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Levitas

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REFLECTIVE PRACTICE

We received and we gladly publish this contribution by distinguished designer and theorist Ian Ritchie, as an example of that bridging research and practice which our journal intends to promote and disseminate. [MS]

ABSTRACT - The design and engineering development of two apex connected square woven flat surfaces, each constrained at ground level by three anchors and lifted to form a 3D gridshell whose theoretical geometry is modified by the small sectional profile of the rectangular members made of wood. The warp and weft of the weave are of identical section and made from Italian red oak. The process of artistic investigation is explained and then taken into theoretical designs, computed, and is then tested iteratively through choice of wood, a 33% physical model which is laser surveyed and fed back into the computer model and FEM (Finite Element Method) analysis, and finally followed by a partial full scale mock up, before realising the sculpture at the Arte Sella environmental art park.

Keywords: anticlastic, Arts & Crafts II, curvature, environmental art, form-finding, gridshell

Arte Sella is an extraordinary project in a magnificent mountain setting, created through Emanuel Montibeller's passion, supported by Carlotta Strobele and Enrico Ferrari, to understand and open a dialogue between artists and the natural world about materially realised art within nature. The dream is to allow artists to respond to the freedom of the open-air setting, to their own creativity, and to the concept of their work's transience within and as a part of nature.

I consider myself as an architect who is an artist, sometimes an engineer, and one for whom performance and purpose inhabit my art of architecture.

The invitation from Emanuele Montibeller to contribute to Arte Sella gave me real pleasure. I had no idea what I would do, or where the work would end up. But I spent time at the mountain, was guided to look at specific areas, enjoyed conversations, good wine and food, and felt the generosity of its spirit of place in the wood, earth, air and views.

“Levitas” grew from this spirit of place. In this account of its creation, development and construction the importance of the symbiosis between idea (thought) and technology – which is the essence of all human creativity, including art – is emphasised. For this reason, unusually for a research paper, equal weight is given to the creative “research” embodied in words, poetry and conceptual drawings and the quantative engineering research that went into Levitas’ structure, which used both highly advanced technology and some of humanity’s most ancient human handicrafts (Fig.1).

PART 1 - WHAT IS ART IN THE TWENTY-FIRST CENTURY?

Art is free. No one can give art freedom.
Is it the only form of freedom that exists on Earth?
Is its boundary unknown until it transgresses human dignity – whatever expression it may be that defines the transgression – be it in a line, a word, a silent or noisy gesture?
Today, it is also nature’s dignity that we must consider, reflect upon and act with, not against.
Embrace the soil, rock, wind and sun, rain, snow, ice, wood and leaves, mulch and meadow and weave an art that searches for a truth about today, and about humanity on Earth.
Art in the twentieth century was severed by a critical knife into concrete and abstract objects interacting with reality, both incomprehensible, in that lonely place where the comprehension which may lie at art’s core is not possible.

All art is an everlasting experiment in finding the truths of our own time.
Art in the twentieth century was chopped into a thousand pieces and presented to us as a complex menu created by a thousand chefs - from stabiles to mobiles, from bold moves in the landscape to escape the constriction of the gallery, to the ephemeral works made of and in nature, to the immaterial digital works that exist forever but are composed of nothing but endless bytes of 0 and 1.
Quantum nature, revealing itself as a continuous sequence of the now, leaves us breathless for stability. And yet that nature is the place where we can be still, silent, looking.

Art and science are one world today. We dreamt of flying – Kazimir Malevich, Yves Klein, and architects in their quest for *levitas*, of overcoming *gravitas* – the thread linking Gothic cathedrals to walking cities and transparency – walking lightly on this Earth.

It is still there and elegantly expressed in the poetic work “The Stylus” by Gianandrea Gazzola, drawing the wind upon water, moved by trees in the wind – nature’s wand.
Invisible mythological wind, history maker, transporter and energy provider, a source of my art.
Art will be the spiritual voice of society - a global refuge in an age of planetary upheaval.
Art will inform and help develop human sensuality – our basic language.
Art is biological, procreative as nature, moving and evolving us in turn.

We live in a thin, screen-age of disinformation.
Society has substituted fickle taste, and amusement without responsibility, for truth.
Artists should disown and ringingly lament this era’s affliction of consumption.
Every act has an impact, so artists should act more than ever, to show the reverberant core of compassion and freedom. We present laughter,

Figure 1. “*Levitas* Night.”

the soul's language, and the victory of this language over dogma creates progress towards a commonality of supporting each other and the planet. Yet a work of art stands in its own truth and will, most likely, be "read" differently from the artist's intention (Fig. 2).

PART 2 - EXPRESSING MY ART IN ARCHITECTURE

As an architect I search to express art in architecture through form, space and reflectance, revealing its conceptual essence, ethical intent and haptic qualities.
This is my art, and it resists fashion and consumerism.
If philosophy informs the ethics of our age, which exist to help guide our human behavior, art exists to inform and help develop human sensuality – our basic language.
If words are losing their meaning and language has become infested with bullshit, what has happened to the way we are expected to see?
The artist, in expressing life's forces, becomes a critical voice in society and will be "burned" as often as celebrated for expressing eternal truths and Art's immortality.
Why paint, sculpt, dance, write, film or compose or extend ourselves into the world?

Figure 2. "*Levitas* from the Air."

Can we artists be in a happy place, when we see all around us worlds on fire, floods, starvation leading to migration at the scale of cities?

Art shows us the passage of humanity on Earth.
Art is not in the service of humanity and like nature has no constancy.
Art is a biological act woven into our DNA and is as mutable as nature, made manifest through movement and structure, re-defining us as we create it. Art is a glimpse into the furnace of creation and does not imitate nature.
Art's biological expression will evolve humanity towards a commonality (community) of sharing and loving each other and the planet.
Art is an unselfish gift to humanity, to the unknown person from the artist exploring the unknown.
Art "plastique" is about movement, as are the performing arts. This is the essence in all Art.
The "lone" artist feels and acts swiftly. No deliberation, no thinking to cloud the action to capture the essence of the moment.
Through art we are made more aware of how others see and feel.
The "team" scientist thinks and acts logically, deliberately, intellectually, to find the answer(s).
Art reveals our humanity, but can it do so without iconography, as science can when revealing our ecology?

CONCEPT

The sculpture at Arte Sella is called "Levitas." It is a response to the devastation caused by the hurricane that tore through this beautiful alpine valley in October 2018, and by the Italian word for saddle (*sella*).
My reading of entropy in the context of artworks at Arte Sella was relatively short-term, not measured in days but over a period of a few years – certainly not decades, centuries or millennia. So stone was not of particular interest to me, though a handful of pieces in the park are of stone, one by a colleague and fellow Royal Academician, Peter Randall-Page.
I did not think of trying to resist nature's effects in terms of durability but was more interested in the manipulation of material which would deliver the sculpture's form. I did not harbor ideas of permanence – as one might consider a tombstone to be permanent.
It inspired thoughts of renewal and of saddle shaped forms – anticlastic structures – that I had helped design in my time at Arup's lightweight structures group in the late 1970s. This suggested to me that emptiness would bring a certain ephemeral quality to the work.
Initially I had an idea of floating the saddles – suspended by trees – with the sculpture moving with the wind's energy transmitted by the movement of the trees. This idea was discarded, however, upon considering the recent destructive actions of the wind, which had demonstrated the potent effect of nature's entropy upon lightness (*levitas*) in this region – though much less so upon the massiveness (*gravitas*) of stone.

So, wood, tensioned into a saddle form (*sella*), and natural light became the essential materials of the resulting sculpture – "Levitas" (Fig. 3).

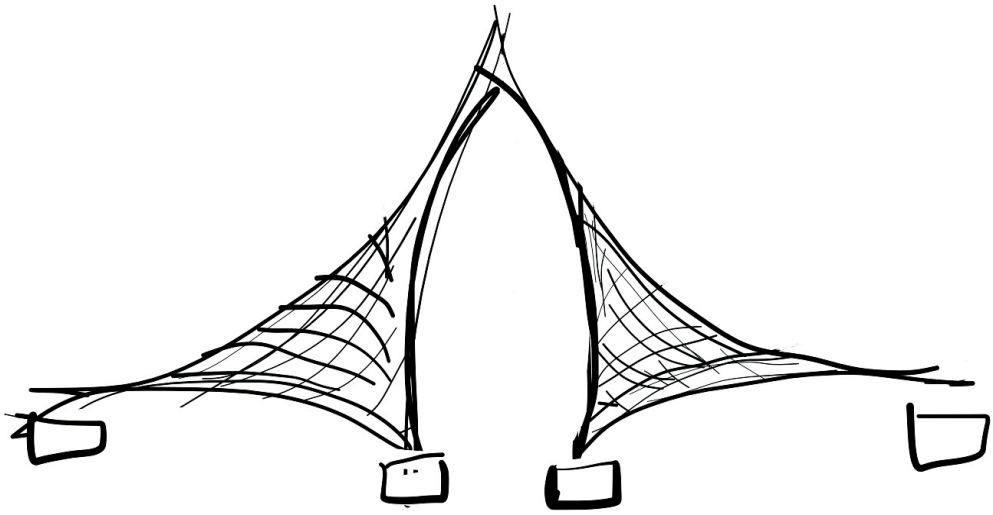


Figure 3. "*Levitas*" Ian Ritchie digital vector sketch, 2018.

Levitas

A symbiosis between architectural space making – lines, emptiness, surfaces, form – and structural engineering's underlying role in that space making through the use of geometry to deliver the stiffness of the form through tension.
The two anticlastic open grid-shell structures, appearing to lean against one another for support, suggest an arch – a window or door to the future – while acknowledging the mountains in the distance. This opening, and the voids in the grid shells, provide an opportunity to imagine beyond destruction, beyond the immediate entropic nature of life, and to appreciate nature from a new perspective (Fig. 4).

If they were laid out upon the ground as two squares, one could count that each structure is composed of 784 spaces formed by the woven grid's indistinguishable warp and weft.
Once in place, each of the 1,568 individual frames creates a unique window upon the environment, a picture frame view. As the shell's angle of curvature changes so does the proportion of each opening visible to the viewer, and these openings also presents different opportunities to falling snowflakes and photons - sunlight. The more vertically inclined frames will become more closed to the sky, while the more horizontal frames will be more open. This will reveal itself in significant ways to the viewer, inviting them physically to engage with Levitas as well as look through from outside and from within it, while snow and sun will leave strange new forms and lines upon the ground below (Figs. 5,6).

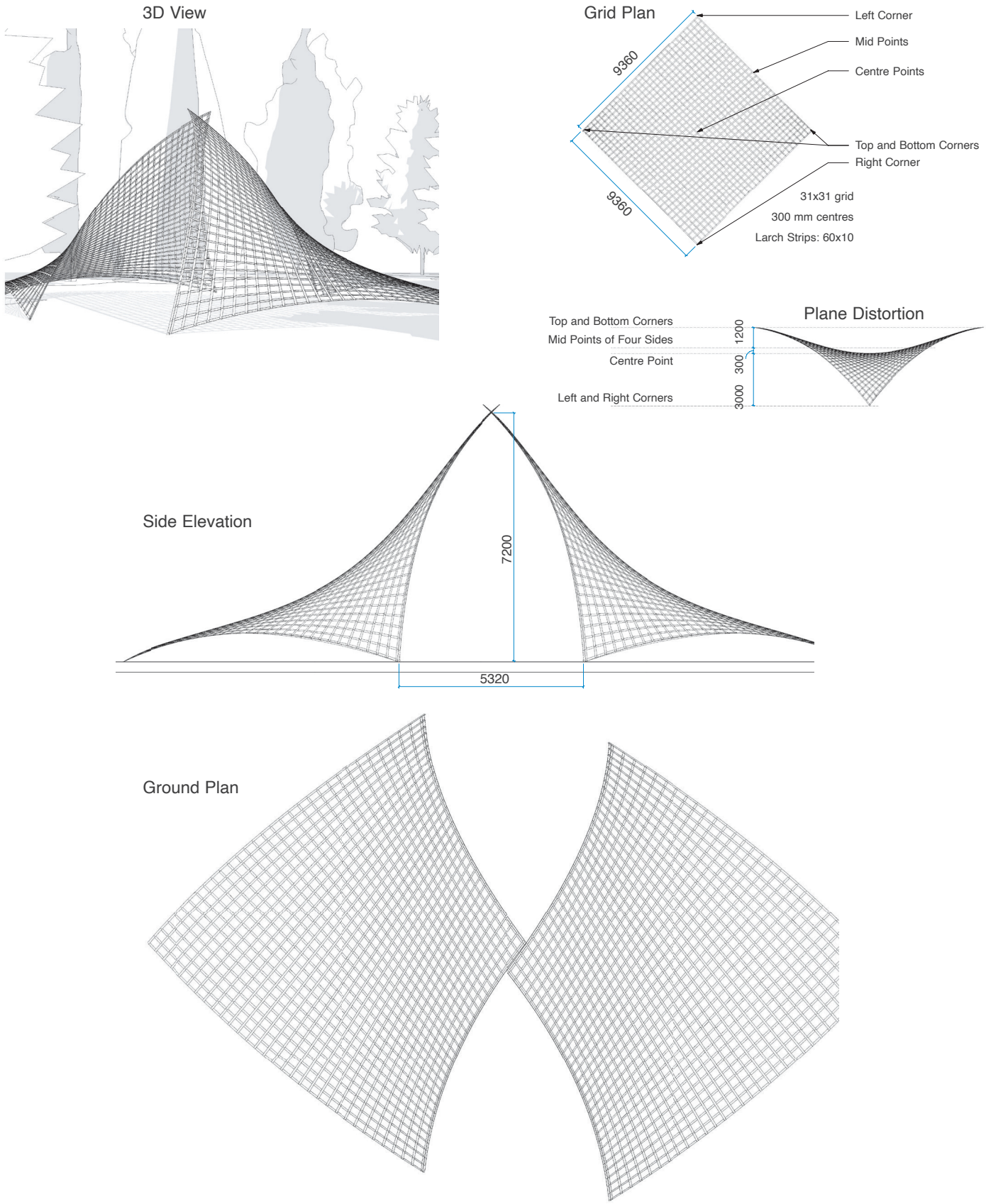


Figure 4. Concept drawing (3D Model) showing grid plan, “ground” plan, elevation, plane distortion & 3D view.

Intrinsic to the architecture and the art that I do is the idea that beauty is defined by non-linear behavior. By this, I mean the manner in which the work becomes part of nature, revealing this through change and the dynamic reaction to climate and weather – light, wind, water and earth. Levitas manifests this quality in many ways, some unpredictable, uncertain and surprising. It can be seen in the ever-changing composition of light and shadow that Levitas casts upon itself and upon the ground; its reflection in water, sometimes moved by the wind; in the way that leaves adhere to its lattice shells; how rainfall randomly changes the color of the wood strips forming the lattice shell; in the way that snow settles upon it, and how snow falls through its voids to create another level of topography upon the ground. This is non-linear beauty – the movement of infinity expressed by life (Fig. 7).

Figure 5. View showing snow pattern on the gridshell.

Figure 6. Beauty of a miniature snowscape created by the gridshell.

Figure 7. Interior view showing reflections, shadow and “windows” into the environment.

LEVITAS

Hovering wings, emerging from the ground,
suspended in time, and folding
as if from vanished roots below
pulled up, a carrier of life, a framing.

Arte Sella’s work in the Val di Sella
captures the spiritual bond
between man and nature,
inviting, enrapturing, un monde.

And as we gaze,
we search for wisdom, memory,
through our awakened spirit of nature.
What does our mind see?

Imagining “Levitas” is to enable
the recovery of a meaningful symbol
of the everlasting cycle of life –
protection, restoration, humble.

TECHNICAL INTRODUCTION

The research underlying the design and structure of Levitas followed simultaneous, parallel paths: a classic modelling/analytical approach as well as a physical/trial and error approach using mock-ups and real sections in wood. This “phygital” approach combined computer-based analytics/calculation and virtual geometry with real-world experimentation, and was particularly important in view of the geometrical and material constraints imposed by the artwork’s unique geometry. The result is a tectonic artifact which emerges from the ground “like a new mountain”, as the Art Director of Arte Sella, Emanuele Montibeller, loves to say.

During the research process it became clear that the lines of the pure parabolic surface in the computer models, where virtual strings (axis) defined a certain geometry, would be subject to transformation when the virtual models were applied to material reality. The woven structure of the flat wooden strips and the “small geometry” of the lattice elements’ rectangular sections affected the “big geometry” of the built sculpture, and created a surprising change in the whole geometry of the artifact. The sculpture acquired a sense of living interconnectivity from the unexpected shape created by the interaction of the wood lattice and the gravity loads distributed within it and supported by the tall arches on three hinges and pin-point ground supports: two lateral points on each side and one “whale tail.”

The magic of Levitas also derives from the embodied process of its creation, during which a kind of “neural connection” grew among all the partners involved, tuned to Ian Ritchie’s wavelength, achieving a unique structure-cum-work of art within a beautiful, natural sylvan landscape.

Material Considerations

The sculpture is constructed of 9 m [29.5 ft.] long wood strips of small section (60 mm x 10 mm - 2.4 in. x 0.4 in.), jointed with wooden bands and M5 metal bolts. It was particularly important to consider the durability and mechanical characteristics of various wood species before deciding which to use, and the choice between two locally sourced woods: black locust (*pseudoacacia*) or red oak (*Quercus Rubra*), was considered during the design phase.
Black locust is not considered a commercially important wood species and it has some potential as a more sustainable alternative to tropical hardwoods. It is a durable, attractive, and naturally rot resistant wood, superior to pressure-treated lumber while non-toxic to the environment. This makes it a locally grown alternative to chemically treated lumber, endangered tropical woods, and decay prone woods.
Limited information is available regarding the mechanical properties of black locust and the species is unaddressed by design codes and grading agencies. Load testing has been performed only on red oak (the wood

finally chosen) using full-scale members and small holes for the connections in order to substantiate average values reported in the literature and to validate model FEM analysis. Local availability of both woods is good, as are lattice elements of 6 m length and over, although transport becomes more complicated when lengths exceed 6 m.

After the realization of the first mock-up, black locust was chosen as the preferred option due to its resistance to weathering and durability when compared with other local woods. In the end, however, red oak – which has similar characteristics of resistance and durability - was the final choice. This was because the quality of the available wood was better, and a rapidly available supply of sufficient quantity was needed – which then had to be subjected to the necessary cutting/drying procedures – in order to have all the material ready for erection in time.

Joints

The original design of the lattice is a 9.6 m x 9.6 m [31.5 ft.] “membrane,” so the red oak lattice strips had to be jointed. It was possible to realize longitudinal joints with complete resistance restoration by coupling with wood-continuity plates. Initially, a section of 60mmx10mm wood elements had been assumed.
The metal elements, laser cut, had been used in the prototype in order to guarantee a consistent curvature because they have the same stiffness as the wooden elements. Finally, wood plates were placed in order to disguise the joint. This joint is easy to manufacture and, as required by Arte Sella’s guidelines, does not require the use of glues. Their positions in the membrane had been well studied in order to harmonize with the overall design. Longitudinal joints were calculated according to Eurocode 5, and the number of bolts was calculated in accordance with the stresses to which the elements would be subjected to.

Boundary Joints

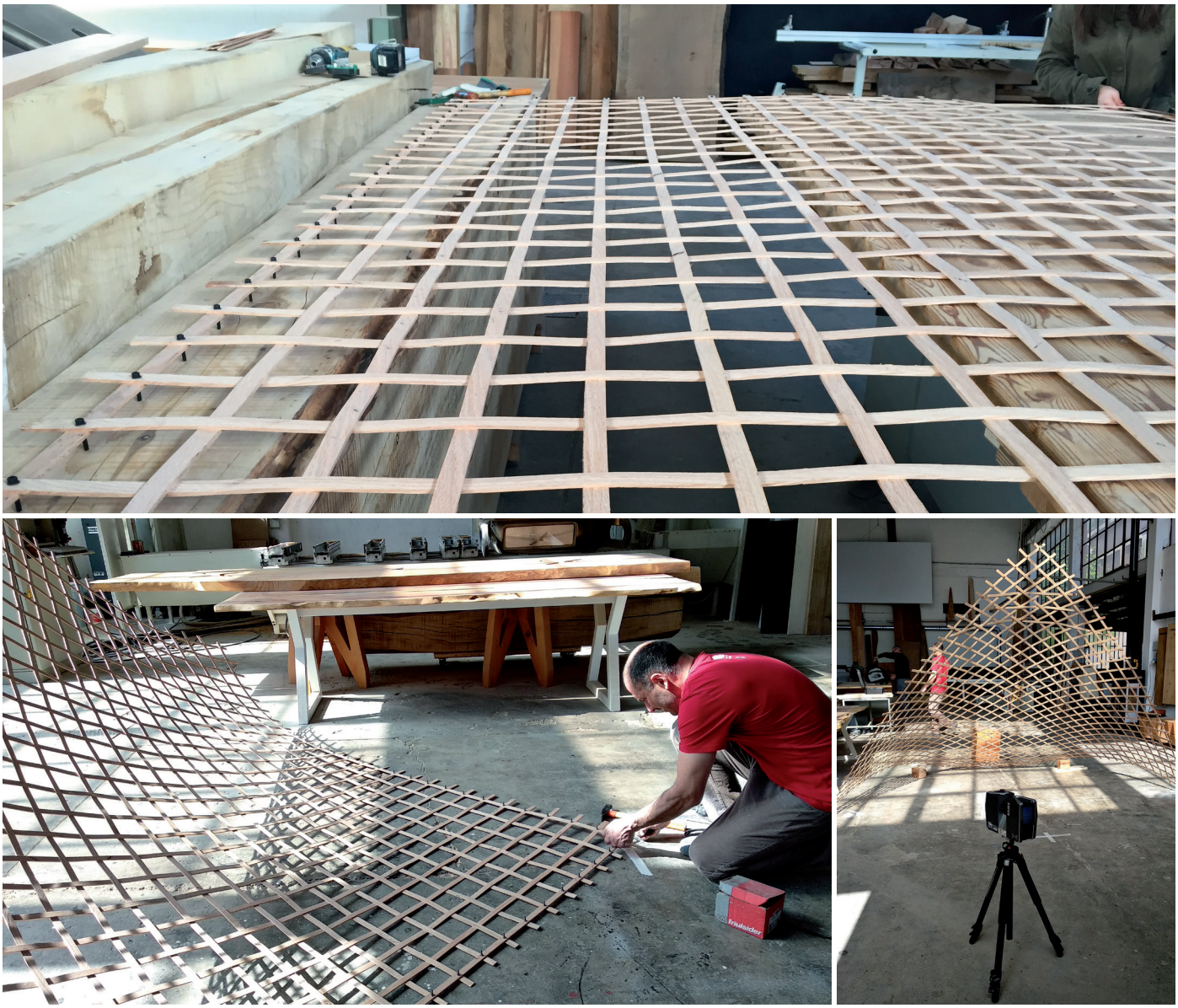
At the edges of the membrane, laser cut and perforated metal plates that can be coupled with wooden elements have been used. In this way, joints with excellent resistance and precision were created. Tests were done of the loads on connection strips, in order to optimize dimensions and quantity.

Mock-up Prototype “Levitas”

Initially, a very rough full-scale prototype in fir was realized by D3Wood in order that it could be analyzed when Ian Ritchie visited their lab during a design session at the Politecnico di Milano (Lecco Campus). This was to enable the team to begin thinking about the grid and the size of the voids in it, in order to analyze its permeability to the heavy snowfalls that normally occur at Arte Sella in winter (Figs. 8, 9).

Figures 8, 9. First full scale prototype in Spruce made in D3Wood Lab in Lecco.

Due to the complexity of the curves/surfaces and their relation to the material a more precise mock-up (scale 1:3,333) was realised for the geometry form-finding. The goal of the physical prototype was basically to understand how to achieve the proposed form. Would it be enough to change the position of the three restraints on the ground to get the desired surface shape? Would the surface obtained differ considerably from the one proposed in the concept? Would the interlaced surface of the strips be strong enough to withstand wind and snow? Red oak strips measuring 20 mm x 3 mm [0.8 x 0.1 in.] in section were freely woven to re-create the grid in scale and it was closed with M4x25 bolts at the ends; the shape obtained was very similar to that of the drawing (Figs. 10-12).



Figures 10-12. Politecnico di Milano team, prototype made 1:3 scale using red oak from Lombardy for laser scanning survey to establish the correct form-finding.

From the first analysis of the prototype, a difference between its edge and that of the 3D computer model was discovered. The edge output of the software model is close to a bow shape, but to get the similar shape on the physical prototype the edge becomes a 3D curve. The subsequent step was to apply a profile shape created as a 3D model to the lattice, and check what the shape of the membrane geometry would have been in an iterative path. With a small reverse engineering process, a new 3D profile was modelled in the correct scale for the final structure. The detailed design phase of fixing the different elements onto the edge, and to make the process easier and cost-efficient, resulted in the circular section of the tall

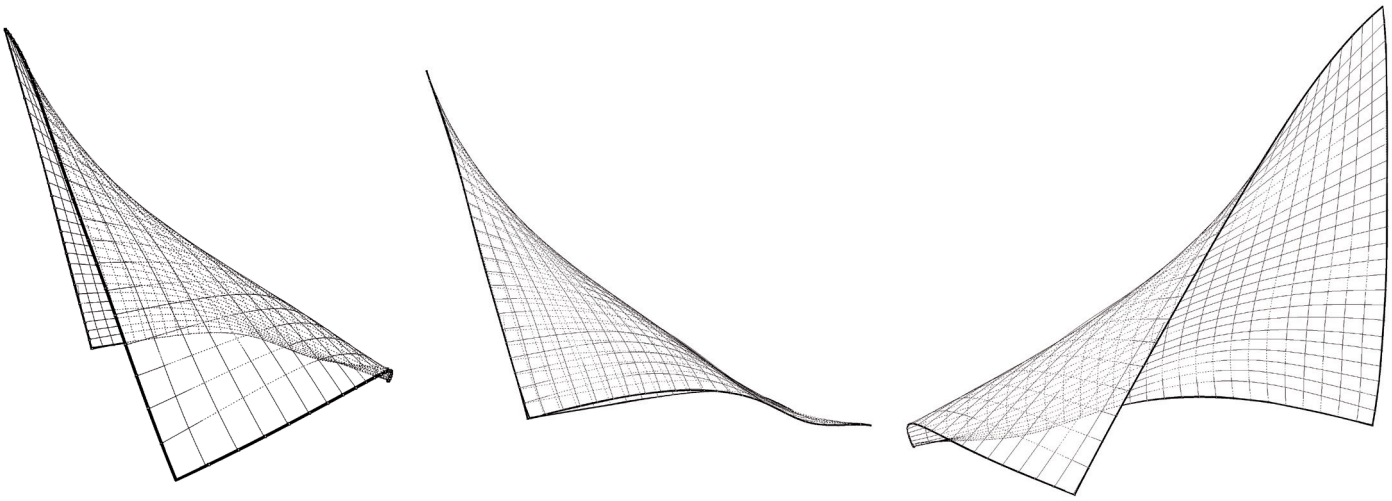
3D arches. The hypothesis of using solid wood on the edge profiles (the 3D arches) would have required well dried wood of good thickness and red oak of this quality was not available. Therefore, the arches have been realized using CNC profiled gluelam Larch, jointed with approved glues and internal metal bars. This solution, chosen as a compromise between aesthetics, economy and ease of fabrication, resulted in a first attempt at achieving the shape of the arches which were built on-site for the opening. The severe climate at Arte Sella and some unexpected torsional load revealed some weakness after one year. It was decided to replace them with tubular COR-TEN steel 3D arches as a final on-site solution, in order to offer better resistance to loads and climate.

Prototype at 1:3

The measurements can be summarized as follows:

- Phase 1: Test of positioning to keep the distance in scale between the anchors on the ground in relation to the original concept design.
- Phase 2: Repositioning of the anchors to search for a more faithful form.
- Phase 3: Capturing the shape with the laser scanning process to create a virtual 3D model. Form-finding and reverse-engineering on to the digital model (Figs. 13-15).

It was possible to use laser scanning technology, thanks to Politecnico di Milano's equipment. 3D Laser Scanning is a non-contact, non-destructive technology that digitally captures the shape of physical objects using a line of laser light. The 3D laser scanner creates a "point cloud" of data from the surface of the object. In other words, 3D Laser Scanning captures the physical object's exact size and shape and this is the starting point from which it is transformed into a digital three-dimensional representation. In



Figures 13-15. Reverse engineering and digital twin of the real parametrical geometry expected on site.

the case of the 1:3 prototype, the degree of fine detail and the accuracy of the sculpture's free-form shape obtained with the real mock-up quickly generated highly accurate point clouds.
Data acquisition via the 3D Laser Scanning Process with specialized software directed the laser probe above the surface of the mock-up. The laser probe projected a line of laser light onto the surface while two sensor cameras continuously recorded the changing distance and shape of the laser line in three dimensions (XYZ coordinates) as it swept along the mock-up. The process is very fast, gathering up to 750,000 points per second and very precise (to ±.0005).

The scanned object is compared - as a sort of "Digital Twin" - to the designer's nominal CAD data. The result of this comparison process is delivered in the form of a "color map deviation report," in PDF format, which pictorially describes the differences between the scan data and the CAD data.
Using specialized software, the point cloud data is used to create a 3D CAD model of the real-life geometry. The CAD model enables the precise reproduction of the scanned object, and the object can be modified within the CAD model to correct eventual imperfections. Laser Design can provide a surface model or a more complex solid model, whichever results are needed for the application. An overlap in Rhino between the theoretical model and the 3D laser scanned model (Digital Twin) has been created (Fig. 16).

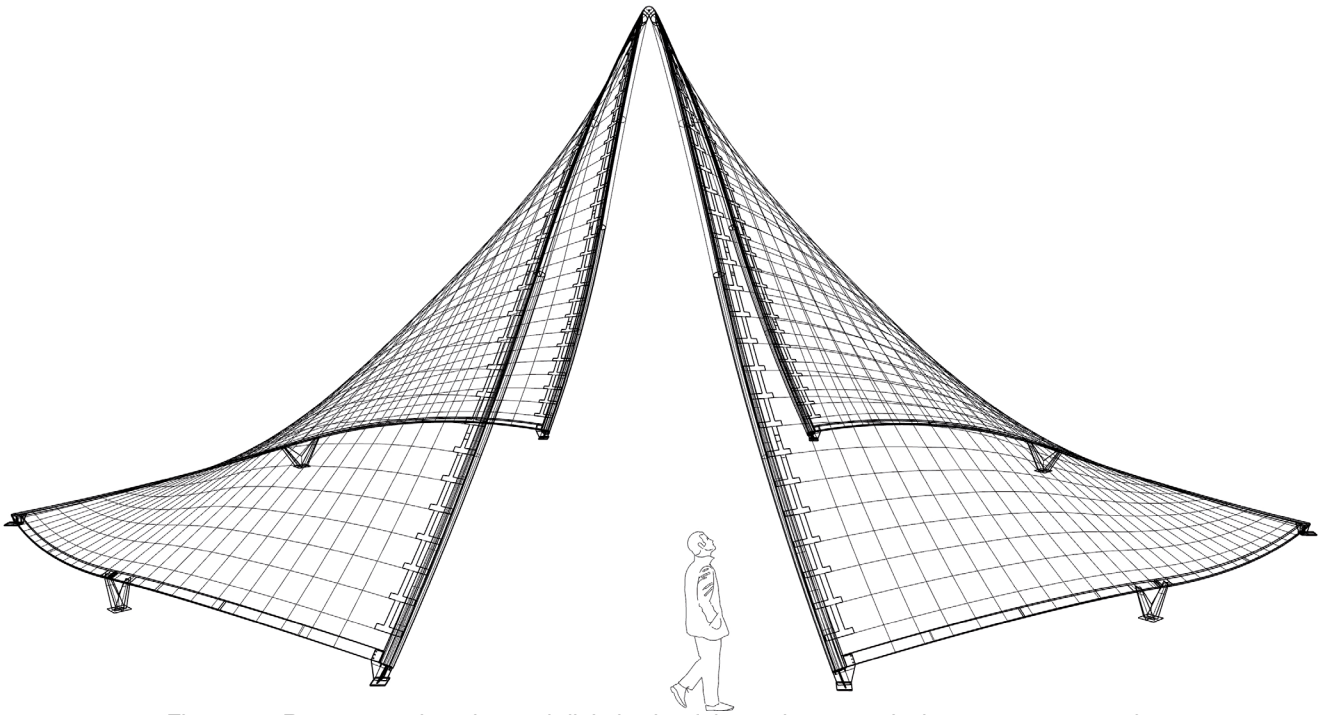


Figure 16. Reverse engineering and digital twin of the real parametrical geometry expected on site.

A double Finite Element Analysis (FEA) assuming equivalent wooden shell strip members and edge profiles was applied to the 3D CAD model with combinations of snow and wind loads; a second analysis was done on the prototype, so that the results could then be compared using several load tests. Other load tests were done on the connections between the wooden strips.

WHAT CAN WE LEARN FROM “LEVITAS”

At the end of this complex design path, we can say that much has been learned and that further steps toward integrating real and virtual design techniques for such complex projects are worth considering.
First of all, the design path: concept, prototyping, digitalization, fabrication, construction, incorporating many tentative solutions and iterative design checks within each phase, was a highly contemporary realization of the synthesis of Art and Science in the field of design. For Levitas, this approach was necessary from the outset because there were no references in the literature for this particular combination of materials, shape and configuration. The challenge was extremely stimulating, especially in view of the limited available budget.
Secondly, the best architecture and design are always based upon dialogues. For Ian Ritchie, and Marco and Claudio Clozza of D3wood, that dialogue took place between the “abstraction” of concept as expressed first in Ian Ritchie’s words and drawings and the abstract pure/perfect geometry of the first digitalization, and the physical reality of the material used: wood, and its inherent characteristics and potentialities, section geometry and behavior both during construction and upon being subjected to the environment.

From the first poem written by Ian upon visiting the site – itself the result of a dialogue between his creativity and that specific landscape – to all the digital tools needed to integrate the concept’s shape and fabrication, and to the CNC routing of the wood and Levitas’ final construction, sophisticated artisanal skills and engineering were used in parallel to make the final work of art possible. The challenges were met with considerable daring; weaving the wood using only friction fixing, for example, was a bold step. Even some of the weaknesses and changes in the final work that developed over time can be considered as part of the discovery process. Perhaps further research at a PhD level, related to the geometry and how the behavior of a small joint may affect perception of the whole shape, might be a worthwhile subject.
Levitas allowed the design, engineering and fabrication team to recognise the synthetic value of analogue (material manipulation) and the digital (virtual) design – perhaps demonstrating the idea of Arts & Crafts II. Working with mock-ups, testing and checking in the real world had been the only way to achieve the beauty of Levitas which, as with any true piece of art, at the very end has revealed itself as unpredictable - its final silhouette a unique piece within the beauty of the Italian Alps at Arte Sella.

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Credits

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