of one species cannot be generalized to other wood species.

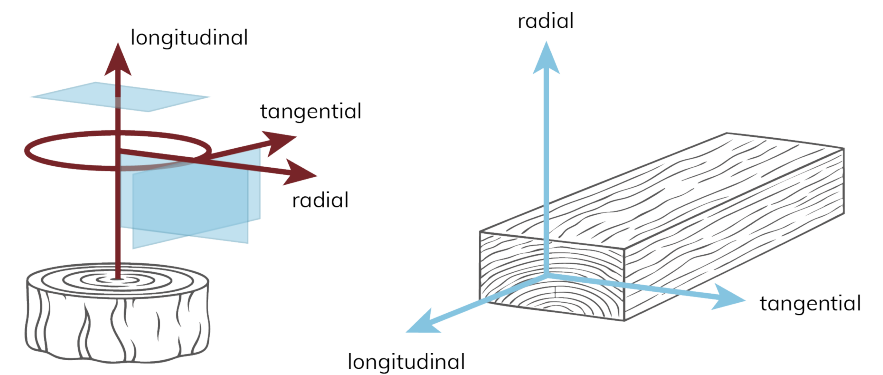


Fig 2. Dimensional directions of wood

2.2 Designing curvature

There are different methods that can be used to enhance the natural curvature and make it possible to design with this material response.

Wood programming

One method is through hot water treatment, referred to as **wood programming**. When wood is heated in water, the internal structure becomes pliable. The lignin, which is the binder that holds the wood fibers together, softens under these conditions. By soaking wood in hot water, the veneer absorbs moisture and swells. When removed from the water, the material begins to curve as it dries. The lignin gradually stiffens again and fixates in the new internal configuration of the curved veneer.

Bilayer structures

Curvature can intentionally be created through bilayer structures. A bilayer consists of two material layers with differing properties. When in contact with moisture, the variation in properties causes each layer to respond differently. Both layers have different swelling and shrinking rates resulting in a bending response. As moisture is absorbed, the layer with the higher swelling rate expands faster, causing the structure to bend towards the less responsive layer. When moisture evaporates, the process reverses and the structure returns towards its original position, the reference state.

Bidirectional curvature

Combining both methods results in an amplified and bidirectional curvature response. When a bilayer structure is programmed through hot water treatment, the material is set into a curved reference state. If the less responsive layer is positioned on the outside of the programmed curvature, the total range of motion increases. When moisture is reintroduced, the layer with the higher swelling rate expands faster, again causing the structure to bend towards the less responsive layer. However since this layer is on the outside of the curved reference state, the material first becomes flat and continues its curvature toward the opposite direction, resulting in a bidirectional curvature response.

3

3.1 Moisture-responsive wood veneer

3.2 Curvature directions

3.3 Testing conditions

3.4 Manufacturing method

3.5 Controlling the performance

ABOUT THE
MATERIAL

3.1 Moisture-responsive wood veneer

The moisture-responsive wood veneer designed and explained in these guidelines is a **quarter cut oak wood veneer with a one sided coating acting as a bilayer**. At around 50% relative humidity (RH), the veneer is in a programmed 'reference curvature'. As the RH lowers, this curvature becomes stronger. When moisture is introduced and the RH rises, the material bends to a curvature in the opposite direction to the reference curvature.

The quarter cut oak veneer is the base material. The combination of oak as a wood species and the quarter cut veneer result in a very uniform material structure, ensuring more reliable results. The veneer is coated on one side with waterproof woodglue, creating a bilayer structure. Waterproof woodglue works well as a coating because it does not soak through the material, thereby creating a second layer. It remains flexible after drying, allowing the coating to bend with the wood. The coating is waterproof and stays on the material with the introduction of moisture.

To achieve the reference curvature, the veneer goes through a hot water treatment, the wood programming stage. The veneer is soaked in a hot water bath of 60 °C for 15 minutes.

3.2 Curvature directions

When wood veneer in its natural form has come into contact with moisture it dries towards one side of the veneer, its natural curvature direction. To simplify further explanations, each side of the veneer has been named based on this natural curvature direction. Figure 3 shows a curved sample with annotated the natural inside curve (NIC) and the natural outside curve (NOC). The woodglue coating of the material is applied to the NOC side of the veneer.

3.3 Testing conditions

The material response has been tested in a controlled environment. In a climate chamber various programs of changing humidity have been tested with a range of 30% to 80% RH at a constant temperature of 20 °C. The fatigue of the material has been tested through multiple cyclic tests in the climate chamber. A change in amplitude between the curvature extremes at 30% and 80% would indicate whether fatigue was occurring. After testing six complete cycles, 96.8% of the initial amplitude remained.

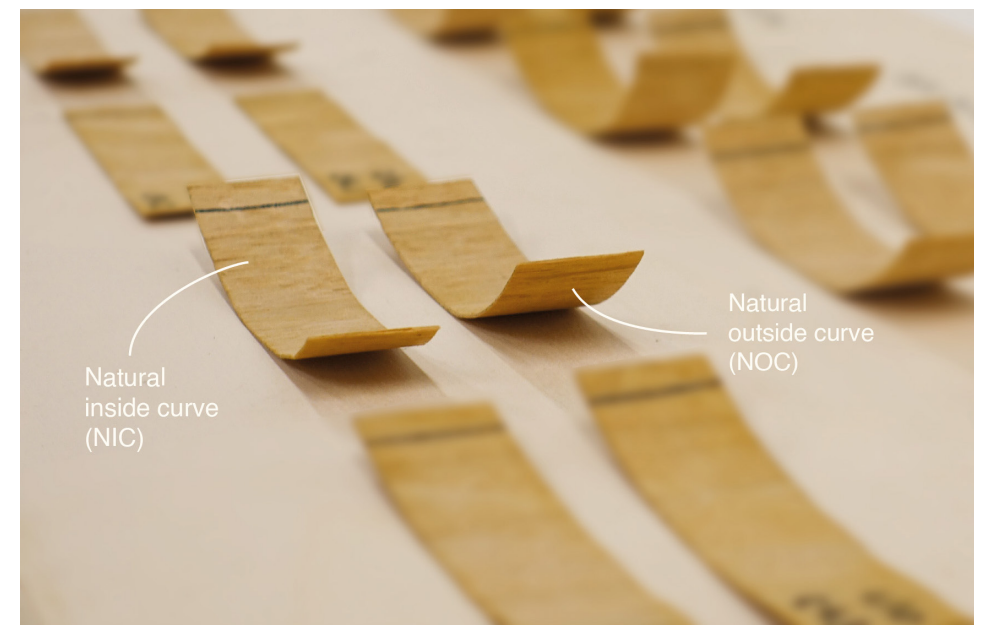


Fig 3. Curvature directions: Natural inside curvature (NIC) and natural outside curvature (NOC).

3.4 Manufacturing method

Test the veneer

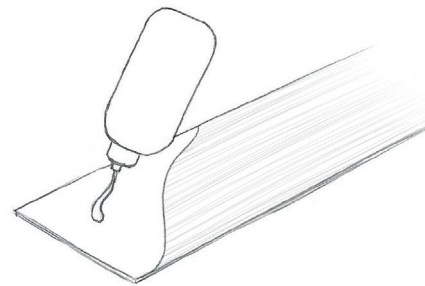
Wood is a natural material and each veneer sheet behaves slightly differently. Before working with the material, the veneer needs to be tested to determine the natural curvature direction.

- Mark all samples on the same side.
- Soak several veneer samples in 60 °C water for 15 minutes.
- After soaking, observe the natural curvature direction of each piece.

1. Apply the glue coating

The first step of the manufacturing phase is coating the material. This can be done before or after cutting shapes. If only certain areas of the sample require coating, it is recommended to coat after cutting the shapes.

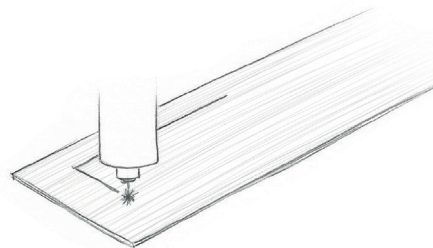
- Apply the glue coating to the outside of the natural curvature side (NOC), as shown in figure 3. One coating layer corresponds to a coating weight of 55 g/m².



2. Design and cut the shapes

Wood veneer always bends perpendicular to the fiber direction.

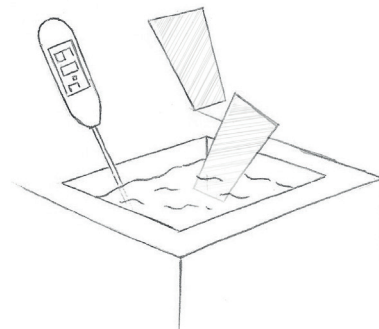
- Decide the fiber direction in relation to your shape based on the desired bending direction.
- Cut the designed shapes from the veneer.



3. Program the samples

- Soak the cut and coated samples in 60 °C water for 15 minutes.
- Remove them and let them dry completely.

After drying, the material is programmed and ready for use.



3.5 Controlling the performance

Although the material has a specific performance and manufacturing process, there are some parameters that can be adjusted to influence the performance. The following aspects of the material curvature performance can be controlled:

Curvature location

The coating layer on the veneer largely influences the curvature response. The placement of this coating can easily be adjusted, thereby influencing where the curvature response will be visible.

Curvature direction

The direction of curvature can be controlled indirectly. Considering the wood structure, the veneer will always bend perpendicular to the fiber direction. However, adjusting the fiber direction relative to the sample allows for some control over the visual fiber direction (figure 4).



Fig 4. Fiber directions and resulting curvature response

Curvature amount

The amount of curvature the material shows is largely dependent on the RH but can also be controlled through the sample design. The thickness ratio between bilayers largely affects the curvature response. Therefore adjusting the thickness of the coating layer influences the amount of curvature. In testing, 1 to 3 layers of coating have been tested. With more coating layers, more curvature was visible.

Instead of literally changing the amount of the curvature, it is possible to visually change the perceived amount of curvature through the design of a sample. Adjusting the length of a sample, for example, affects how much curvature is visible. A longer sample appears to have a stronger curvature because a greater section of the curve can be seen.

Instead of increasing the amount of curvature, there are also ways to limit it. One approach is to apply a second layer of veneer to specific areas, especially with the fiber direction perpendicular to that of the first layer. When designing a structure from multiple veneer pieces, curvature can also be controlled through the method of assembly. By securing areas of the veneer that would be expected to curve, the resulting curvature can be limited.

Chapter 5 presents various sample structure examples. With each example, different parameters for controlling performance are implemented and explained.

4

4.1 Material performance limits

4.2 Exploring variables and opportunities

4.3 Scaling and future development

MATERIAL LIMITATIONS & OPPORTUNITIES

4.1 Material performance limits

The material explained in these guidelines comes with a few limitations to consider when working with it. These findings were acquired through experimental testing and climate chamber testing.

Sample response time

The speed of movement of the material is a complicated characteristic to define. With natural RH fluctuations, the material follows the environmental humidity through constant exchange of moisture between the wood veneer and the environment. During climate chamber testing it was discovered that with fast RH changes, the material needed time to respond. During this test the RH went from 30% to 80% with 1% RH change per minute, stayed constant at 80% for 5 minutes and then returned to 30% RH again with 1% RH change per minute. The veneer needs to adjust to the environment, which therefore creates a delay in response time, in this tested scenario of roughly 10 minutes.

Within the climate chamber tests, this response time was optimized for the test. Resulting in a minimal constant holding time of 30 minutes when the humidity switches from going up to 80% to going down to 30%. In this specific scenario, the fastest response time of the material to keep up with the surrounding environment was 30 minutes.

Connecting this finding to possible design applications, means a delay should be expected with very sudden moisture changes. However if the material is used in an application where it responds to the natural environmental humidity changes, it is expected that these natural changes are slow enough for the material to follow.

Stress relaxation effect

Through the testing phase of the material it was also tested how the material performs at constant humidities. It was found that at high humidities, tested at 80% RH, the material could not retain a constant curvature. While at low humidities the curvature of the material remained the same with a constant RH, with approaching high humidities the material would curve to its most extreme point and almost immediately return while the RH stayed constant. This is likely caused by the high moisture content in the veneer, making the material flexible and limiting its strength.

When using this material for an application, this limitation becomes a design constraint. In high-humidity environments, the material is not suited to remain in an extreme curvature state and might fail or drift from its extreme curvature. A high humidity can initiate strong curvature but the curvature cannot remain like that.

To work with this limitation, there could be possibilities in for example mechanically restraining the material at high humidities. This has however not been tested and would require further exploration.

Natural material variations

Another observed limitation or consideration of the material is the reliability of curvature response. The programmed material makes use of the natural curvature response of wood and enhances this. Therefore most of the natural materials qualities remain. Every piece of wood is different in structure, and no two pieces are identical. Therefore the response of the material is also not always identical, even if treated exactly the same. Where some pieces may have a stronger curvature than others where it would be expected they would show the same response

These natural variations within the material could be viewed as a limitation if the goal is a perfectly predictable performance, but it can also be seen as a beauty of the material. After all, wood is a natural material and this slight difference in performance shows that. It is not a completely engineered material and it still has some of its natural remaining qualities.

4.2 Exploring variables and opportunities

The material explained in these guidelines has been tested on multiple variables. To provide opportunities for further research, certain variables are elaborated on. This is done by explaining the influence of the variables on the current material and possibilities of expanding outside of what has been tested, including the expectations of the impact of changing variables.

Wood species

The species of wood used to create the moisture-responsive wood veneer described in these guidelines is oak. Other wood species that were tested (rosewood, ash, beech, maple and teak) showed varying curvature results. Similar bidirectional curvature behaviour could possibly be created with other wood species, but would require adjustments of the created method. Differences in microstructure of wood species affect the amount of moisture absorption and rate, in turn affecting the curvature response per wood species. Therefore the method used with oak veneer cannot be generalized to other species.

With research into other wood species, hard woods are likely to provide better results than softwoods based on the balance required between strength and flexibility. Additionally, uniform structure and consistent fiber spacing are important qualities to look for in a wood species to create a reliable response.

Structure size and thickness

For the material of these guidelines, a veneer thickness of 0.6 mm was used. Changing the thickness will likely impact the curvature behaviour. Thicker veneer will be stronger but less flexible, probably reducing the amount of curvature. And thinner veneer will be more flexible but also weaker. The thickness ratio between the veneer and coating influences the bidirectional curvature, making it important to balance these variables. When considering changing the veneer thickness the material should be strong enough to prevent breaking, flexible enough to bend repeatedly, and have a balanced veneer to coating thickness ratio.

The size of the veneer pieces is another opportunity for further research. The maximum size tested were samples that measured approximately 10x10 cm. Smaller pieces are possible but will show less visible curvature because the curvature amount is not dependent on sample size. The maximum size of a veneer piece is limited by tree size. The size of the pieces may cause a difference in behaviour due to the balance of weight. Retaining the 0.6 mm thickness but increasing the size of the samples means the very thin material needs to support more weight and is likely to break earlier. Therefore at larger scales, increasing the thickness will likely be necessary.

Fiber directions

In these guidelines the influence of fiber directions becomes clear. Rotating the fiber direction relative to a sample shape visually changes the curvature direction. During the testing phase, fibers along the length, width and on different angles have been tested. With a 45° angle as a midpoint between the fibers along the length and width. This variable offers interesting experimentation possibilities, particularly on the integration in a design application.

Wood programming

During the wood programming stage, the water temperature is a key variable. The lignin in the wood needs to soften to enable the curvature response, but temperatures too high can cause the wood structure to degrade and reduce the dynamic response. The material in these guidelines is programmed at 60 °C. To avoid losing the programmed response, it is recommended to avoid re-exposure to temperatures of 60 °C or above.

Soaking time is another influential variable. Although it has not been tested extensively, longer soaking times seemed to result in stronger curvatures, where 15 minutes was tested as the maximum value. Longer durations might enhance the curvature effect further.

With wood programming, finding the ideal balance between soaking temperature and time is crucial. Changing other variables such as the wood species or veneer thickness likely require adjustments of the programming stage. For example thicker veneer pieces or wood species with lower water absorption rates may benefit from longer soaking times in order to reach the same amount of saturation as the oak wood veneer in these guidelines.

Coatings

The bidirectional curvature response of the material is created by the wood glue coating, applied in two to three layers. Where tree layers was the maximum amount tested. Although an increase of coating layers has shown to create stronger curvature, it is expected that beyond a certain point this effect will decrease. When the coating becomes too thick relative to the veneer, impacting the bilayer thickness ratio, the curvature response could be affected negatively.

Exploring other coating types could lead to interesting results. When experimenting, several requirements should be considered: The coating should not soak into the veneer too far to ensure a bilayer remains, it must be waterproof to withstand the programming stage, and it should remain flexible to bend with the material.

4.3 Scaling and future development

Although the size of a single veneer sheet is limited by the dimensions of the tree it is cut from, full structures are not restricted to this scale. During the testing phase of these guidelines, multiple veneer pieces were combined into structures by gluing segments together, though other joining methods could also be explored.

With increasing the scale of applications, the manufacturing method would need to be adjusted accordingly. The three main stages of manufacturing are coating the samples, cutting desired shapes, and programming. These stages can be adjusted according to variation in availability of resources, levels of expertise and budgets.

In its most basic form, coating the material can be done manually by spreading the glue by hand. Cutting the veneer is possible with scissors or a knife. And for the programming stage a simple setup can be used with a container and thermometer. Approaching the process this way, allows for the possibility to create the material in almost any context with limited required materials, though it is time intensive and lacks accuracy.

For a more refined approach, cutting the material with a laser cutter improves the possibilities, accuracy and speed of the process. For the wood programming stage, a circulating water bath that remains at a constant temperature allows for more reliable and equal results.

The cost of designing with this material is dependent on the chosen manufacturing method, where a more professional approach would greatly increase the cost of production. As an indication of the material cost, 0.6 mm oak veneer typically costs between 15 and 50 euros per square meter, depending on the quality of the material and supplier. The waterproof wood glue used as a coating ranges from approximately 12 to 25 euros per liter, depending on the brand and supplier.



5

- 5.1 Flower structure
 - 5.2 Wave structure
 - 5.3 Twist structure
 - 5.4 Frame structure
 - 5.5 Diamond pattern
-

SAMPLE STRUCTURES

This chapter introduces five sample structures made from moisture-responsive wood veneer. These examples are meant to serve as a source of inspiration by demonstrating the potential of the material. They represent an intermediate step between the underlying material principle and a functional application of the material.

Chapter 3 explained several parameters that can be adjusted to influence the resulting performance. The effect of modifying these parameters becomes visible in the following examples, not only on the performance result of the samples but also in the way the manufacturing process is affected.

Assembled and patterned structures

The examples can be divided in two categories: assembled structures and patterned structures. The first three examples are assembled structures, meaning the veneer is initially cut into multiple separate segments which are connected and combined into one structure. The last two examples are patterned structures. These are made from a singular piece of veneer from which shapes are cut out, creating a pattern.

Active and non-active parts

As mentioned previously, strategically placing the coating determines the curvature location. In the assembled structures, all sample pieces are fully coated on one side and therefore function entirely as active parts. In the patterned structures, only selected areas of the veneer are coated. This results in a division within the structure between active areas and the remaining non-active area.



Flower structure



5.1 Flower structure

The flower structure is the first of the assembled structures. This structure is a construction made from several individual petals which form a flower. Each petal is made from wood veneer and is glued onto a plywood base, creating a layered structure. The arrangement of the veneer petals defines the overall flower shape and fixes the sample in its final configuration. When this sample is activated by moisture, the petals appear to be opening and closing, bending towards the center of the structure.

What do you need?

The structure is made from 8 flower petals all with the same fiber orientation perpendicular to the petal length. It includes a plywood circular base on which the petals are glued. All the petals will be coated and act as the active part of the system. Figure 5 shows the materials needed to create this flower structure.

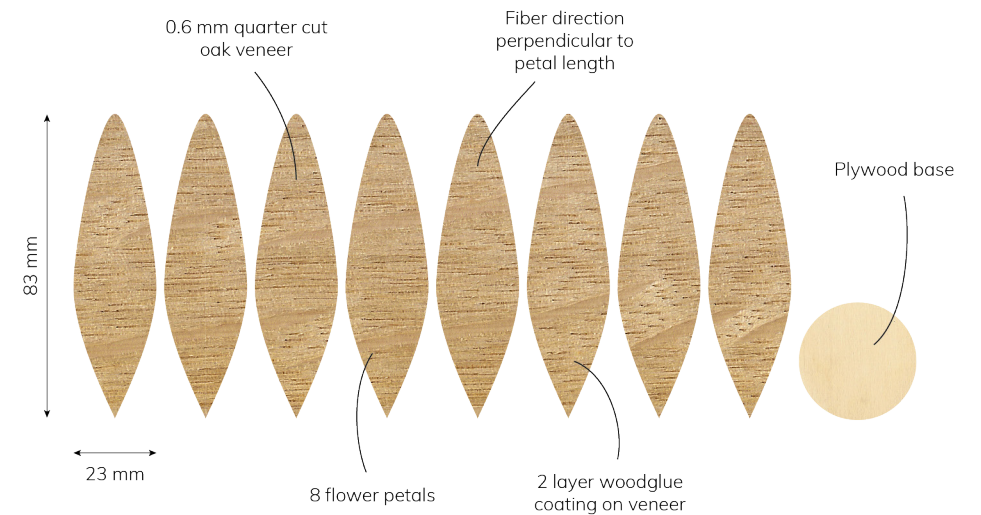


Fig 5. Materials needed to create the flower structure.



Scan to watch
this sample move

How it's made

The images in figure 6 show the manufacturing process of the sample structure, from preparing the veneer to programming the wood and assembling the structure.

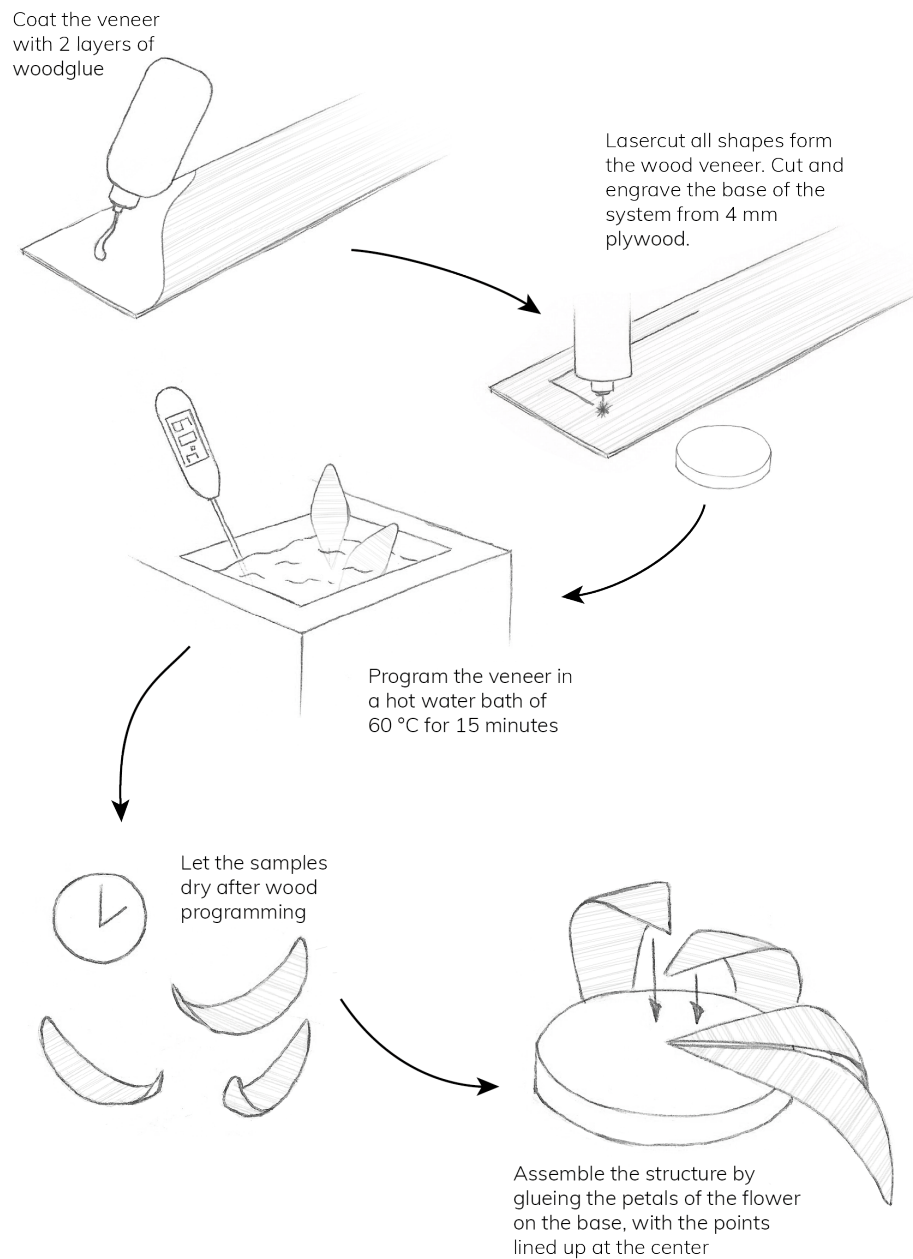


Fig 6. Manufacturing process of the flower structure.

How it performs

The sample structures were tested on their curvature performance by spraying them with water. With this method, the curvature change of the samples could be mapped out over time. The images in figure 7 show the movement stages of this sample structure at different time intervals after being activated.

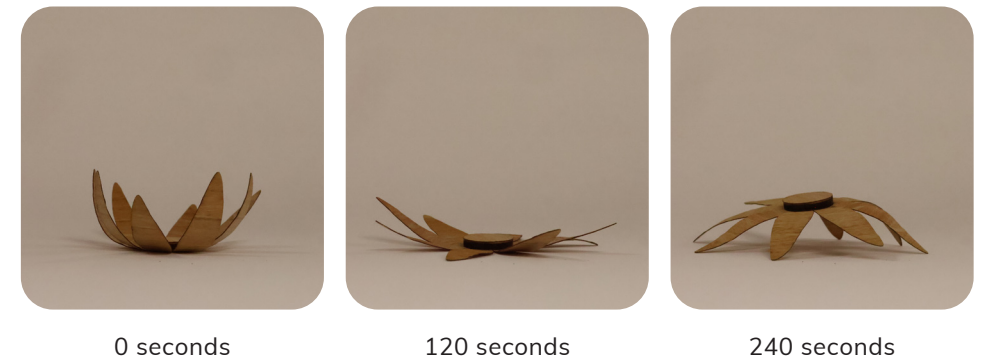


Fig 7. Sample movement stages at 0, 120 and 240 seconds.

The graph in figure 8 shows the average curvature change over time of the flower sample structure. The initial negative value is the curvature of the sample in a dry state where the curvature is towards the NIC side. At 0 seconds the sample is sprayed with water and begins to change curvature directions, ending at 240 seconds with a positive curvature value. Although the measurements stop at 240 seconds, in reality the sample would return with the same path mirrored to its initial state.

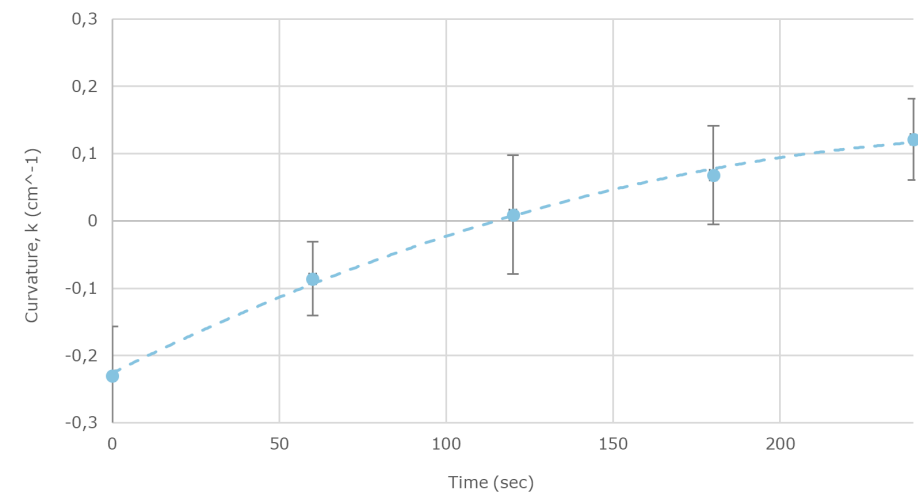


Fig 8. Graph showing the average curvature change over time of the sample.

Wave structure



5.2 Wave structure

The wave structure is another assembled structure consisting of a combination of petals and a plywood base. The petals all vary in size and are ordered according to their size. They are placed on slightly varying angles relative to each other as well as slight displacements parallel to the petals to create more interest in the overall form.

What do you need?

For this structure a total of 17 petals are made in 8 different sizes. Except for the largest sized petal, all petals have a duplicate. The fiber direction of the veneer is placed along the straight edge of each piece. The plywood base has lines engraved matching the size of the flat edges of each of the petals in order to glue them exactly in place. All materials needed can be seen in figure 9. The spacing between pieces is an important aspect to consider for any design with the veneer. In this case the spacing between the engraved lines needs to be large enough to allow movement of each petal without interference of a petal placed next to it, in this case about 5 mm.

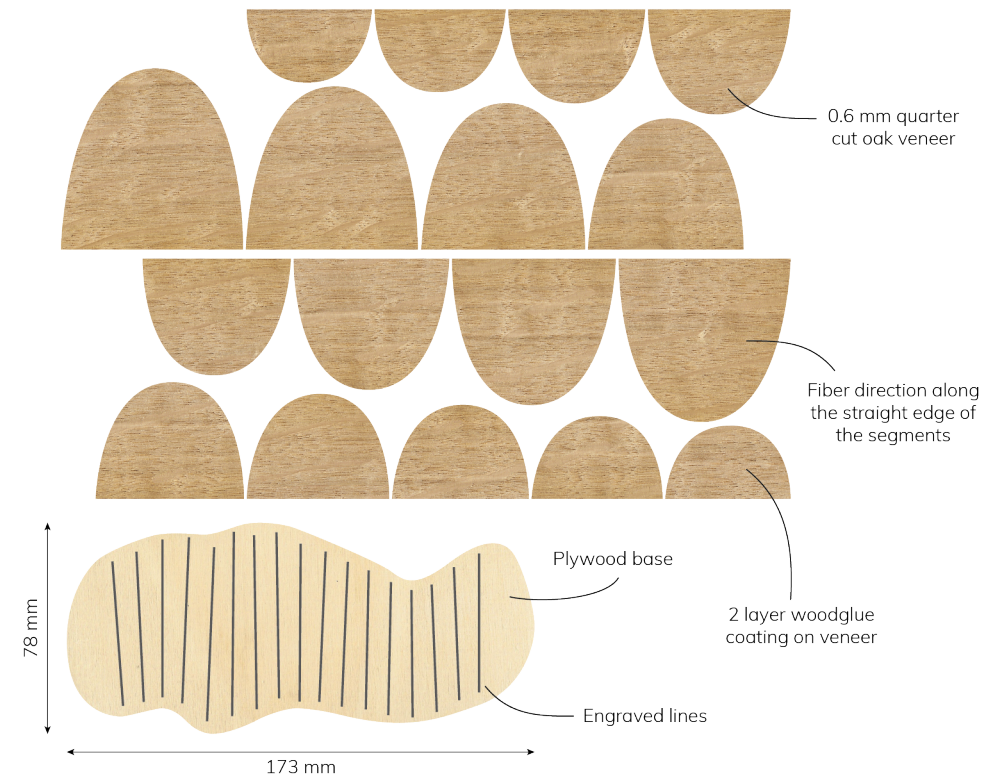


Fig 9. Materials needed to create the wave structure.



Scan to watch
this sample move

How it's made

The images in figure 10 show the manufacturing process of the sample structure, from preparing the veneer to programming the wood and assembling the structure.

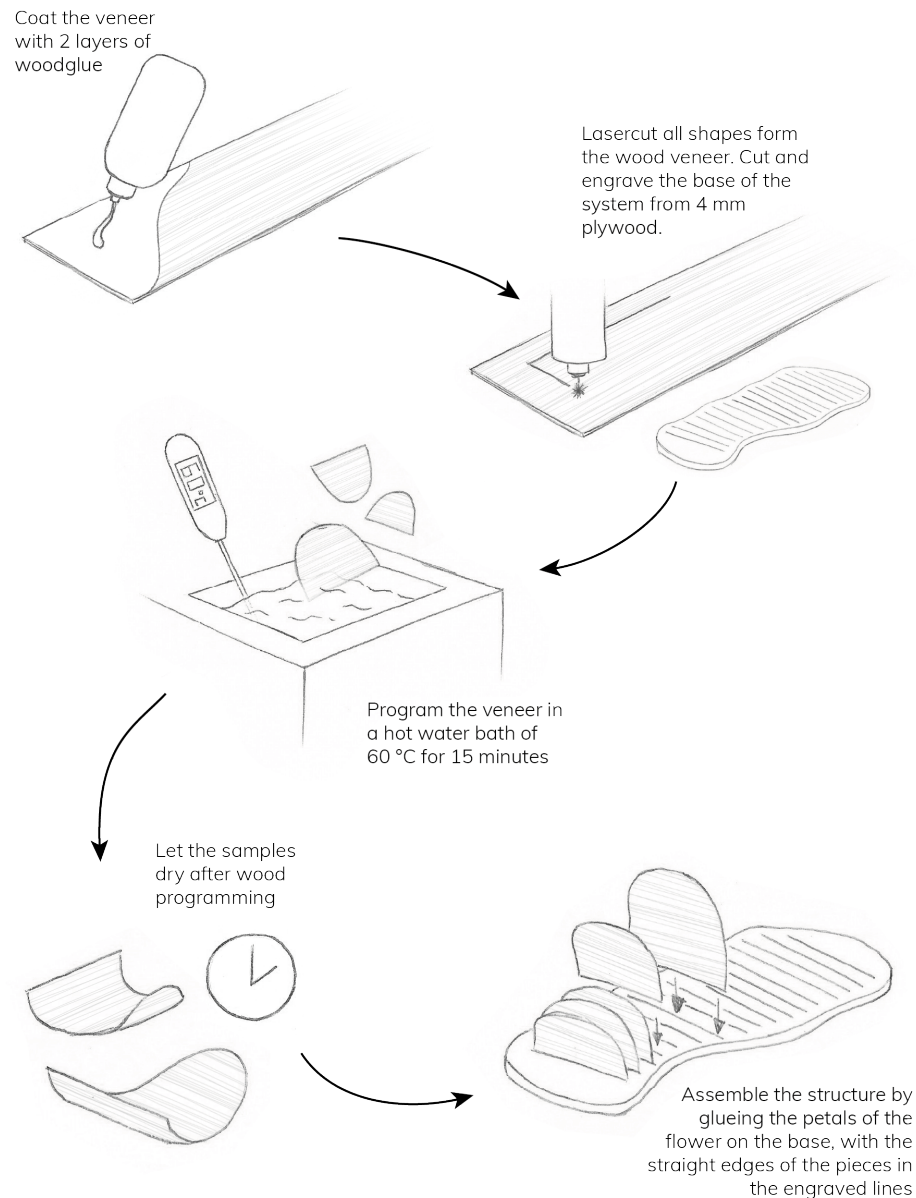


Fig 10. Manufacturing process of the wave structure.

How it performs

The images in figure 11 show the movement stages of this sample structure at different time intervals after being activated.



Fig 11. Sample movement stages at 0, 120 and 240 seconds.

The graph in figure 12 shows the average curvature change over time of the wave sample structure. Starting at the initial negative value representing the curvature in a dry state with curvature towards the NIC side. At around 90 seconds the sample begins to bend towards the NOC side.

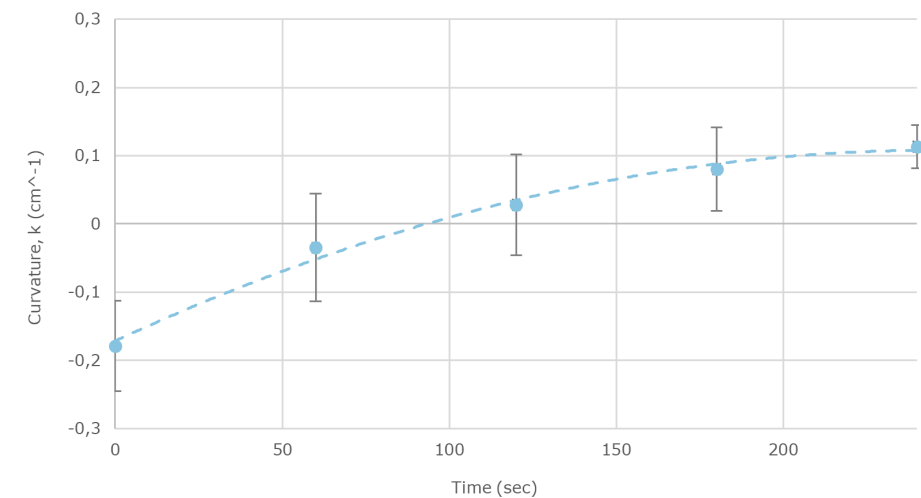
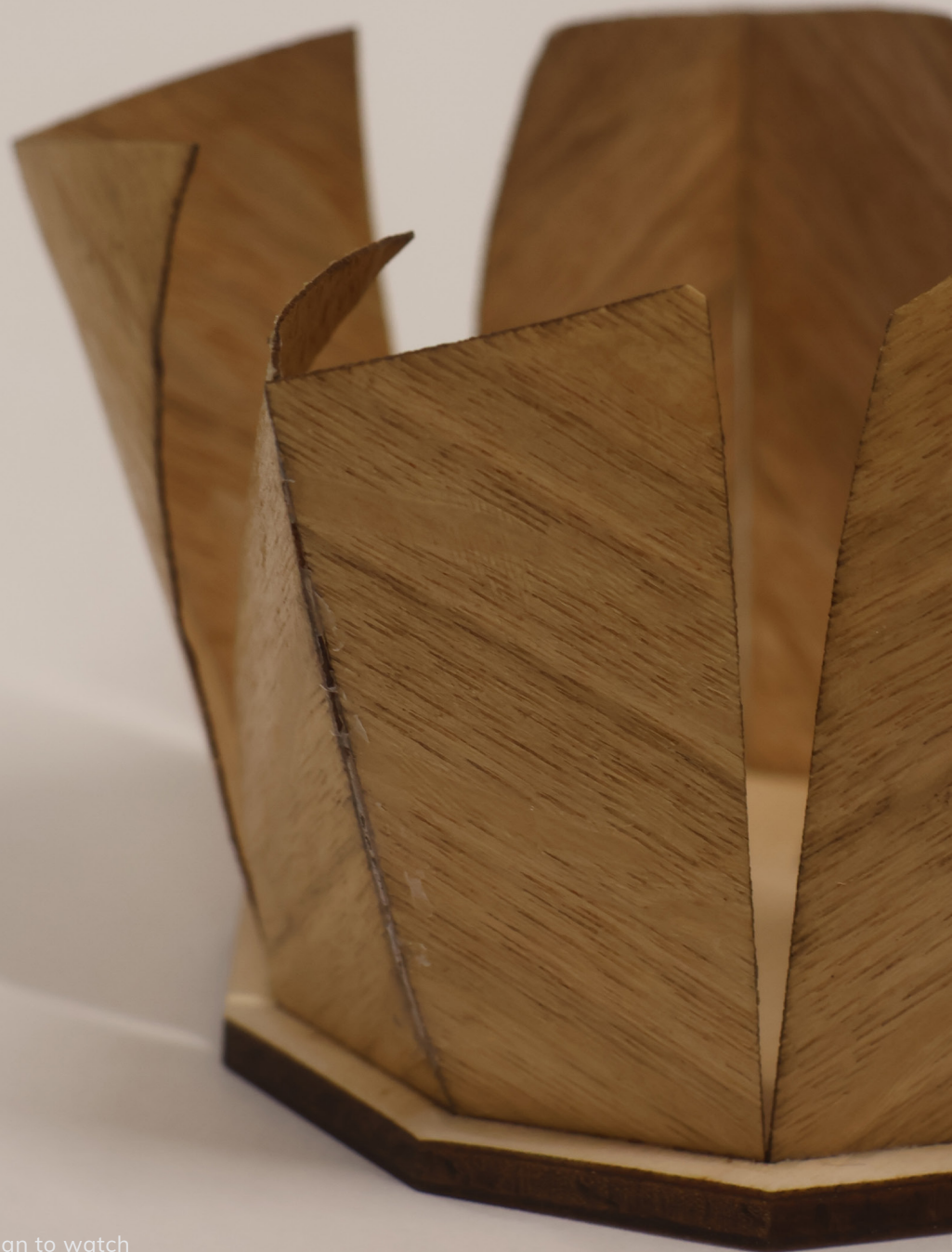


Fig 12. Graph showing the average curvature change over time of the sample.

Twist structure



5.3 Twist structure

The twist structure is the last assembled structure. Similar to the wave structure, it is made by gluing veneer pieces in engraved lines of a base. However this structure differs from the previous because it utilizes the possibility of changing the visual curvature direction. The fibers in this structure are angled resulting in a twisting motion. The structure is made from multiple mirrored pieces of veneer combined in pairs. Each pair is glued together and the bottom edges are glued in the base. This structure demonstrates the possibility of limiting curvature through the assembly design. Without gluing the veneer pieces together, the bottom edge would twist. However, through the method of assembly, this twisting motion on one end of each veneer piece is restricted.

What do you need?

This system is made with pairs of two samples. The system consists of 5 pairs glued in engraved lines on the plywood base. Each pair is made from two mirrored pieces of veneer that are glued together at the seam, creating a twisting motion where only the corners of the pairs move. The direction of the fibers is placed at a 45° angle relative to the sample length. All materials are listed in figure 13.

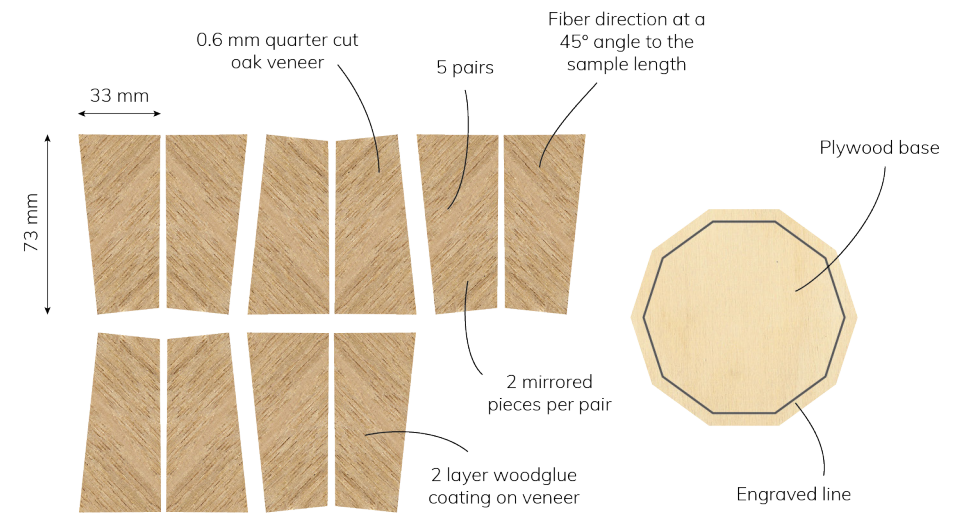


Fig 13. Materials needed to create the twist structure.



Scan to watch
this sample move

How it's made

The images in figure 14 show the manufacturing process of the sample structure, from preparing the veneer to programming the wood and assembling the structure.

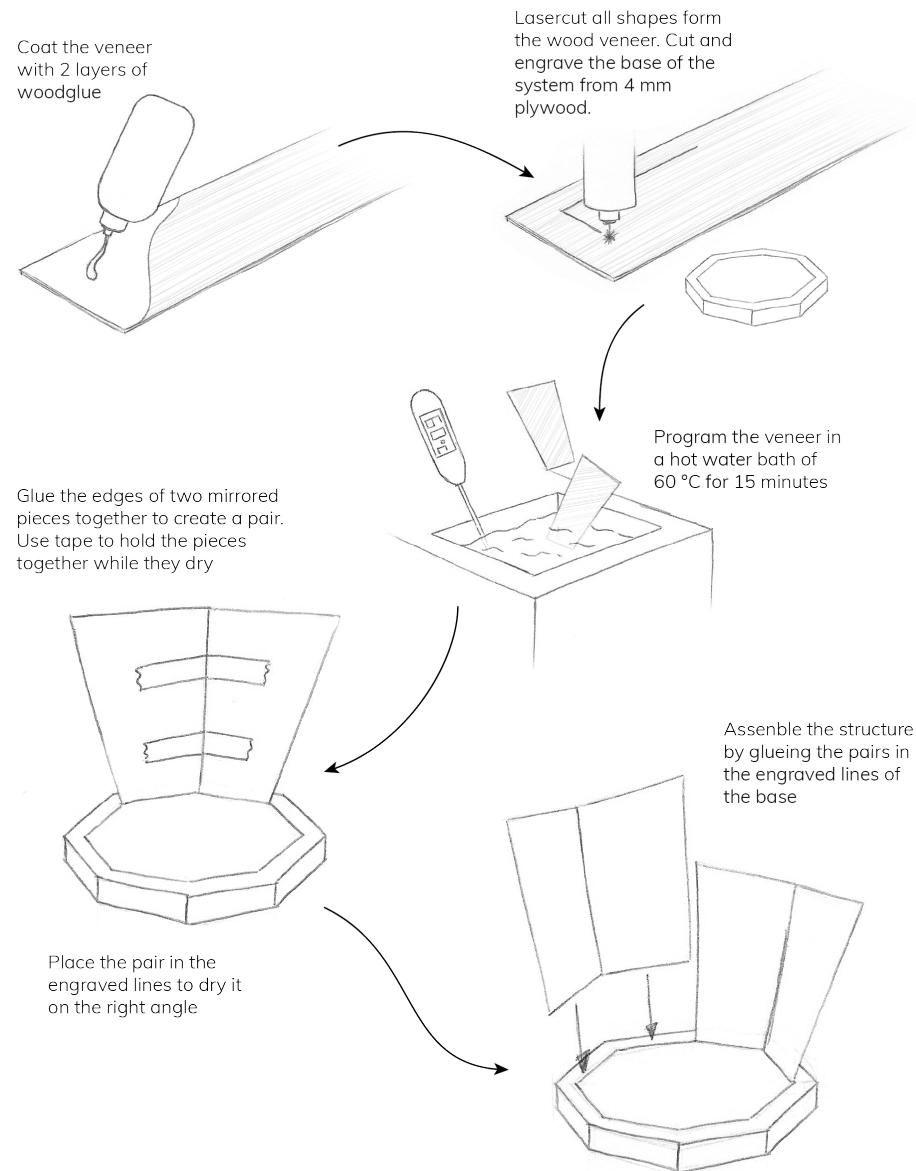


Fig 14. Manufacturing process of the twist structure.

How it performs

The images in figure 15 show the movement stages of this sample structure at different time intervals after being activated.

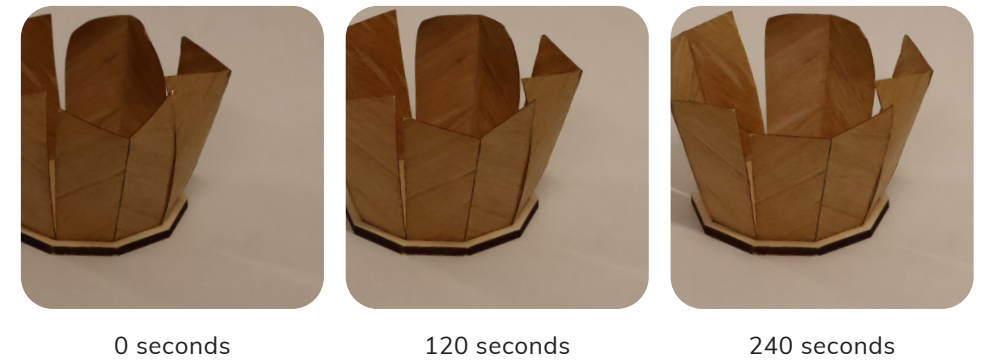


Fig 15. Sample movement stages at 0, 120 and 240 seconds.

The graph in figure 16 shows the average curvature change over time of the twist sample structure. The initial negative curvature value of this sample is quite strong. This results in a relatively late change of curvature direction from the NIC side to the NOC side, at around 220 seconds.

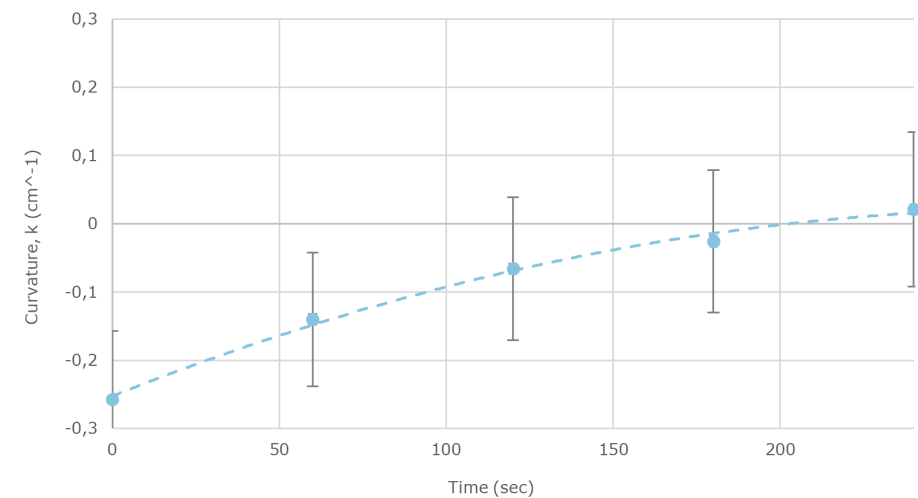


Fig 16. Graph showing the average curvature change over time of the sample.

Frame structure



5.4 Frame structure

The frame structure is the first of the patterned structures. It is one piece of veneer from which lines are cut, creating various frames. The frames in this structure are considered the active areas, while the surrounding material is expected to remain flat. The fiber direction is placed vertically on the structure. In combination with the direction of the cut-outs, this results in frames moving back and forth. An important aspect of a patterned structure like this is the required tolerance spacing. Since the frames are expected to move through the surrounding material, a slight spacing is required to prevent the surrounding material from blocking the movement of the frames.

What do you need?

This structure consists of one piece of veneer with lines cut out creating small frames that move back and forth, with tolerance spacing in between the cutouts. The active areas, the frames, are covered with wood glue. The surrounding veneer is left uncoated. Figure 17 shows the sample with specifications.

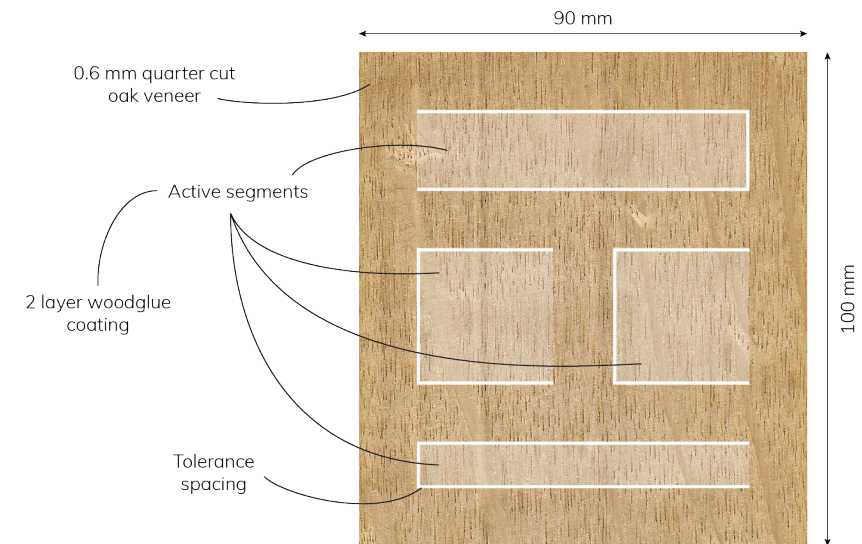


Fig 17. Materials needed to create the frame structure.



Scan to watch
this sample move

How it's made

The images in figure 18 show the manufacturing process of the sample structure, from preparing the veneer to programming the wood and assembling the structure.

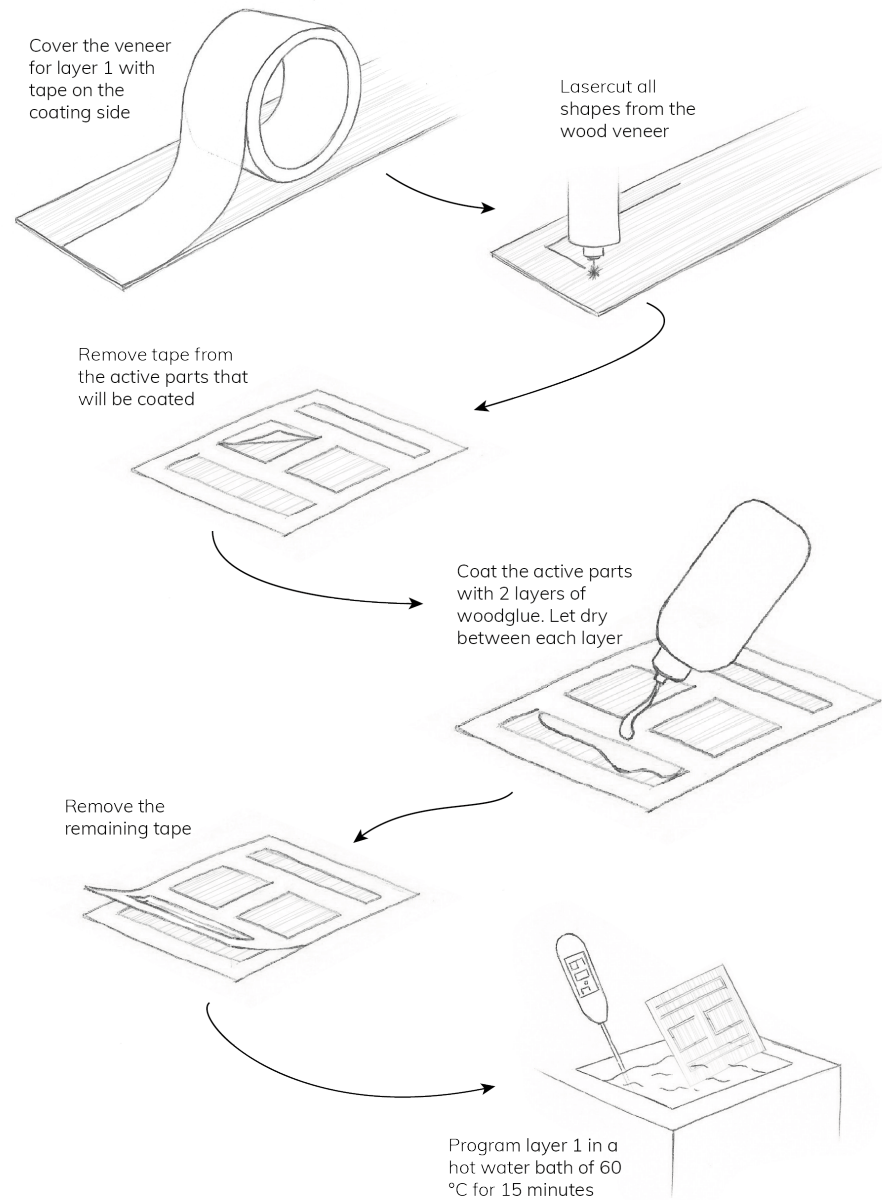


Fig 18. Manufacturing process of the frame structure.

How it performs

The images in figure 19 show the movement stages of this sample structure at different time intervals after being activated.

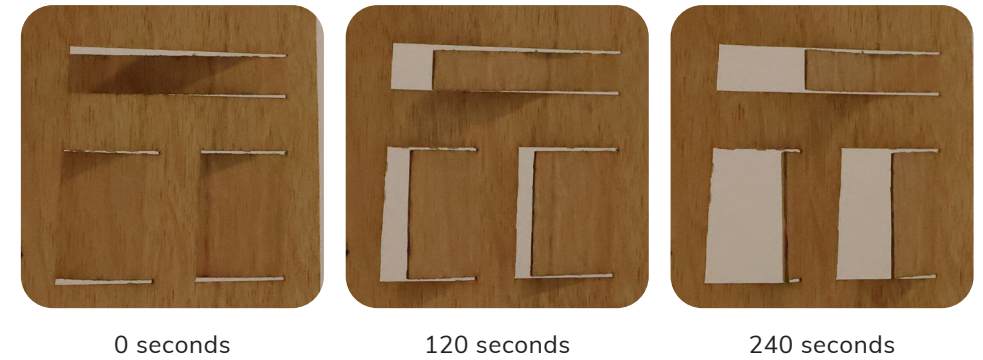


Fig 19. Sample movement stages at 0, 120 and 240 seconds.

The graph in figure 20 shows the average curvature change over time of the twist sample structure. This sample shows a lot of movement in the early stages of the measurements. The change in curvature side happens already at around 80 seconds. After 120 seconds, it can be seen that the slope of the graph decreases, meaning the rate of curvature slows down.

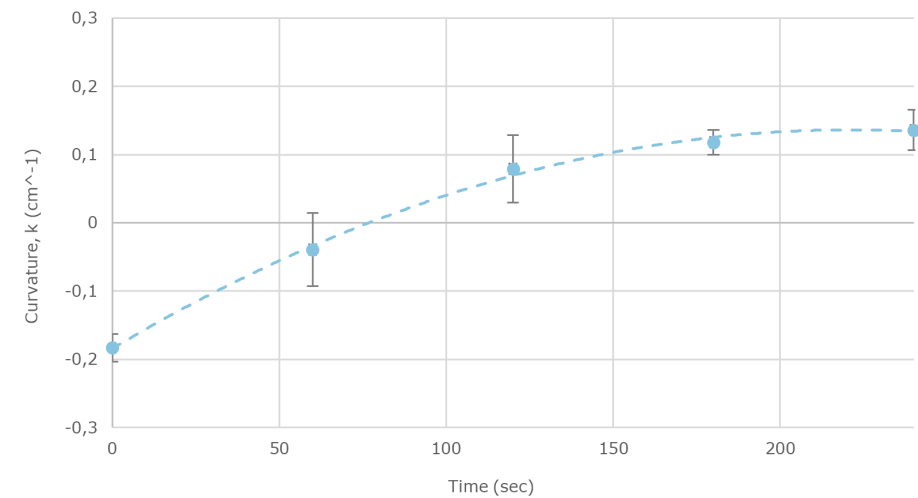


Fig 20. Graph showing the average curvature change over time of the sample.

Diamond pattern



5.5 Diamond pattern

The diamond pattern is the last patterned structure. It is made similarly to the frame structure where certain areas of one veneer piece are cut out. However, this structure is made from two layers of veneer. In comparison to the frame structure, the diamond pattern relies on the second veneer layer to limit the movement of the non-active area of the sample. The fiber directions of this second layer are placed horizontally, perpendicular to the vertical fiber of the first layer. Layer 1 includes the active parts of the structure. To prevent restriction of the movement, layer 2 has cut-outs in the exact place of the active parts.

What do you need?

The system consists of two layers with perpendicular fiber directions. Layer 1 includes the coated active parts. Layer 2 covers only the non-active part of layer 1 and prevents any residual movement of the non-active part. Similarly to the frame structure, the cut-outs of both layers include tolerance spacing to allow unrestricted movement. Figure 21 shows both layers with their specifications.

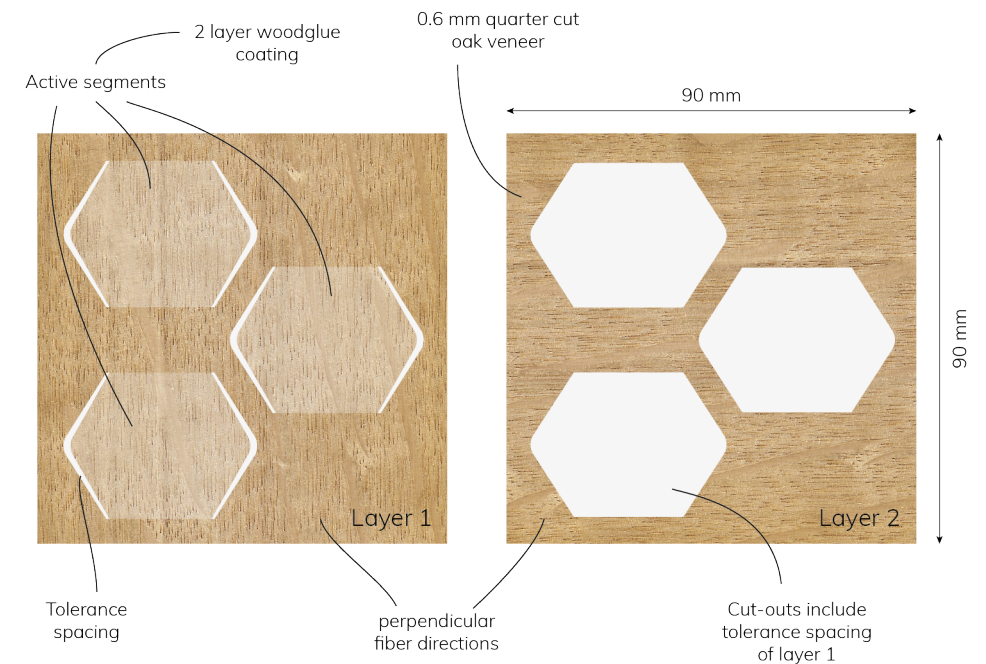


Fig 21. Materials needed to create the diamond pattern.



Scan to watch
this sample move

How it's made

The images in figure 22 show the manufacturing process of the sample structure, from preparing the veneer to programming the wood and assembling the structure.

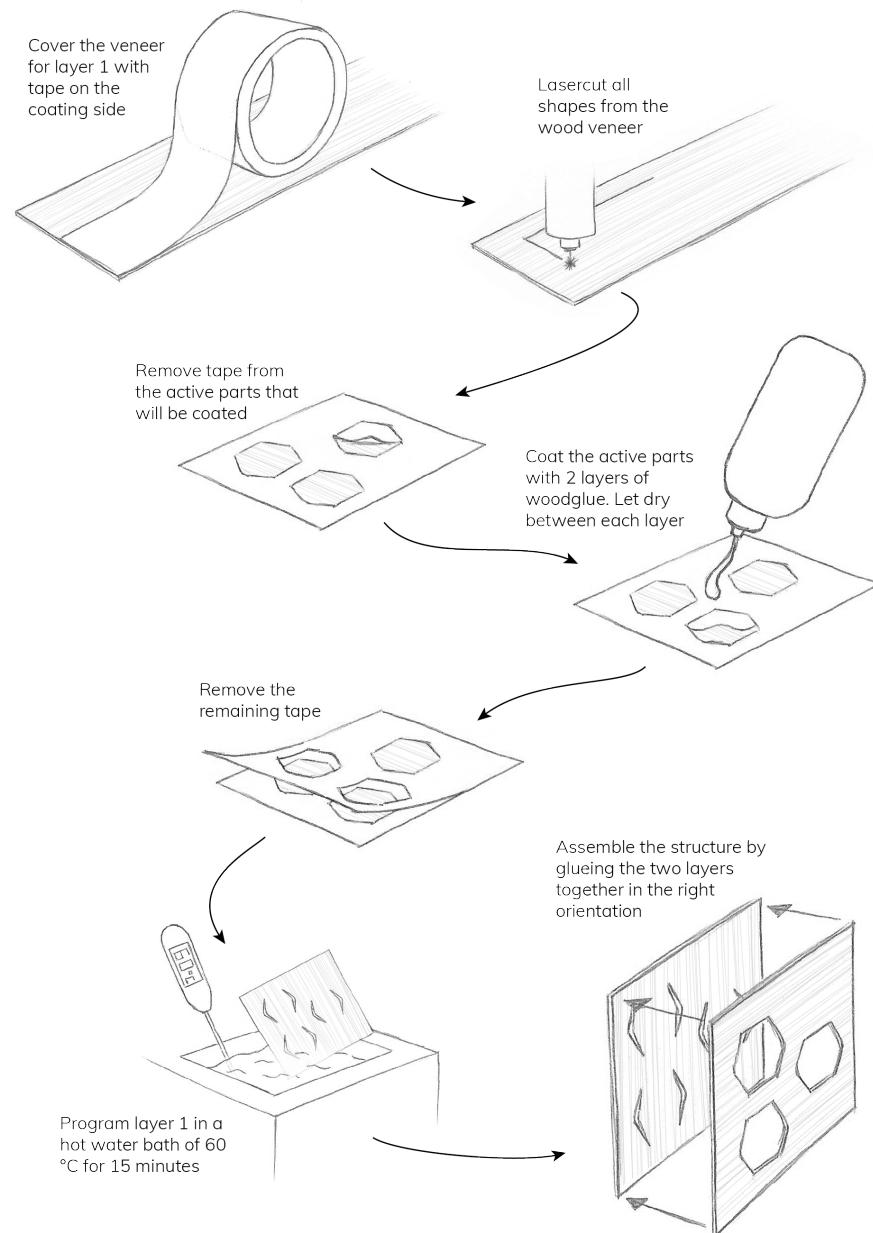


Fig 22. Manufacturing process of the diamond pattern.

How it performs

The images in figure 23 show the movement stages of this sample structure at different time intervals after being activated.



Fig 23. Sample movement stages at 0, 120 and 240 seconds.

The graph in figure 24 shows the average curvature change over time of the diamond pattern sample structure. The curvature change of this structure is similar to that of the frame pattern, with a steep initial slope that decreases after 120 seconds. The difference is that this structure did not have a very strong initial negative curvature and therefore already changes curvature sides from NIC to NOC at 60 seconds.

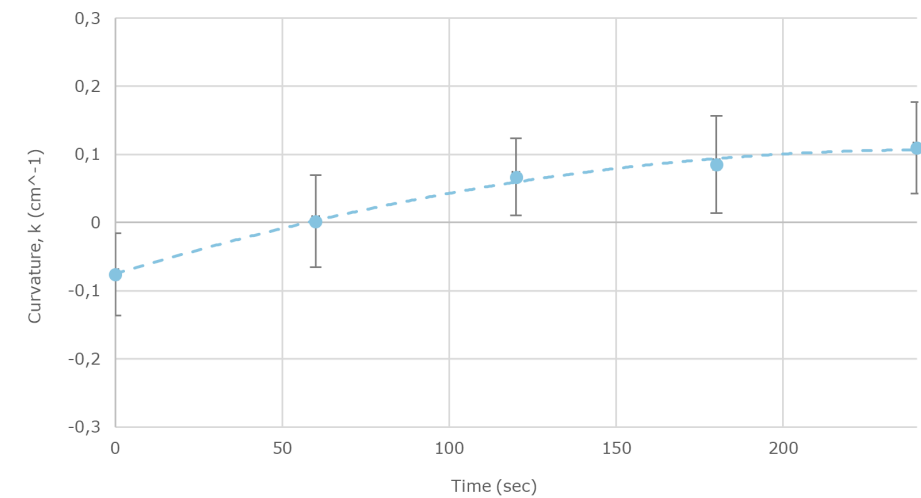


Fig 24. Graph showing the average curvature change over time of the sample.

6

6.1 Responsive column

6.2 Interactive surface

INSPIRATION

This chapter presents a series of generated images that illustrate possible applications of the material as inspiration for its potential use. The examples focus on indoor architectural contexts, highlighting the aesthetic value of the wood veneer and demonstrating how it can be implemented at a larger scale. In these examples, the material contributes to the atmosphere and character of a space.

As a biobased and renewable material, wood is a lower-impact material to apply in large scale applications. In addition to the sustainable qualities of the material itself, the exhibited movement functions as a form of passive actuation. No mechanical systems or external energy sources are required. Instead, the material responds directly to environmental conditions, resulting in subtle movements that reflect changes in the surrounding climate. Together, the examples in this chapter demonstrate how the material can be applied in architectural contexts as a responsive structure that expresses environmental interaction.

6.1 Responsive column

The first example presents a centrally placed column within a large interior space, expanding outward into a structure that connects to the roof. The wood veneer is integrated by covering the main column with multiple smaller veneer segments. This example demonstrates how a large-scale architectural element can be made from many smaller pieces. By integrating the veneer in segments, the column gains a layered texture. The fiber direction of the pieces is oriented horizontally, allowing them to bend upward or downward in response to changes in relative humidity, as illustrated in Figure 25. This results in a subtle opening and closing movement caused by the natural curvature of the material. Through this gentle motion, the column becomes a responsive element within the space. Rather than functioning as a static structure, it translates invisible environmental fluctuations into visible and tactile changes, allowing the material to communicate its interaction with the surrounding climate and contributing to a more dynamic interior experience.

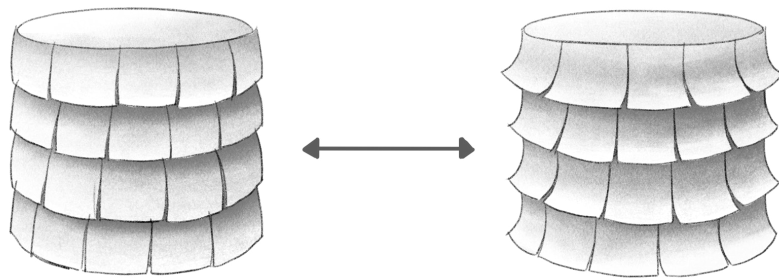


Fig 25. Illustrated movement of the responsive column design.



6.2 Interactive surface

This second example shows the veneer being integrated into a decorative wall in a hotel lobby. The wall is composed of vertically connected veneer pieces, and through variation in cutting patterns, a ripple effect is created across the surface. The fiber directions are oriented vertically, allowing the elements to move from side to side in response to fluctuations in relative humidity, as illustrated in figure 26.

Within the context of the lobby, the wall functions as a defining feature of the space. It draws attention and provides a calm atmosphere. The subtle movement quietly reflects the environmental conditions and enhances the visual quality of the space.

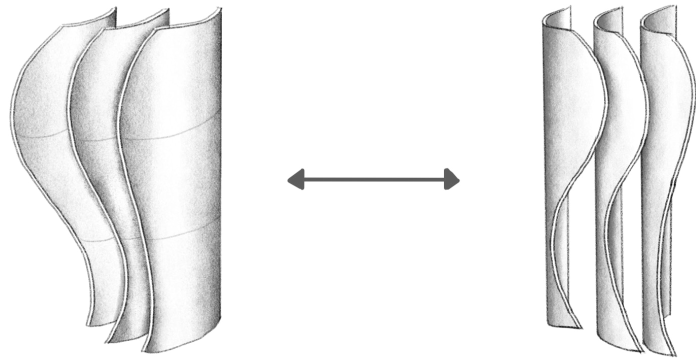


Fig 26. Illustrated movement of the interactive surface design.

