木霊

KODAMA

Spirit of the forest

The name of the pavilion **"KODAMA"** is associated with a spirit in the beautiful forest of Arte Sella:

"KO" of means "tree", and **"DAMA"** means "spirit" or "sphere" in Japanese.

Kengo Kuma's Exhibition, Tokyo, March 2018

A project by:
Kengo Kuma Lab

Structural calculations:
Ing. Marco Clozza, D3WOOD
Jun Sato, Professor at the University of Tokyo

Prototype:
Ing. Marco Clozza, D3WOOD
Ri-legno Srl

CNC works:
Ri-legno Srl
Ing. Giulio Franceschini, Project Manager Ri-Legno Srl
Ing. Lavinia Sartori, Sales Manager Ri-Legno Srl
Arch. Ing. Giorgio Franceschini, Ri-Legno Srl

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Prof. Andrea Vanossi, BIM Manager - ABC Department
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Clara Rinaldi, Architectural - Engineering student
Federica Brunone, PhD Candidate ABC Department

University of Tokyo:
Toshiki Hirano, Assistant Professor at the University of Tokyo
Takahiro Hirayama, Engineering student
Masumi Ogawa, Engineering student
Ifan Yim(tbc), Engineering student

Material supply:
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In collaboration with:
Arte Sella: the contemporary mountain

Kuma-LAB 東京大学隈研究室 Kuma Laboratory
ARTESELLA THE CONTEMPORARY MOUNTAIN
POLITECNICO MILANO 1863
東京大学 THE UNIVERSITY OF TOKYO
WOOD www.d3wood.it
RI·LEGNO®

Kengo Kuma Lab & Toshiki Hirano
5th June 2017

CONCEPT

First Concept Ideas - with bending

Render option 1 - width 200 mm

Render option 2 - width 100 mm

Render option 1 - width 300 mm

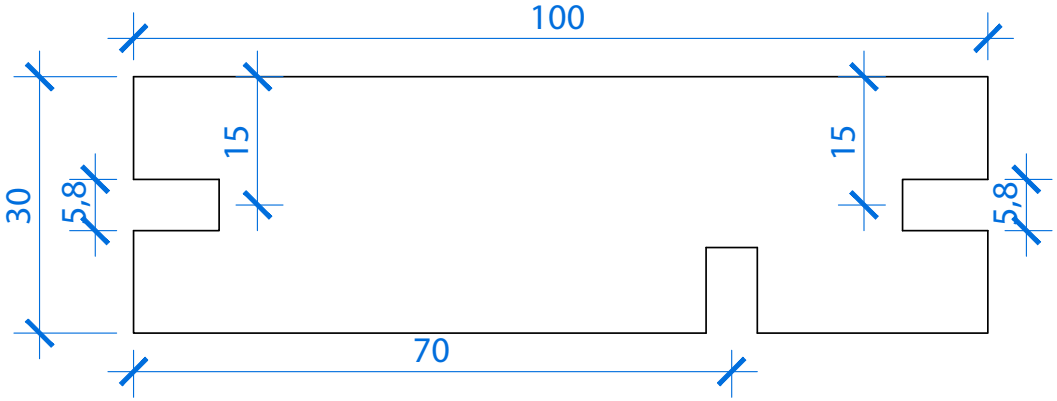
Render option 2 - width 200 mm

Kodama - Project ideas

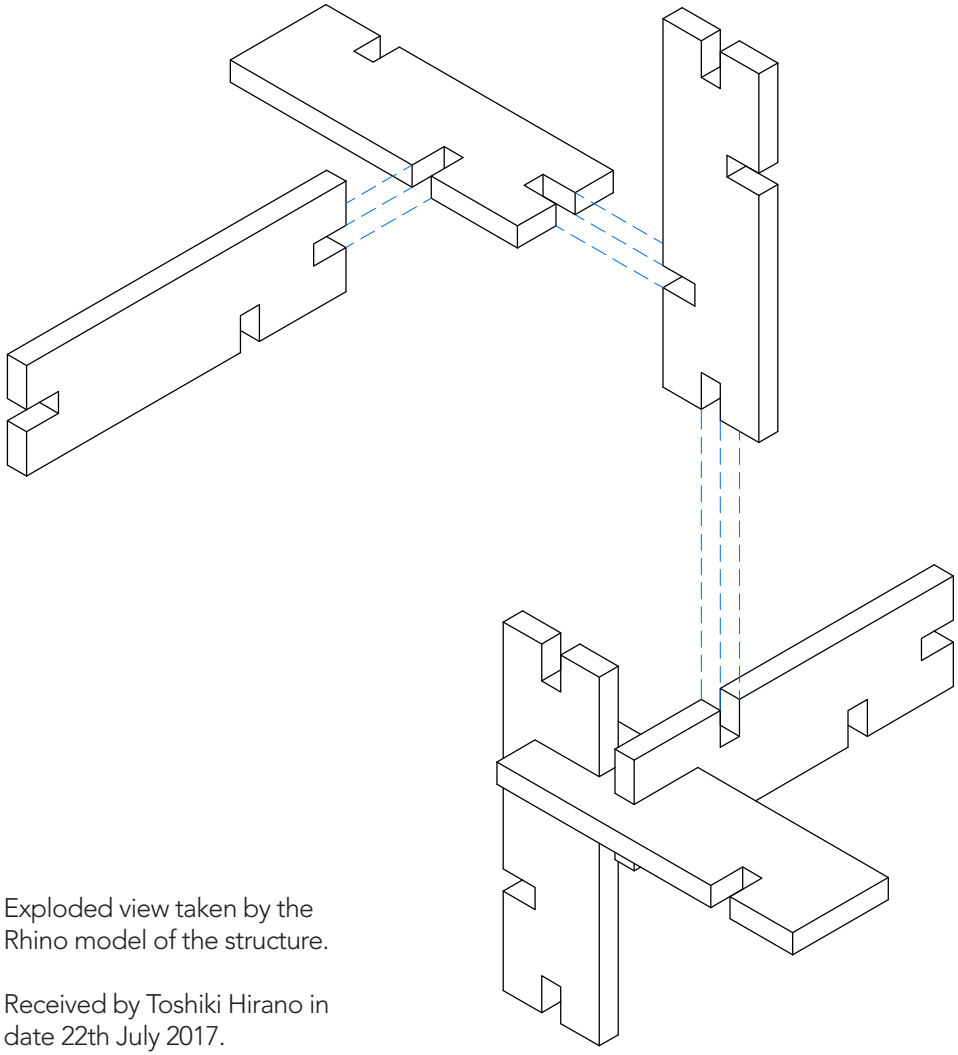
Final Concept Idea - without bending

Render - Last version

Basic unit - measurements



Exploded view



Exploded view taken by the Rhino model of the structure.

Received by Toshiki Hirano in date 22th July 2017.

Marco Imperadori, Marco Clozza & D3Wood
9th July 2017

KODAMA
MOCKUP 1:3
MADE IN LARCH

Final mockup

Final node

Basic units

Final node

Marco Imperadori, Marco Clozza & D3Wood
22nd July 2017

KODAMA
MOCKUP 1:1
MADE IN CEDAR

Cutting

Cedar trunk section

Measurements

Rough boards

Trunk fixing (creation rectangular section)

Smoothing - First and second step

Smoothing

Smoothing

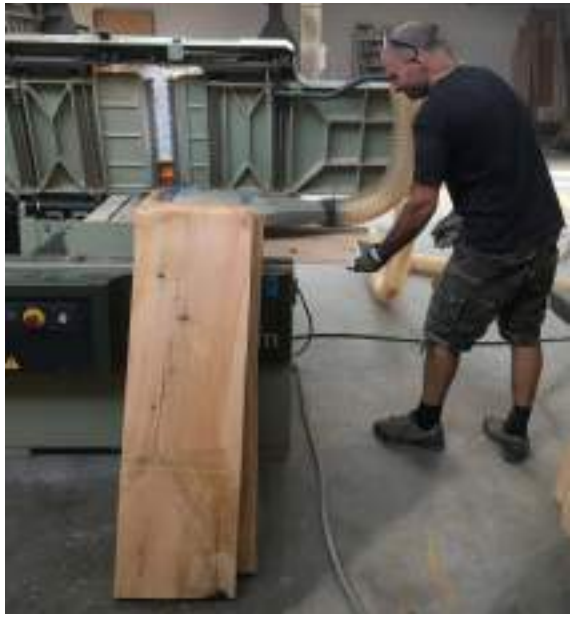
Smoothed boards

Smoothing - Third step

Final smoothing

Final smoothing

Final smoothing



Gathering of wood chips

Boards ready to be trimmed

Trimming

Long side trimming

Short side trimming

Boards ready to be carved

Carving - First step

Marking

Carved detail

Carved boards

Carved detail

Carving - Second step

Marking

Carving frame

Manual carving

Carved detail

Carving frame

Assembling

Structure base

Structure base

Fixing by means of bolts

Flatness check

Assembling

Assembling the first block

Checking and fixing the first block

Fixing the first block

Assembling

Assembling

Joint detail

Construction team

Final mockup

Final node

Final node

Arch. Ing. Giorgio Franceschini & Ri-Legno Srl
4th September 2017

KODAMA
MOCKUP 1:1
MADE IN FIR

Main issues

Broken board

Creped board

Checking the width

Fixing with screws

Fixing with glue

Due to the fact that we need to work with jointed elements, one of the main problems is the effective slide of the wooden boards that are together connected. Even though the cuts of the different pieces were made with a "CNC machine" there is some error in the joint. The wood milling is often less than 50 mm and doesn't allow the proper connection till the end of the two pieces.

This problem was temporarily solved widening the wood milling and hitting with an hammer to make the wooden table slide together.
This violent impact caused in many points the crepe formation, till the complete break of some of the elements, as you can see in the pictures on the side. The critical points are the one in the corners of the milling, node where the wood has a low traction resistance in the orthogonal direction of the fibres.

To proceed to the construction of the prototype some of the pieces were fixed with glue and some others, the one already positioned, with wood screws.

In order to avoid all this problems it has to be consider a tolerance of 1 mm: the wood boards remain of 50 mm, the milling wood became of 51 mm instead.

Main issues

Second block assembled

Second block assembled

Assembling second block with the first

Challenging has been the assembling of the prototype.

This mockup has been built creating compact blocks of few pieces and than assembling them maintaining a unique direction of all the joints. This decision has been taken due to the fact that, in case of proceeding board by board there is a final point in which the stiffness of the material doesn't allow the contemporary connection of two joint with orthogonal direction.

This procedure has been possible in this location and with this reduced amount of pieces. In this mockup the elements have been fixed together proceeding with an horizontal direction.

In an executive project this organization would be difficult due to the spherical final shape of the pavilion. Is recommended a vertical growth of the structure and a possible assembling board by board instead of block by block.

Due to the complexity of the model is request a specific building manual for the workers.

Cutting

CNC machine

CNC machine

CNC machine

Final boards

Assembling - First block

Assembling the first boards

Connection with the base

Connection with the base

Shaving

Measurements

Assembling - First block

Fixing with the hammer

Fixing with the hammer

Fixing with the hammer

Assembling - First block

Assembling

Assembling

Assembling - Second block

Assembling

Final mockup

Final mockup - with support

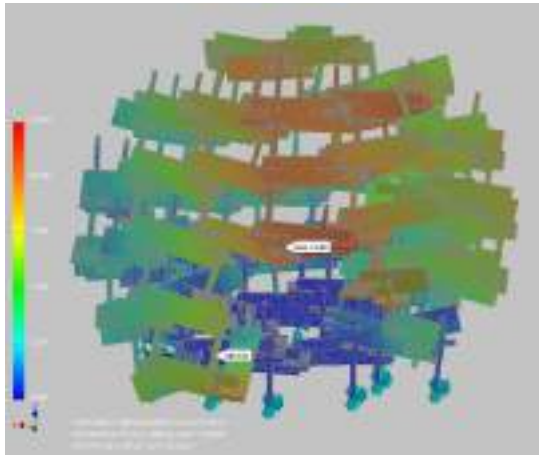
Final mockup

Final mockup - without support

Eng. Marco Clozza & D3Wood
Since July 2017

KODAMA
CALCULATIONS
FULL STRUCTURE

Calculations reports



First structural analysis

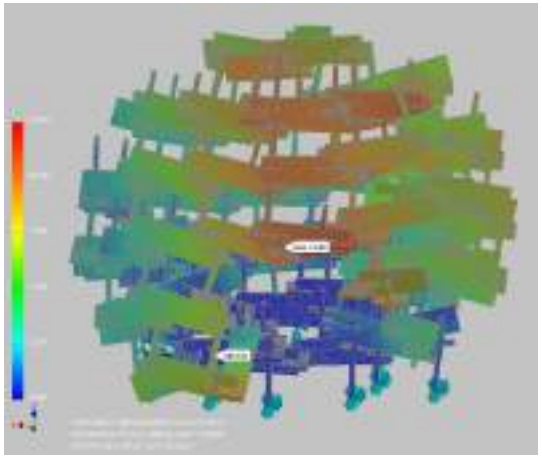
28 august 2017

D3WOOD via Sant'Ambrogio 48 23900 Lecco cell 3311331530 www.d3wood.it info@d3wood.it

Il carico da neve e l'effetto staccionata

30 agosto 2017

D3WOOD via Sant'Ambrogio 48 23900 Lecco cell 3311331530 www.d3wood.it info@d3wood.it



Second structural analysis

03 september 2017

D3WOOD via Sant'Ambrogio 48 23900 Lecco cell 3311331530 www.d3wood.it info@d3wood.it

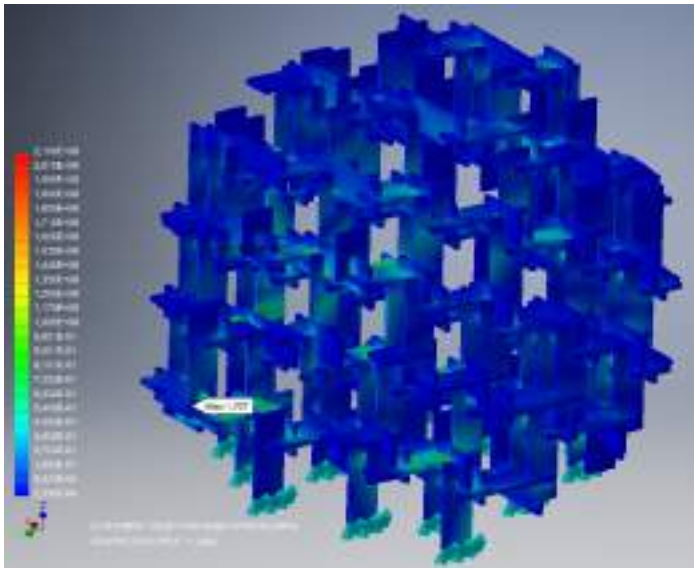
Conclusions from the last report

"Starting with 65 mm commercial thickness of slab, after treatment with thicknessing planer, it is possible obtain panels of 57-58mm. This means an important increase of 15% of resistant material. Future step should change the last geometry increasing the thickness in according with panels manufacturer disposition. With new model it will be possible evaluate new strength values in order to decide if it is necessary to introduce new restraints and/or change his positions or only adopt local reinforce. Future analysis will have to provide a more accurate mesh model and as written in the first report it means to arrive at more hight stress values. Future analysis will also consider multi-axial interaction of stress. It is indispensable validate FEA analysis with real stress test."

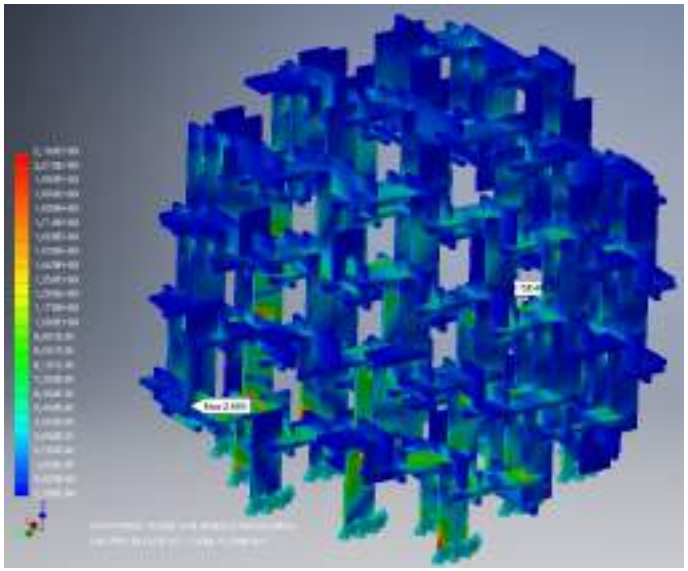
Eng. Marco Clozza, D3Wood

Calculations reports

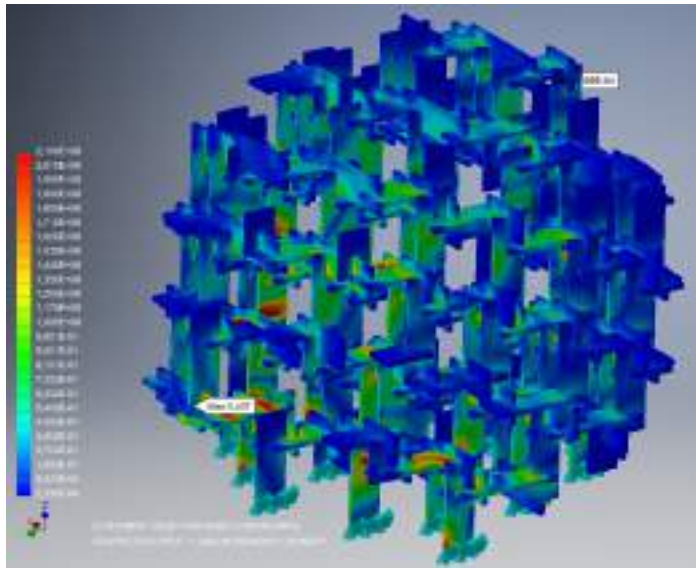
Load: Own weight



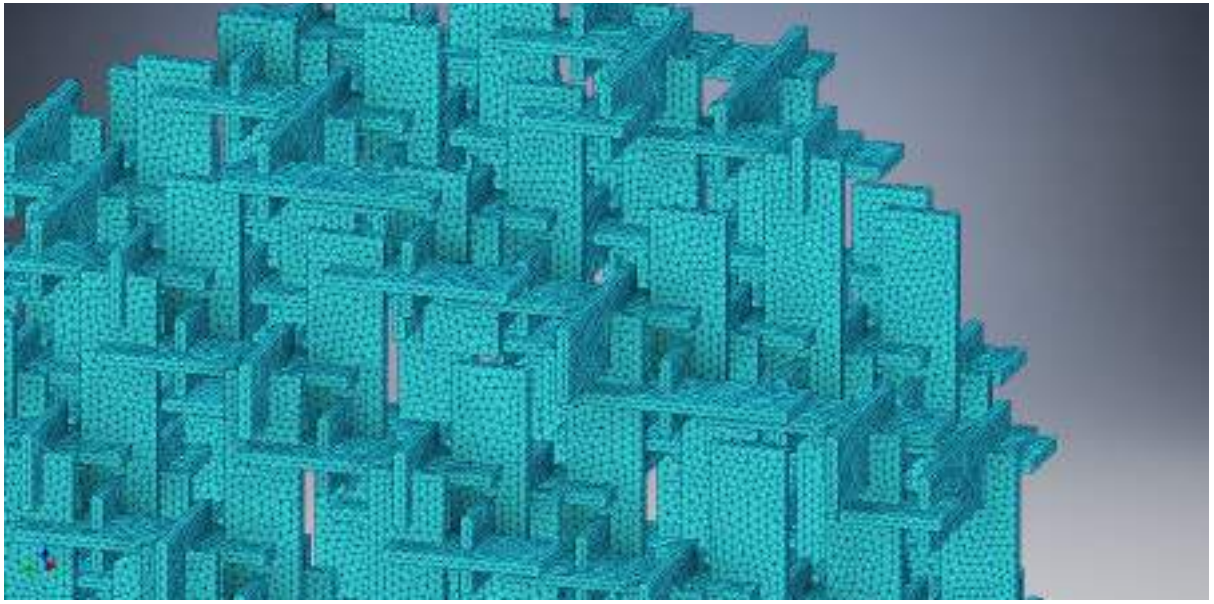
Load: Own weight + Wind



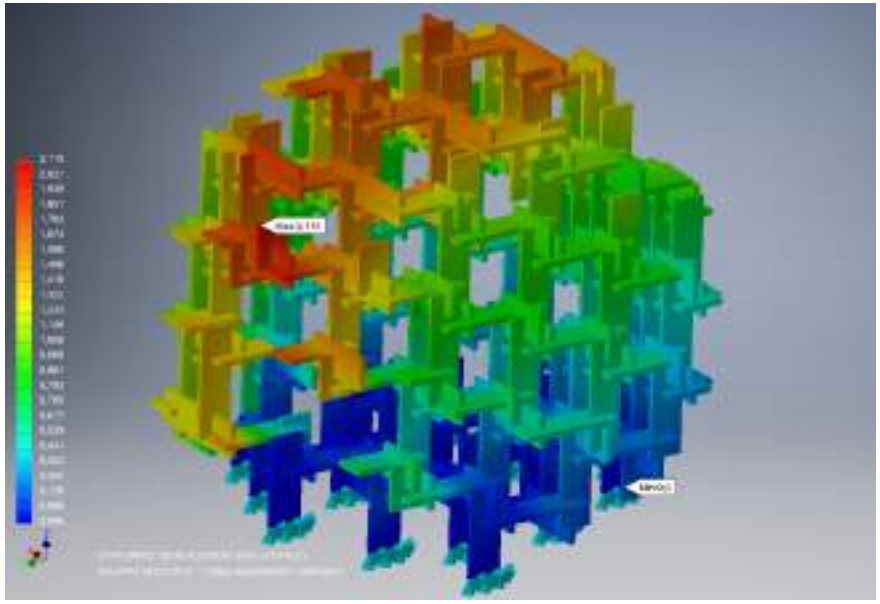
Load: Own weight + Snow + Wind + Snow



Glued model mesh



Glued model displacement



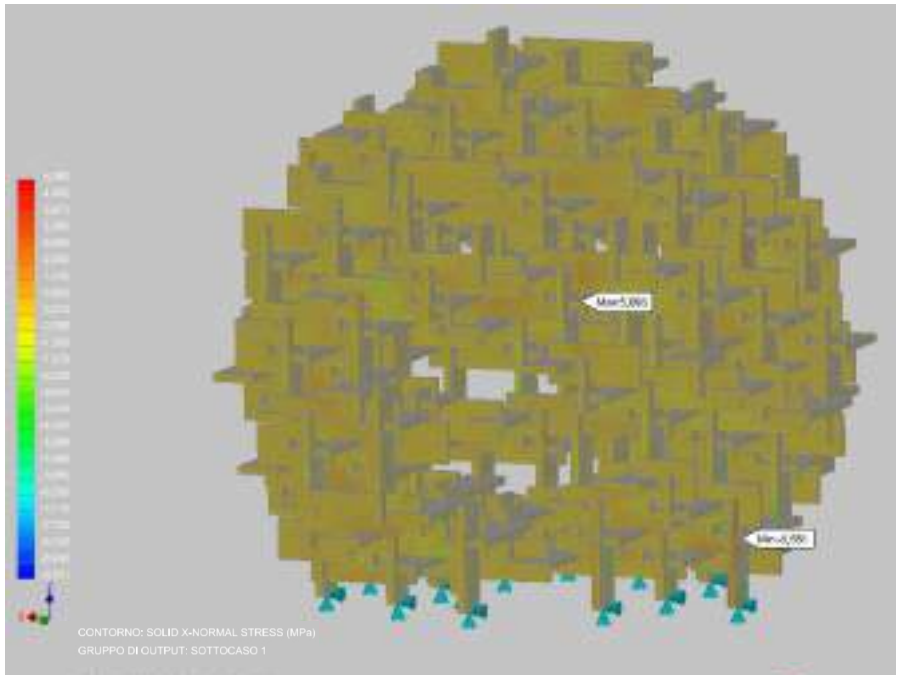
Calculations - board final thickness 58 mm

Larch – new snow load thickness=58mm

	min	limit	max	limit	
fx	-9,55	-12,0	5,09	8,4	
fy x panels	-0,42	-2,16	**0,28**	0,24	1 panel over stress limit
fz x panels	-0,83	-2,16	**0,56**	0,24	5 panels over stress limit
fy y panels	-0,47	-2,16	**0,40**	0,24	3 panels over stress limit
fz y panels	-0,96	-2,16	0,17	0,24	
fy z panels	-0,77	-2,16	0,14	0,24	
fz z panels	-1,69	-2,16	**0,47**	0,24	1 panel over stress limit
xy	-0,6	-2,28	0,63	2,28	
yz	-0,52	-2,28	1,07	2,28	
zx	-1,48	-2,28	1,01	2,28	

disp. (mm) 6,02

total number of panels over stress limit **10**

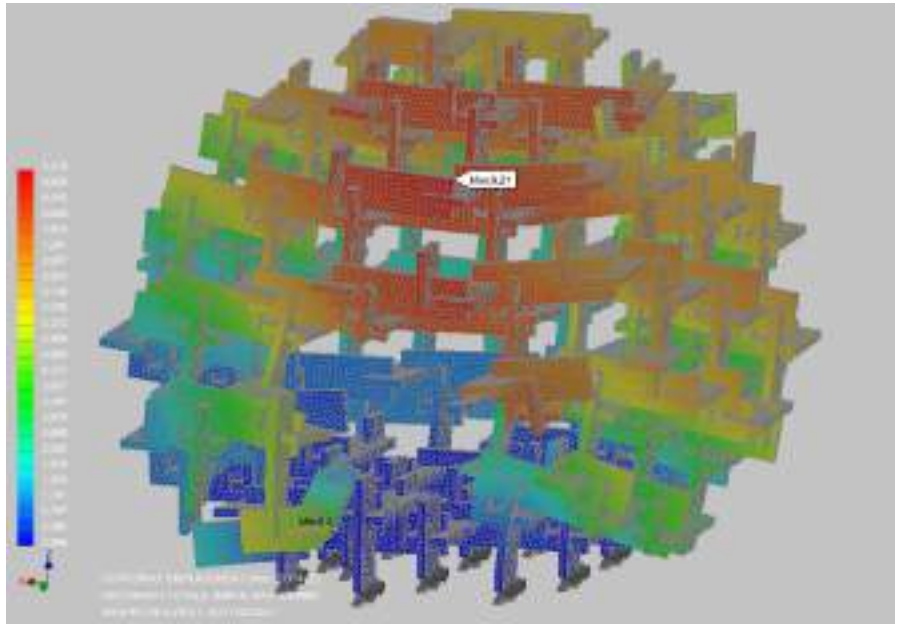


Larch – new snow load thickness=58mm
two additional restraints

	min	limit	max	limit	
fx	-8,51	-12,0	3,74	8,4	
fy x panels	-0,24	-2,16	0,20	0,24	
fz x panels	-0,97	-2,16	**0,60**	0,24	5 panels over stress limit
fy y panels	-0,31	-2,16	**0,35**	0,24	1 panel over stress limit
fz y panels	-0,76	-2,16	0,10	0,24	
fy z panels	-0,81	-2,16	0,11	0,24	
fz z panels	-0,83	-2,16	**0,38**	0,24	2 panels over stress limit
xy	-0,56	-2,28	0,69	2,28	
yz	-0,35	-2,28	0,51	2,28	
zx	-0,77	-2,28	1,00	2,28	

disp. (mm)

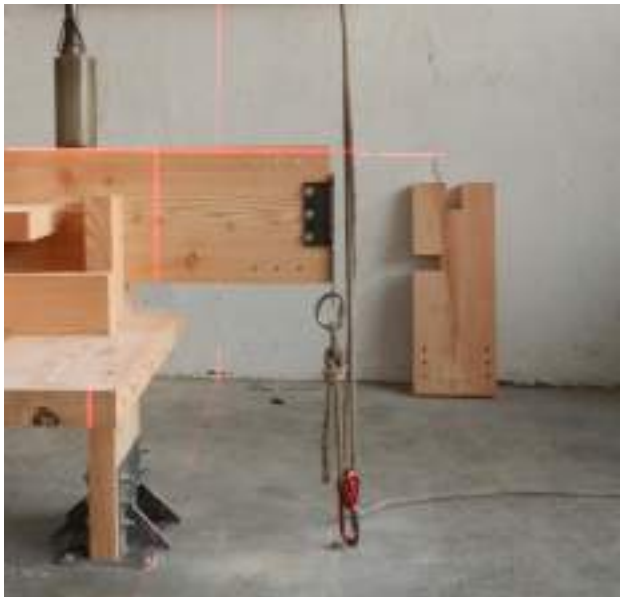
total number of panels over stress limit **8**



D3 Wood, Federica Iachelini & Clara Rinaldi
24th January 2018

KODAMA
LOAD TEST
NODE 1:1 IN LARCH

Used tools

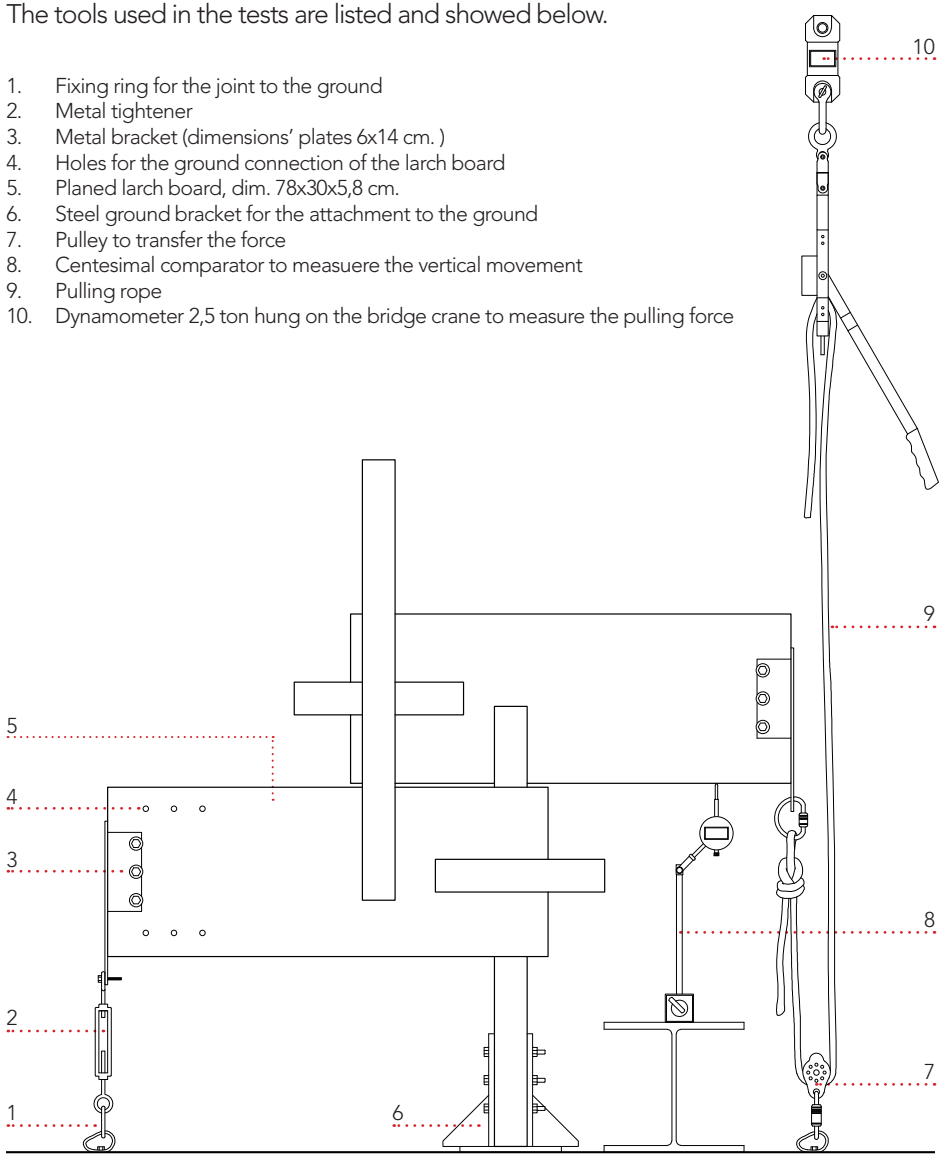


Base wood units

Static Scheme

The load tests have been set up following two different static schemes. The first set up uses a restraint opposite to the point of the pulling force and the second set up uses only a fixed support to the ground. The first test is the best simulation of the reality, with the second restraint to the ground. In fact, in the second case the force turns out to be too eccentric and the resistance to compression of the element needs to be reduced. The tools used in the tests are listed and showed below.

1. Fixing ring for the joint to the ground
2. Metal tightener
3. Metal bracket (dimensions' plates 6x14 cm.)
4. Holes for the ground connection of the larch board
5. Planed larch board, dim. 78x30x5,8 cm.
6. Steel ground bracket for the attachment to the ground
7. Pulley to transfer the force
8. Centesimal comparator to measuere the vertical movement
9. Pulling rope
10. Dynamometer 2,5 ton hung on the bridge crane to measure the pulling force

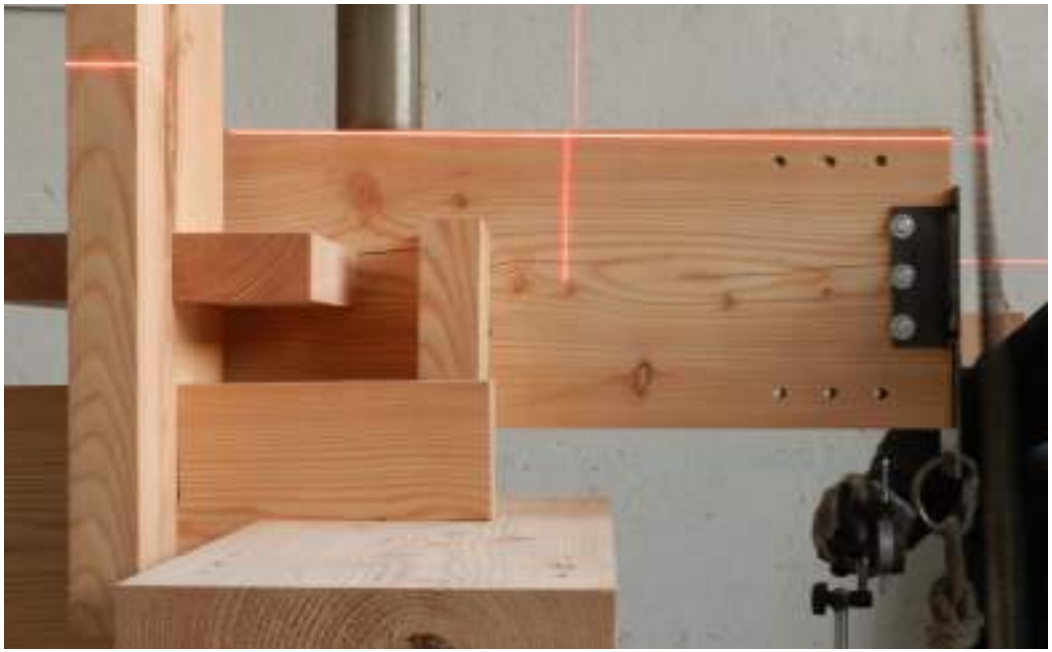


First Static Scheme

Steel ground bracket fixed to land

Assembling the node

Elements for the Junction System



Pulling System components

Load Tests

Conclusions and comparisons

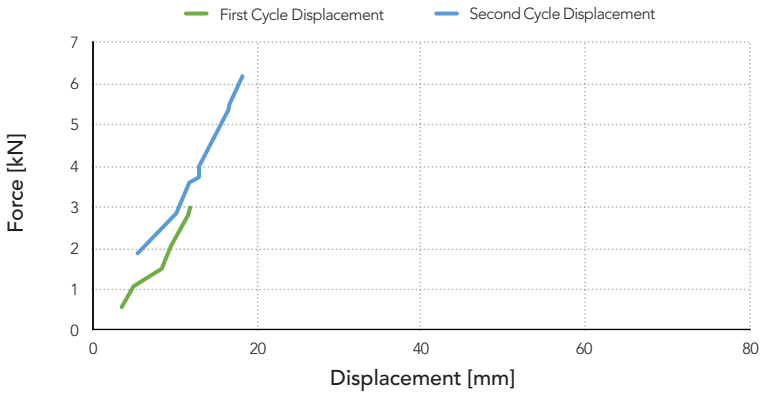
The observations made by engineer Marco Clozza during the load tests and the eventually drawn conclusions will be discusses in the following.

"The results of the tests are very positive for different aspects:

1. There is a good correlation of stress and deformation between the FEM analysis and the reality. Initially the reached displacement was higher than the one calculated due to the recovery of the tolerance of 3/10 of the joints, instead closer to the breaking point the real displacement was lower than the calculated.
2. Before arriving to the break point, with 7 kN of pulling, the knot has remarkable reserves of plastification. The software at 6 kN of pulling calculates values of stress of at least an higher order than those we have in the global model with real forces at ULS.
3. In case of centred force (Static Scheme 1), at the first break point with more than 7kN of pulling force, the hyperstaticity reserves influence the result and the dynamometer revealed still 4 kN of pulling."

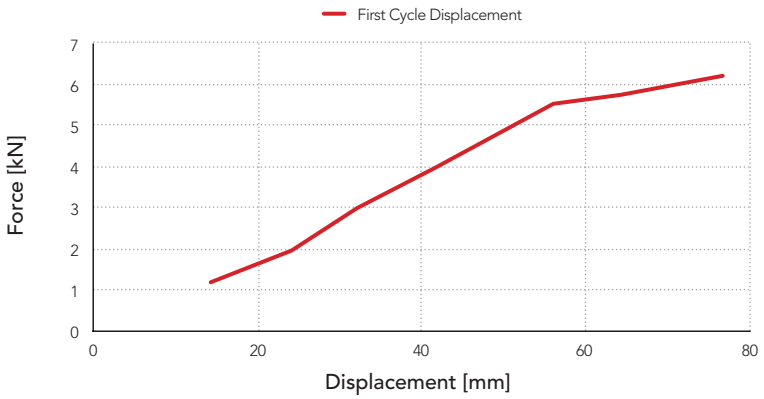
Load Test - Scheme 1

In the preceding page is reported the final image of the knot at the breaking point is presented (Load Test - Scheme 1) of which on the right the graphic Force versus Displacement. In this case the breaking force is 7 kN circa: the last recorded value that is measured is an imposed force of 6,2 kN after which it verified a peak of force of 7,3 kN with the consequence of breaking the larch board.



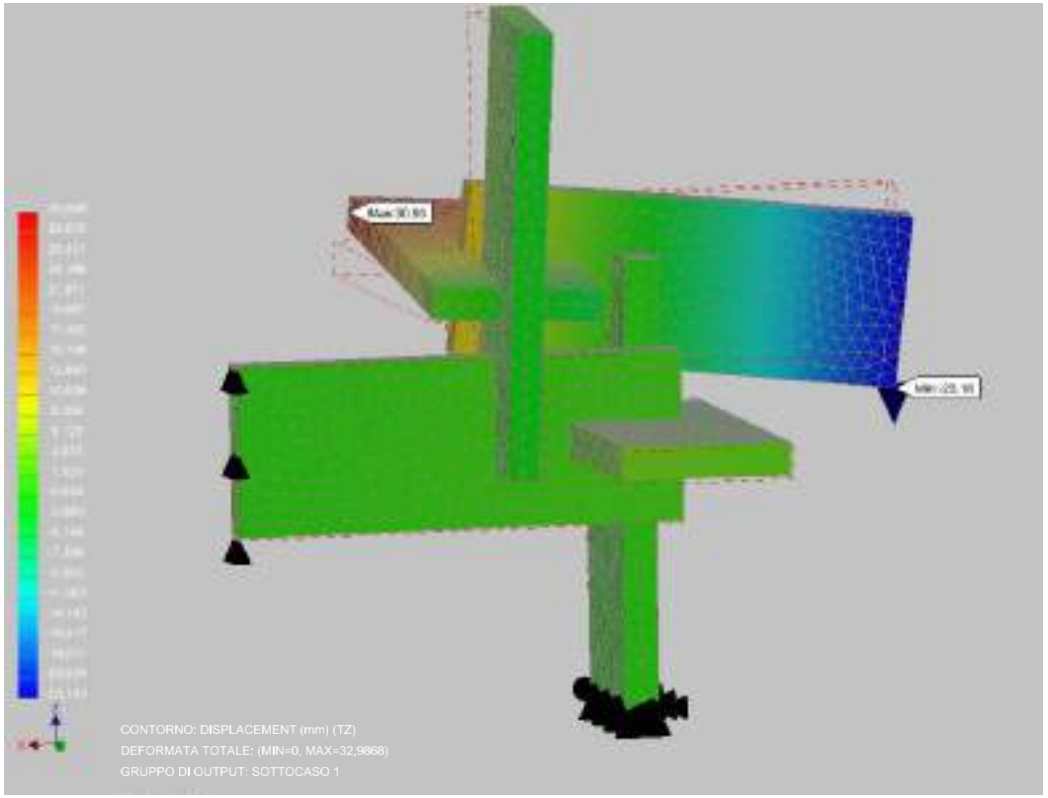
Load Test - Scheme 2

In the second test it was expected to measure a lower breaking force, due to the lack of the restraint and the consequent force's eccentricity. The node broke at 8,5 kN, indicating a better resistance to compression of the element. This test shows a more fragile type of break: it happened without the verifying of all the plastic deformation, stood out in the first in hyperstatic configuration.

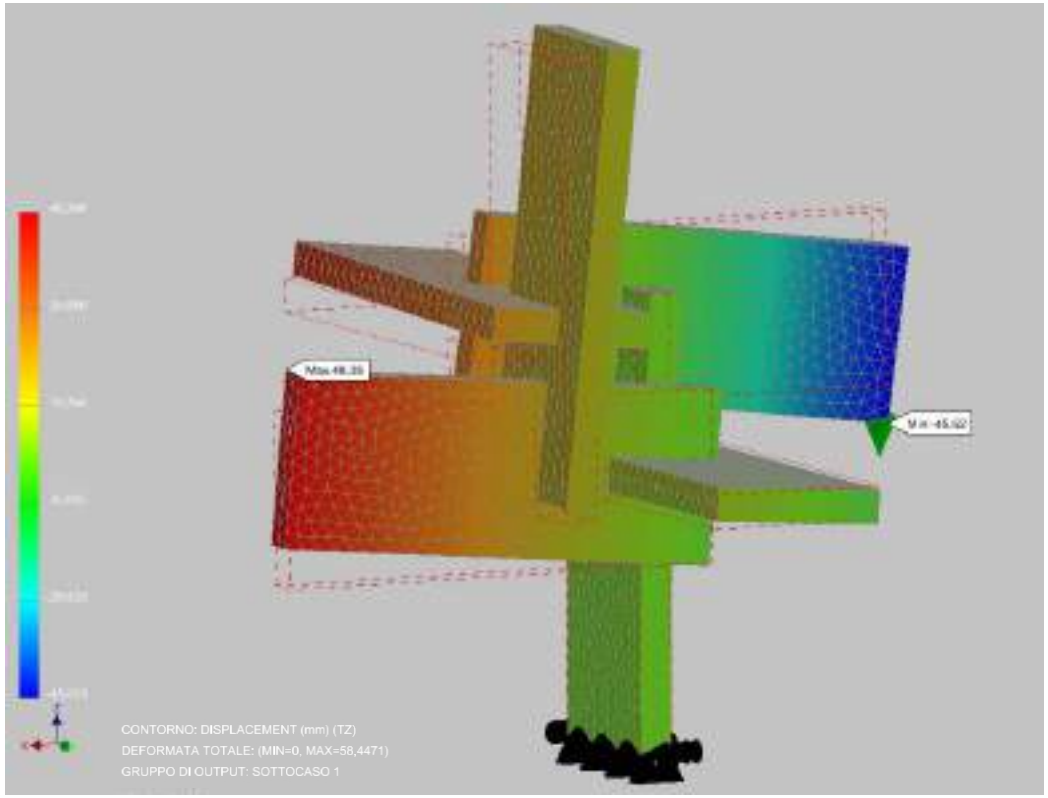


Simulation displacements

With the joint to the ground



Without the joint to the ground



Forze Applicate [Kg]	Deformazione Modello [mm]	Deformazione Reale [mm]
187	6,99	5,48
285	10,66	10,22
360	13,46	11,8
400	14,96	13
538	20,12	16,59
550	20,56	16,68
620	23,18	18,3

Forze Applicate [Kg]	Deformazione Modello [mm]	Deformazione Reale [mm]
115	8,46	14
200	14,72	24,23
290	21,34	31,16
370	27,23	39,23
450	33,12	46,43
550	40,48	56,17
620	45,62	76,86

Marco Imperadori, Marco Clozza & D3Wood
20th October 2017

KODAMA
MOCKUP 1:5
MADE IN YEW

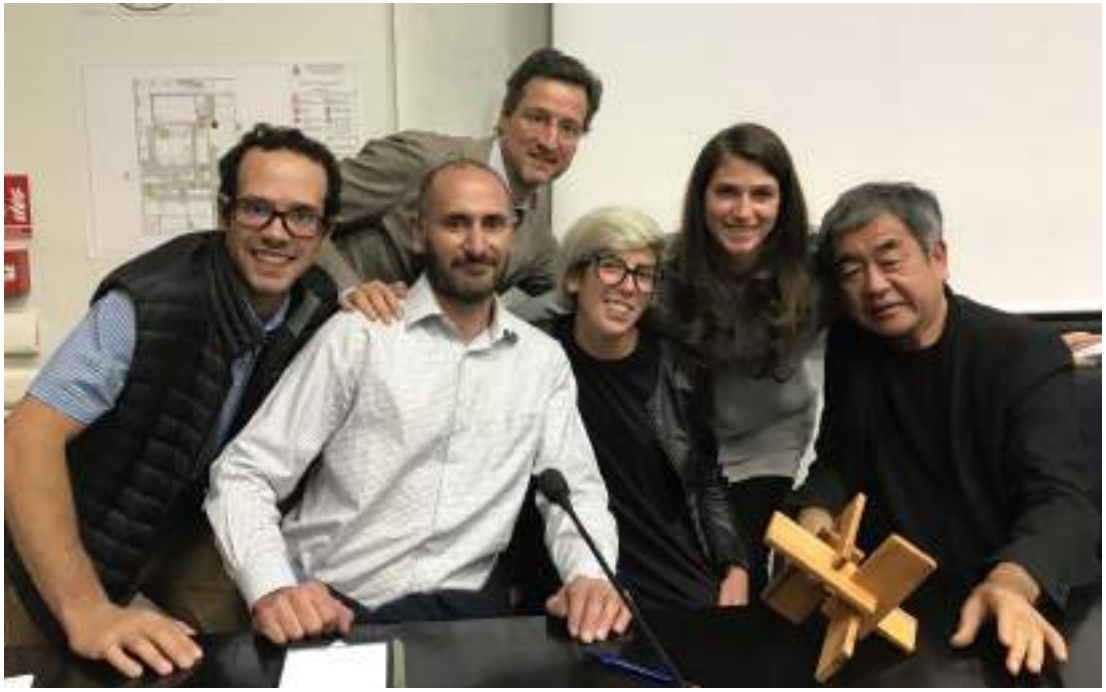
Final mockup

Node detail

Separate elements to compose

Separate elements to compose

Delivery of the mockup to Kengo Kuma



D3Wood, Federica Iachelini & Clara Rinaldi
4th April 2018

KODAMA
MOCKUP 1:5
MADE IN OAK

Oak mockup realized in D3Wood laboratory

Pieces' classification and realization of the first ring

Oak mockup realized in D3Wood laboratory

Realization of the fourth ring

Joint detail

Oak mockup realized in D3Wood laboratory

Final mockup

Oak mockup located in Villa Strobele garden

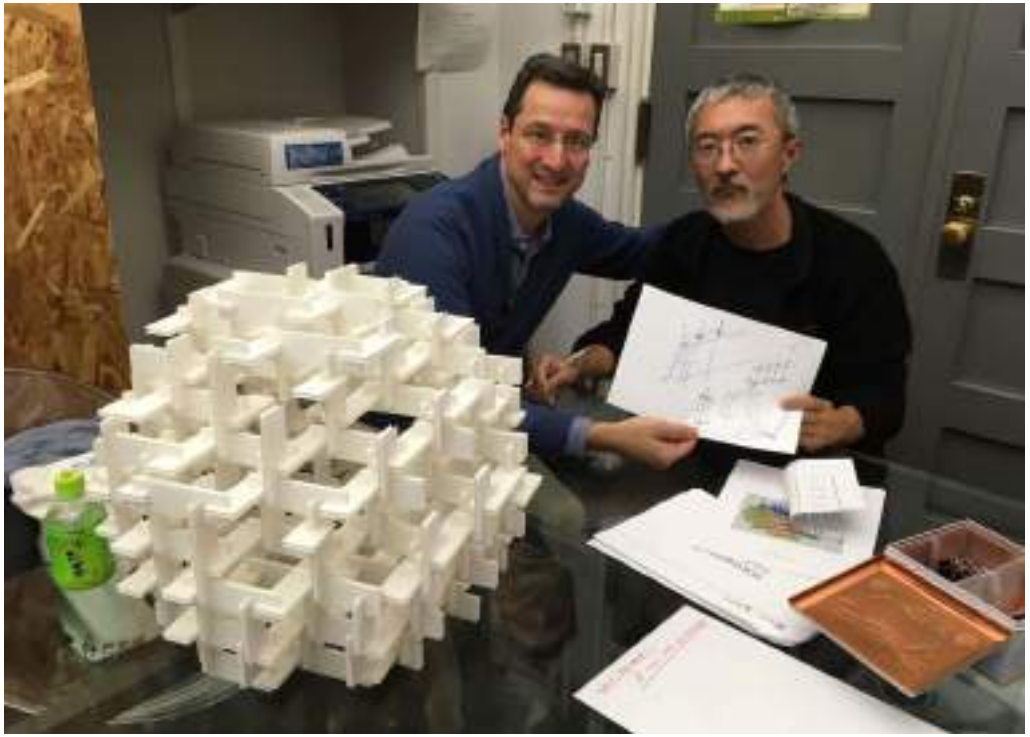
Final mockup

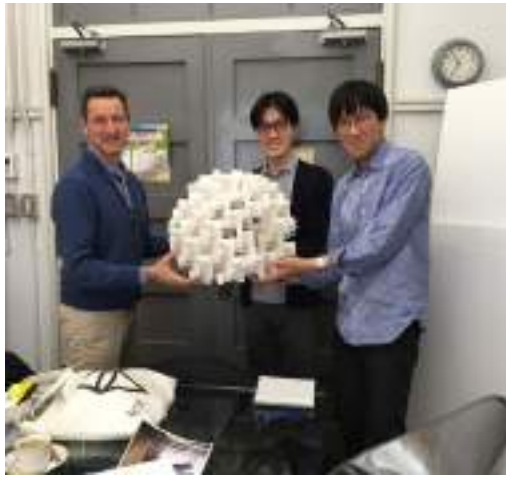
Marco Imperadori & Kuma-LAB
15th November 2017

KODAMA
MOCKUP 1:10
MADE IN POLIPLAT

Mockup realized in Kuma-LAB

Analysis and realization of the mockup





Final mockup

Mockup realized in Kuma-LAB

Insertion in real context

Federica Iachelini & Clara Rinaldi
15th April 2018

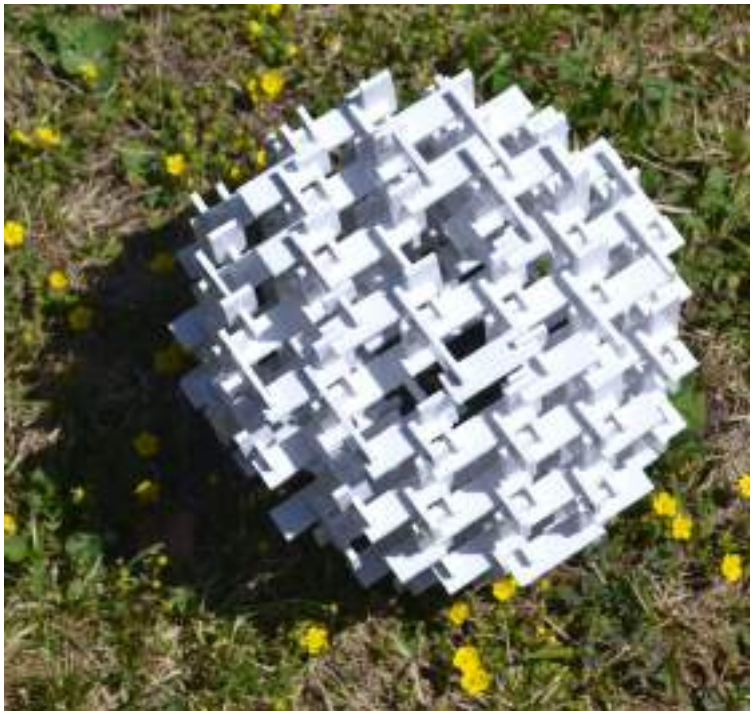
KODAMA

MOCKUP 1:20

MADE IN METHACRYLATE

Final mockup located in Villa Strobele garden

Final mockup



Arch. Ing. Giorgio Franceschini & Ri-Legno Srl
4th April 2018

KODAMA
ON-SITE
ELEMENTS' PRODUCTION

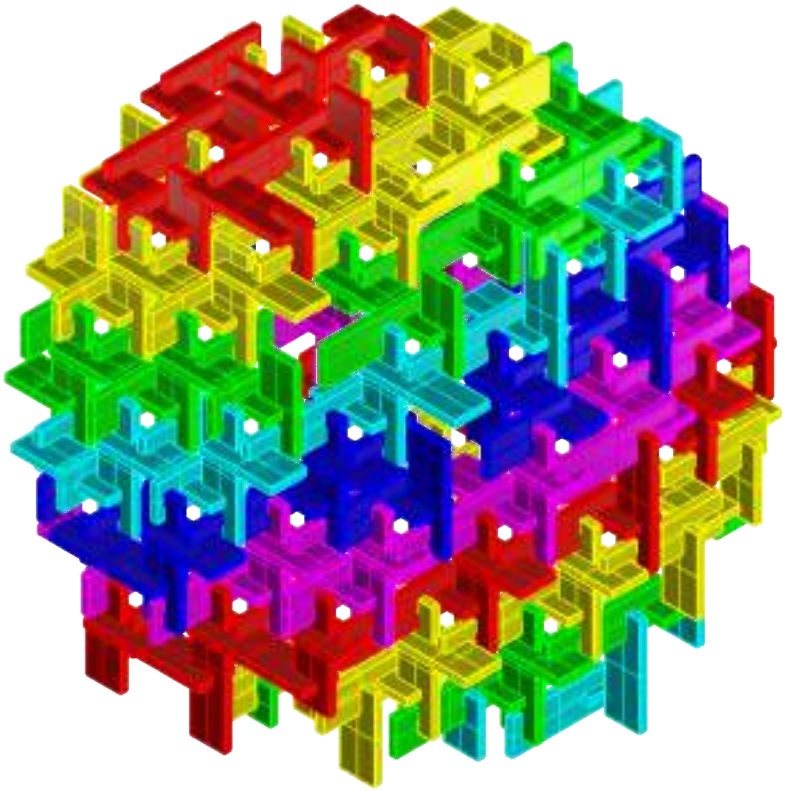
Model codification

All the model was codified following precise rules. First of all every pieces was classified for type with a number. Secondly to each one was assigned a specific, unique numerical and alphabetical code.

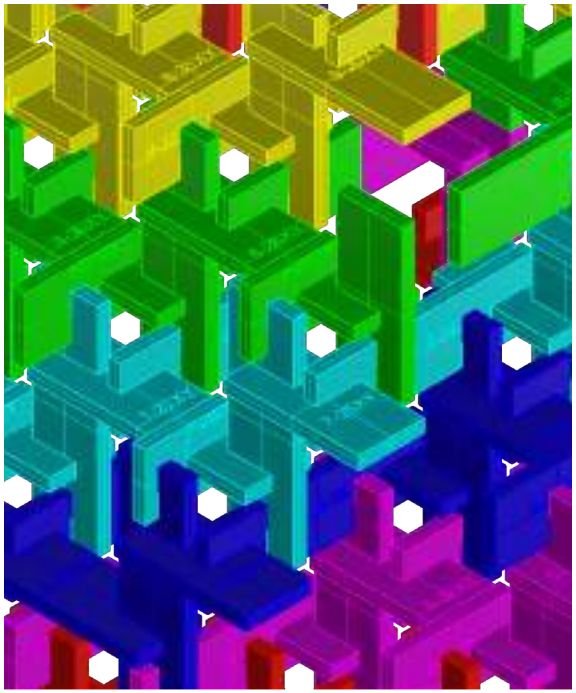
1-10YZ

Ring number | Assembling order | Piece orientation

Each type of piece had a related number and was assigned to a specific stock pallet (corresponding to the structural ring).



Final codes and excel organization file



Piece Type	Code	Package
127.0	1-10YZ	FAB_L01
32.0	1-11YZ	FAB_L01
32.0	1-1YZ	FAB_L01
33.0	1-2YZ	FAB_L01
113.0	1-3XY	FAB_L01
35.0	1-4ZX	FAB_L01
5.0	1-5ZX	FAB_L01
128.0	1-6YZ	FAB_L01
105.0	1-7XY	FAB_L01
33.0	1-8YZ	FAB_L01
115.0	1-9ZX	FAB_L01
8.0	2-10XY	FAB_L02
8.0	2-11YZ	FAB_L02
148.0	2-12XY	FAB_L02
8.0	2-13ZX	FAB_L02
8.0	2-14ZX	FAB_L02
93.0	2-15YZ	FAB_L02
8.0	2-16XY	FAB_L02

Cutting

Original boards in larch

CNC machine

Final boards

D3Wood, Federica Iachelini & Clara Rinaldi
16-20th April 2018

KODAMA
ON-SITE
CONSTRUCTION IN LARCH

Construction-book

The pavilion's building had been based on a strict assembling scheme that stem from the study of the parametric model. Kodama is composed by 335 panels characterized by bidirectional joints; this complex geometry requires a construction organized by phases.

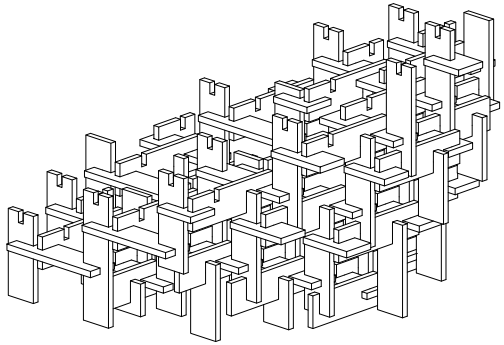
Through "a rings scheme" the realization of the entire pavilion was allowed. This procedure provide a separate mounting of each ring that is jointed to the precedent in a second moment. For this reason, the parametric model has been subdivided in 10 different, connected between each other following only the vertical direction.

This model dissection facilitated the structural phases of the entire work and was also extremely useful for the construction-site organization. The 335 larch pieces cut by the CNC machine (RiLegno Srl) have been stocked on 5 different pallet according to the parametric model codes.

The Kodama construction lasted 5 days (from 16th to 20th of April 2018). The first one has been used to place the foundations beams made in larch and to fix the metal plates. The wood structure, completely jointed without any metal connections, started on the 17th of April 2018 and continued for 4 days.

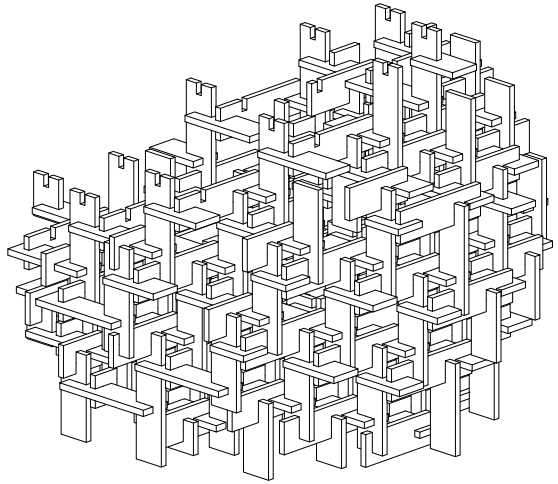
Day 2 - 17th April

First, second, third and fourth ring



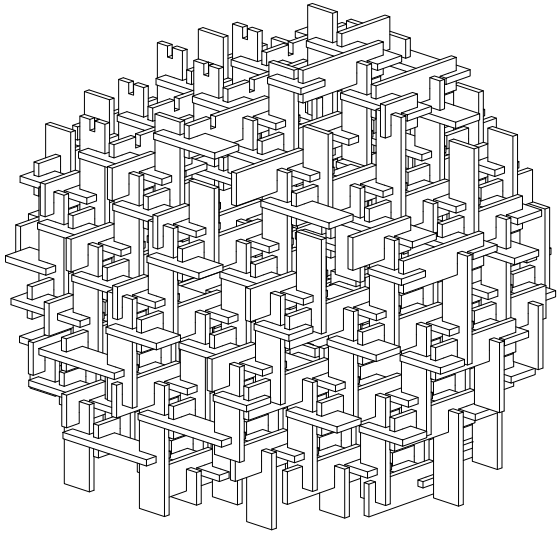
Day 3 - 18th April

Fifth, sixth and seventh ring



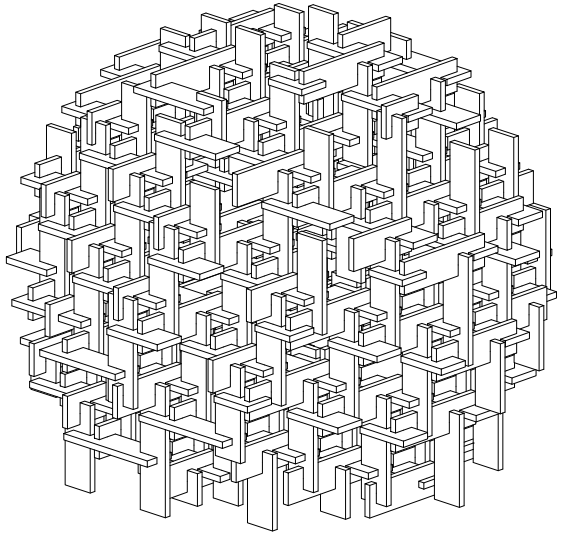
Day 4 - 19th April

Eighth and ninth ring



Day 5 - 20th April

Tenth ring



Day 1 - 16th April

Placement of the root beams

Day 1 - 16th April

Placement of the metal plates

Day 2 - 17th April

Realization of the first and second ring

Day 2 - 17th April

Realization of the third and fourth ring

Day 3 - 18th April

Realization of the fifth ring

Day 3 - 18th April

Realization of the sixth and seventh ring

Day 4 - 19th April

Realization of the eighth and ninth ring

Day 5 - 20th April

Final pavilion

Day 5 - 20th April

Detail

Day 5 - 20th April

Federica, Claudio, Marco and Clara

Marco Imperadori, Federica Iachelini & Clara Rinaldi
18th January 2018

STEPPING STONES

STROBELE HOUSE GARDEN

Japanese Gardens

The stone path: Stepping Stones

As the tradition wants, the stone path begins from the tea hall (Chashitsu), sacred room where the Cha No Yo, tea ceremony, takes place.

The sacredness of this ceremony imposes that also the approach to the hall follows a specific rules. The so-called Stepping Stones begins in front of the entrance of the hall, where there is positioned the biggest stone of the path. This element represents the point of division and connection between the sacred hall and the garden, a kind of neutral limbo, scene of inner transition. Leaving the hall, the host dwells on the first stone and takes his time to prepare himself to the change. From here the path takes the host to the places of interest of the garden, drawing a sinuous and curvilinear route.

The voluntary lengthening of the trail helps the observer to understand how tiring and never obvious is the road to the equilibrium.

The stones: how to choose and place them

The stones, which are always chosen in different sizes and shapes but always of the same material, are never positioned at an equal distance and with the barycentre slightly moved from the imaginary line that indicates the run.

Once again, the co-existence of order and disorder, is a symbol of harmony.

The stone path is never enclosure and it never goes back over himself. This characteristics symbolise a spiritual conquest route that brings the host to isolated and hidden differnet areas dominated by a grove, a glade or a lantern and hidden from an outside observer.

Luserna Stone

Dimension of the stones

The drawing of the path is stricktly dipendent from the size of the Luserna Stone plates, material that comes from Trentino's valleys. Since ancient times, this stone has been used for paths in gardens and walkways in urban crowded roads. The possibility to have plates of great dimensions and shapes that bestly simulate the traditional configuration of the Stepping Stones of the Japanese Garden, make this material becomes a perfect project candidate.

In the specific are used stones with avarage length of their diagonals that varied from 70 to the 90 cm and with a typical not homogenea coloration, tending to gray.

Geological and geographic location

The Stone of Luserna is a schistose metamorphic rock belonging to the group of the Gneiss. It is about particularly Gneiss lamellar type, composed by differents layers.
This stone, whose natural extrapolation is documented from the middle of XVII century, has been used as a construction material from the remotest times.

Stepping Stones - Chosen Option

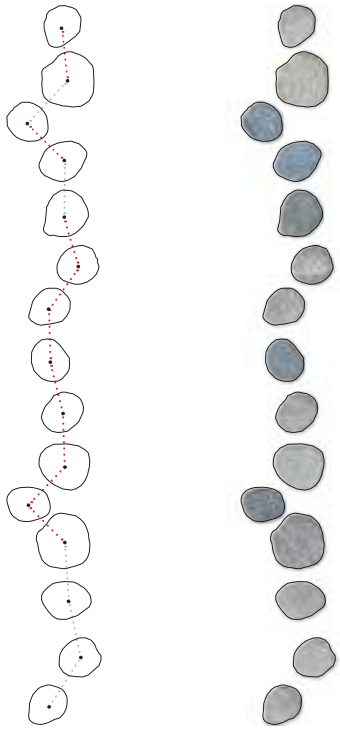
Below is exposed the final hypothesis of the Stepping Stone that leads from Villa Strobele to the Kodama. From this, that symbolize the sacred hall of tea, begins the stone path that leads to the pavilion starting next to the existing road in the garden.

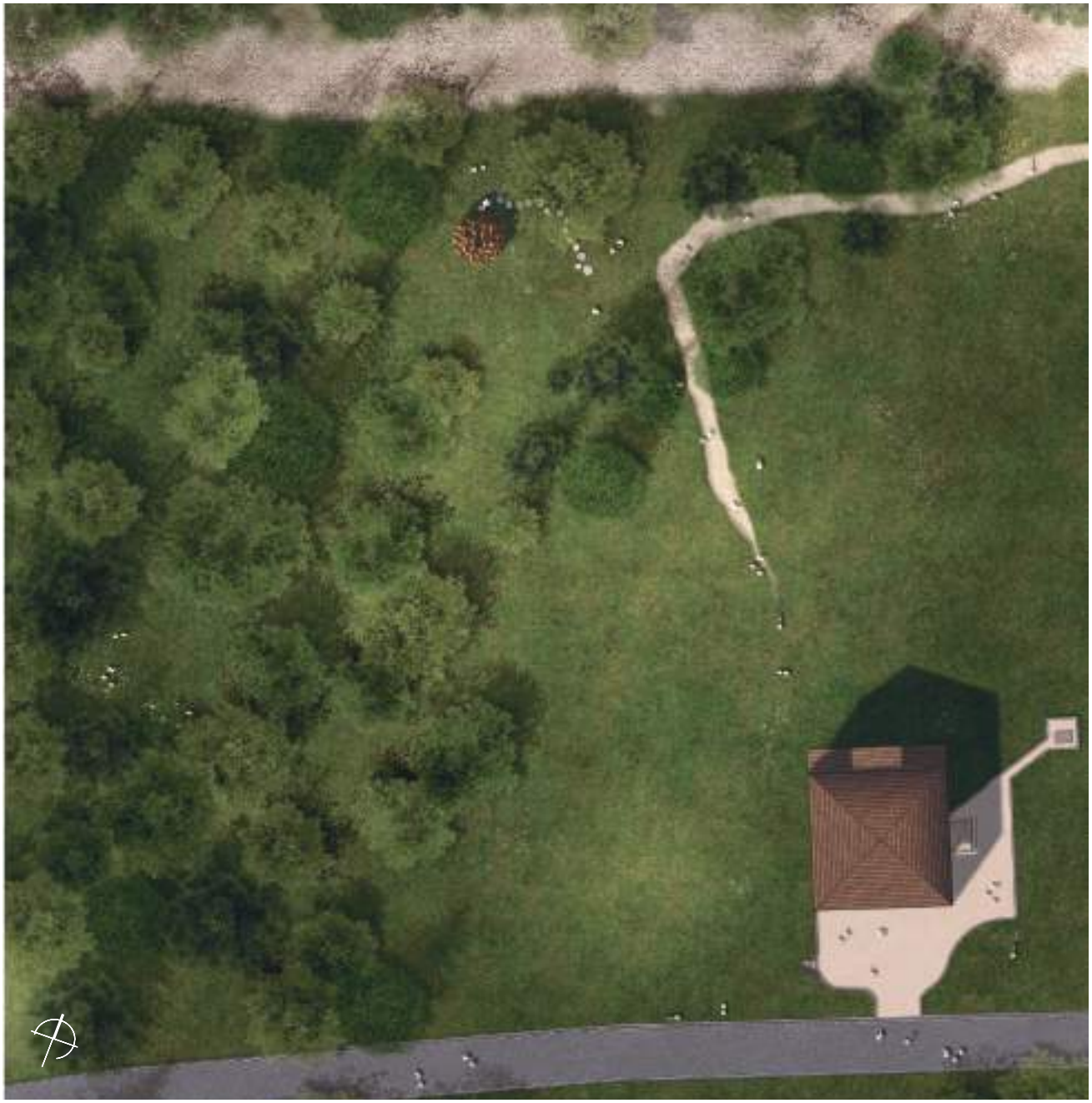
The main idea is to conceal the entrance to the observer till the last moment, offering him a run inside the garden and let him enjoying the fantastic natural view of the sorrounding. For this reason the entry of the Kodama has a northwest orientation. This configuration allows also to hide till the last moment that the pavilion is also accessible from the inside: up to the last step the Stepping Stone seems like a tortuous way form which enjoy the surrounding view without having the certainty to be able to enter in the final hall.

The shape of the path is inspired to the "Niren-uchi", one of the eleven traditional typologies of Japanese Garden as reported in the book "Design Parts Collection in Japanese Traditional Style Garden."

Distances bethween the stones:

- Center of gravity
- 100 cm
- 90 cm





D3Wood, Federica Iachelini & Clara Rinaldi
16-20th April 2018

KODAMA
ON-SITE
STONE PLACEMENT

26th April

Placement of the sign

Kengo Kuma's autograph

26th April

Placement of the stone path

26th April

Final layout

26th April

Final layout

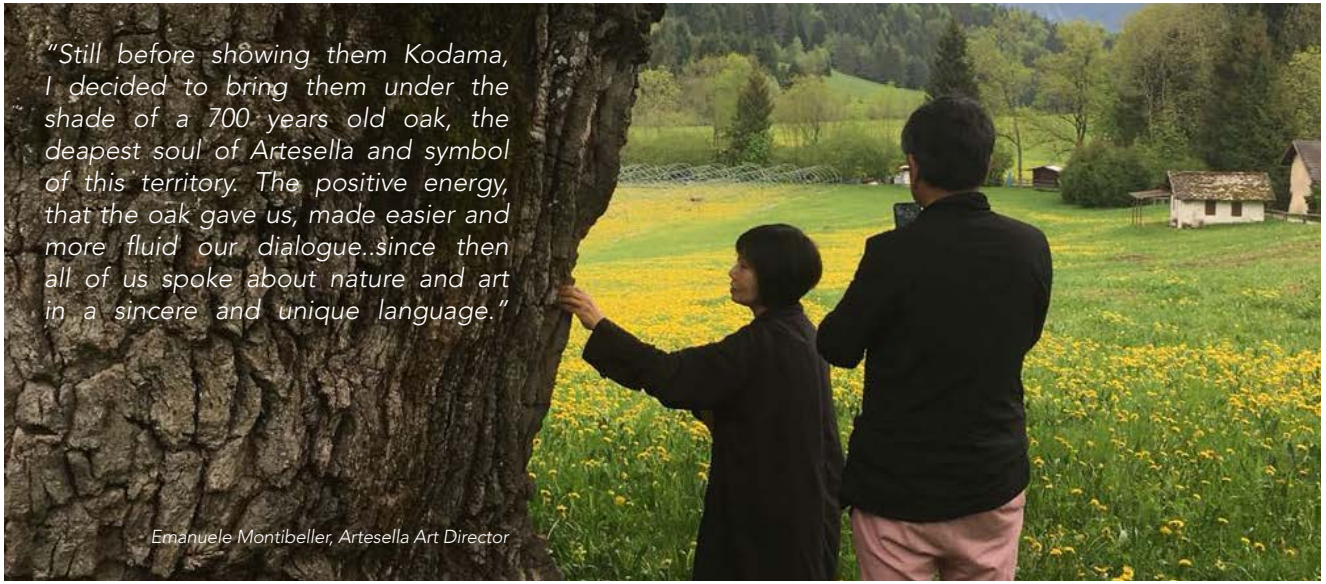
05-06th May 2018

KODAMA
OPENINGDAYS

ARTE SELLA, BORGO VAL SUGANA

Saturday, May 5th

Satoko Shinohara and Kengo Kuma arrival in Val di Sella



Kengo Kuma sensei arrival in Artesella

Lunch time in Malga Costa

Emanuele Montibeller during the visit of Vlla Strobele

Satoko Shinohara and Kengo Kuma durind the visit at Villa Strobele

Kuma Sensei discovering Kodama for the first time

First approach

Kuma Sensei discovering Kodama for the first time

First approach

Kuma Sensei discovering Kodama for the first time

Climbing to the top

Exchanging gifts

Yew jewel for Satoko Shinohara and Kodama report for Kengo Kuma

Sunday, 6th May

Opening cerimony

Opening cerimony

Opening cerimony

Opening cerimony

Ferrari cerimony

From left to right: Giacomo Bianchi, Kengo Kuma Sensei, Marco Clozza, Emanuele Montibeller, Claudio Clozza, Satoko Shinohara, Marco Imperadori, Federica Iachelini and Clara Rinaldi

From left to right: Masumi Ogawa, Takahiro Hirayama, Toshiki Hirano, Clara Rinaldi and Federica Iachelini Rinaldi

KODAMA
OBJECTS

HANDMADE NODES AND JEWELS

Kodama node in scala 1:5

D3Wood version on sale in Artesella (Borgo Val Sugana)

Japanese version on sale in Kengo Kuma's exbhition (Tokyo Station)

Kodama node in scala 1:5

D3Wood version in oak and Japanese version in cedar

Kodama jewel in scale 1:20

From the gift for Kuma Sensei to the jewel for Satoko Shinohara