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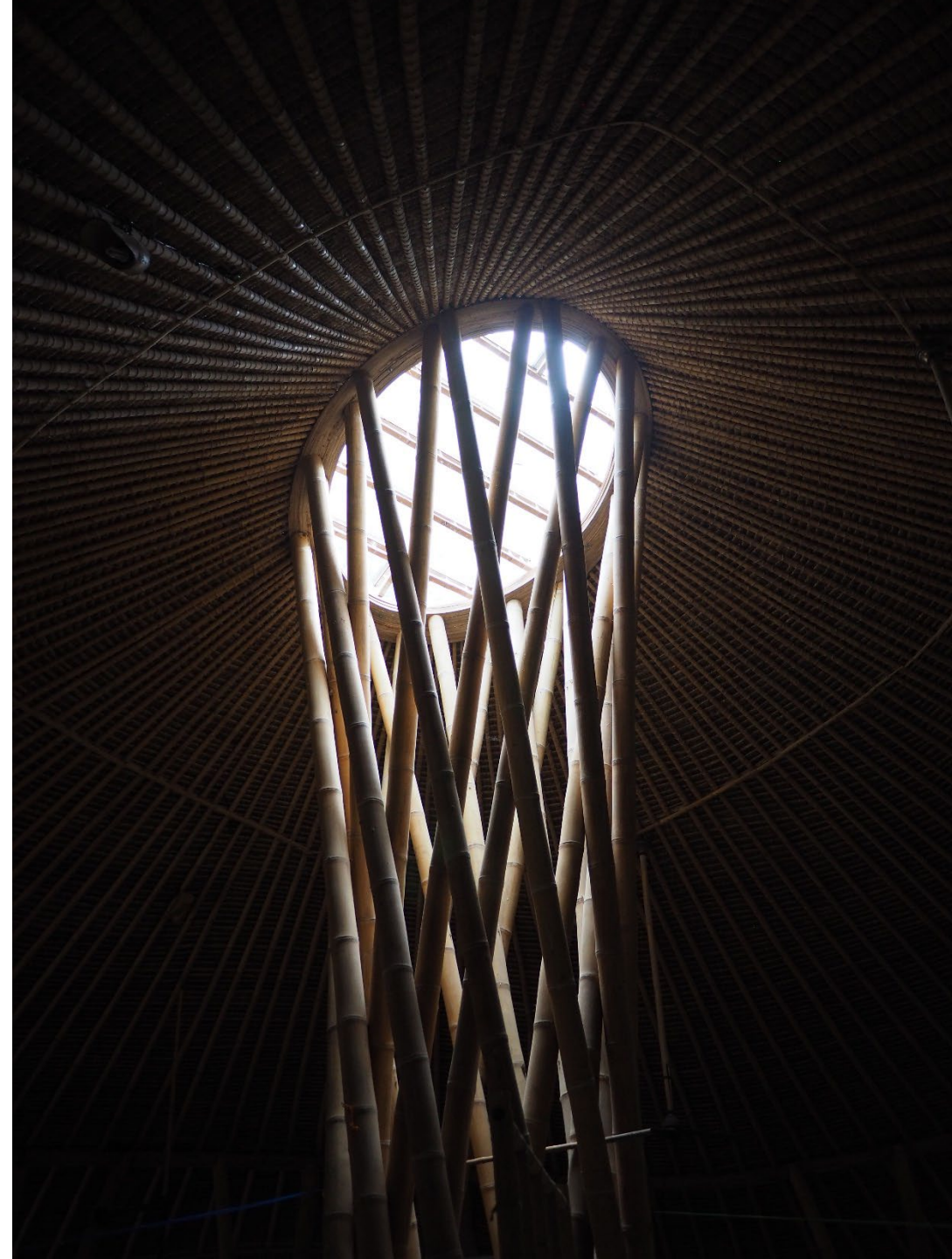
西交利物浦大學

HYPERBOLOID STRUCTURE (RECIPROCAL TOWER) IN BAMBOO ARCHITECTURE

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ABSTRACT

This paper **aims** to share an application of **one sheeted hyperboloid structure**, particularly in bamboo architecture. A combination of **interviews** and **case study analysis** of seven iconic bamboo structures built over a span of **15 years** are used to investigate the role of this type of combination between shells and space frame structures in the **Bali region**. Initial investigation shows that as a main structural system, it is an **efficient structural element** which is mostly used as **a central column**. Mostly they are used to substitute a column in a bamboo context, and there is potential in terms of scalability and flexible use in multiple storey structures in mainstream construction.

OUTLINE

1. INTRODUCTION
2. LITERATURE REVIEW
3. METHODOLOGY
4. RESULTS
5. DISCUSSION
6. CONCLUSION AND FUTURE WORK

INTRODUCTION

RATIONALE

Understudied this type of structural element in particular bamboo architecture application
ISO 22156:2021¹
Considering bamboo in mainstream construction

RESEARCH QUESTION

What is the role of the hyperboloid structures in bamboo architecture?

SCOPE

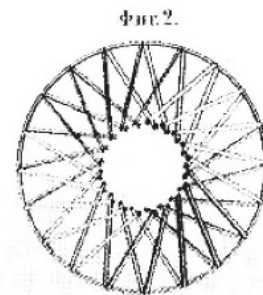
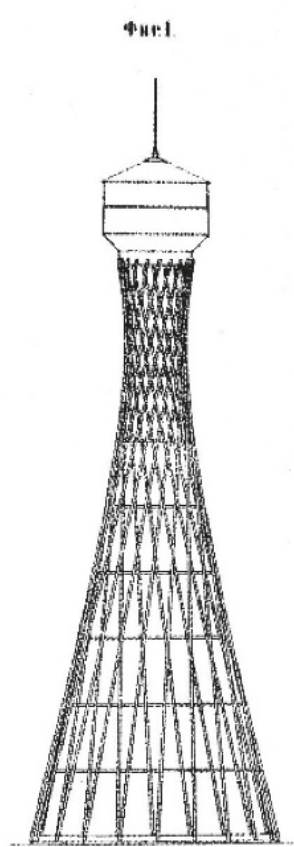
Full-culm bamboo
Hyperbolic lattice bamboo structure
Bali region

¹ISO, *Iso 22156:2021 Bamboo Structures — Bamboo Culms — Structural Design* (2021).

LITERATURE REVIEW

1: HYPERBOLOID OF ONE SHEET GEOMETRY

- Vladimir G. Shukov (1853-1939)
- Structural system which used minimal materials, time and labor
- Derived from Russian wicker baskets²
- Lattice tower patent in 1899
- Solution for a common tower problem
- Two examples: Polibino Tower (1896) and Shabolovka Radio Tower (1922)



Left image: Shukhov Patent
Right image: Shabolovka Radio Tower

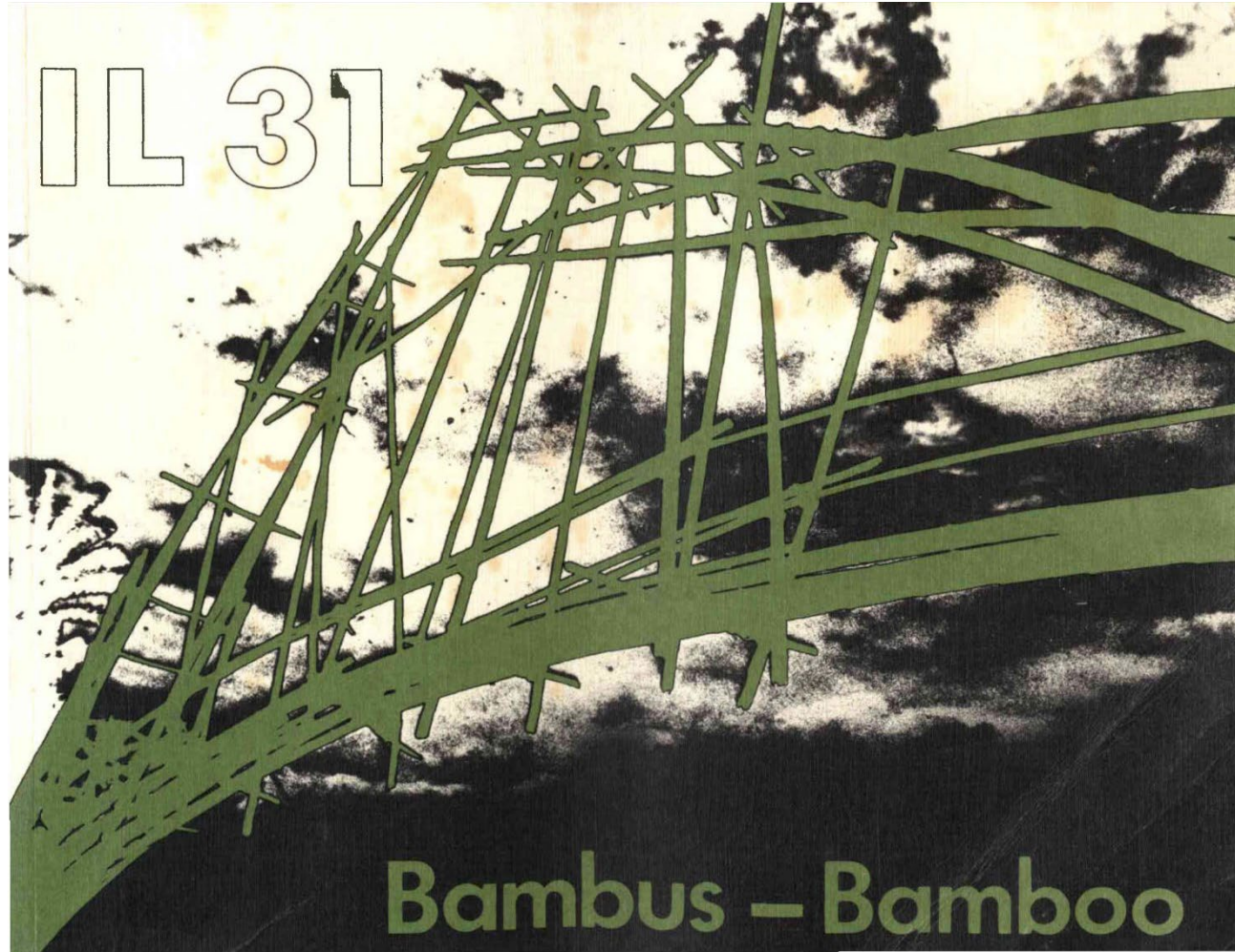
² Elizabeth C English, Vladimir Shukhov and the Invention of Hyperboloid Structures, Structures Congress 2005: Metropolis and Beyond (2005).

LITERATURE REVIEW

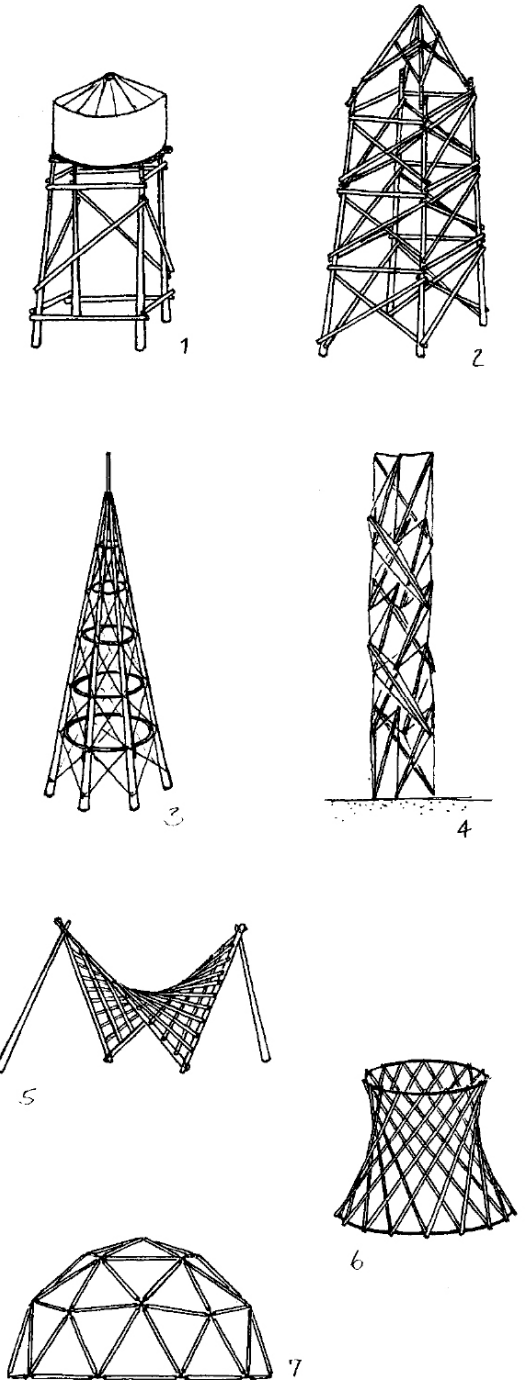
Shukhov described the structure as “A **lattice-form** tower characterised in that its **load-bearing structure** consists of **straight** wooden beams, iron tubes or angle profiles which **cross over one another** and lie on the directrix of a solid revolution and that takes the form of a tower. They are riveted to one another at the crossing points and also **connected by horizontal rings.**”³

³ Matthias Beckh, *Hyperbolic Structures: Shukhov's Lattice Towers-Forerunners of Modern Lightweight Construction* (John Wiley & Sons, 2015).

LITERATURE REVIEW



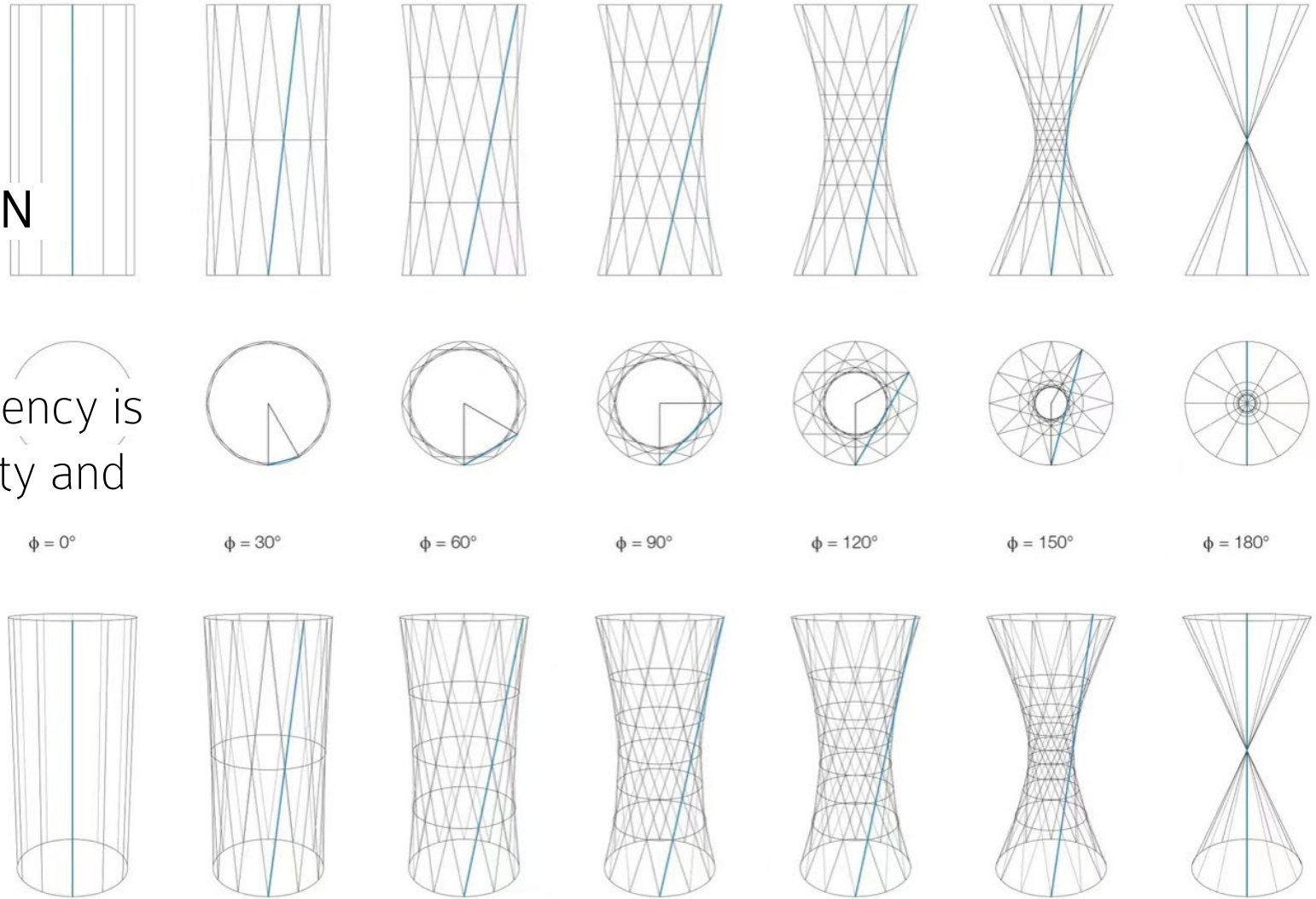
⁹Klaus Dunkelberg et al., "Il 31 Bamboos Bamboos," Institut fur Leichte Flachentragwerke (1985)



LITERATURE REVIEW

2: RELATIONSHIP BETWEEN FORM AND TECTONICS

- Shape and performance of hyperbolic structures, efficiency is achieved in terms of velocity and temperature⁵
- Five design parameters



⁵Rachele Angela Bernardello, and Paolo Borin, "Form Follows Function in a Hyperboloidal Cooling Tower," Nexus Network Journal (2022).

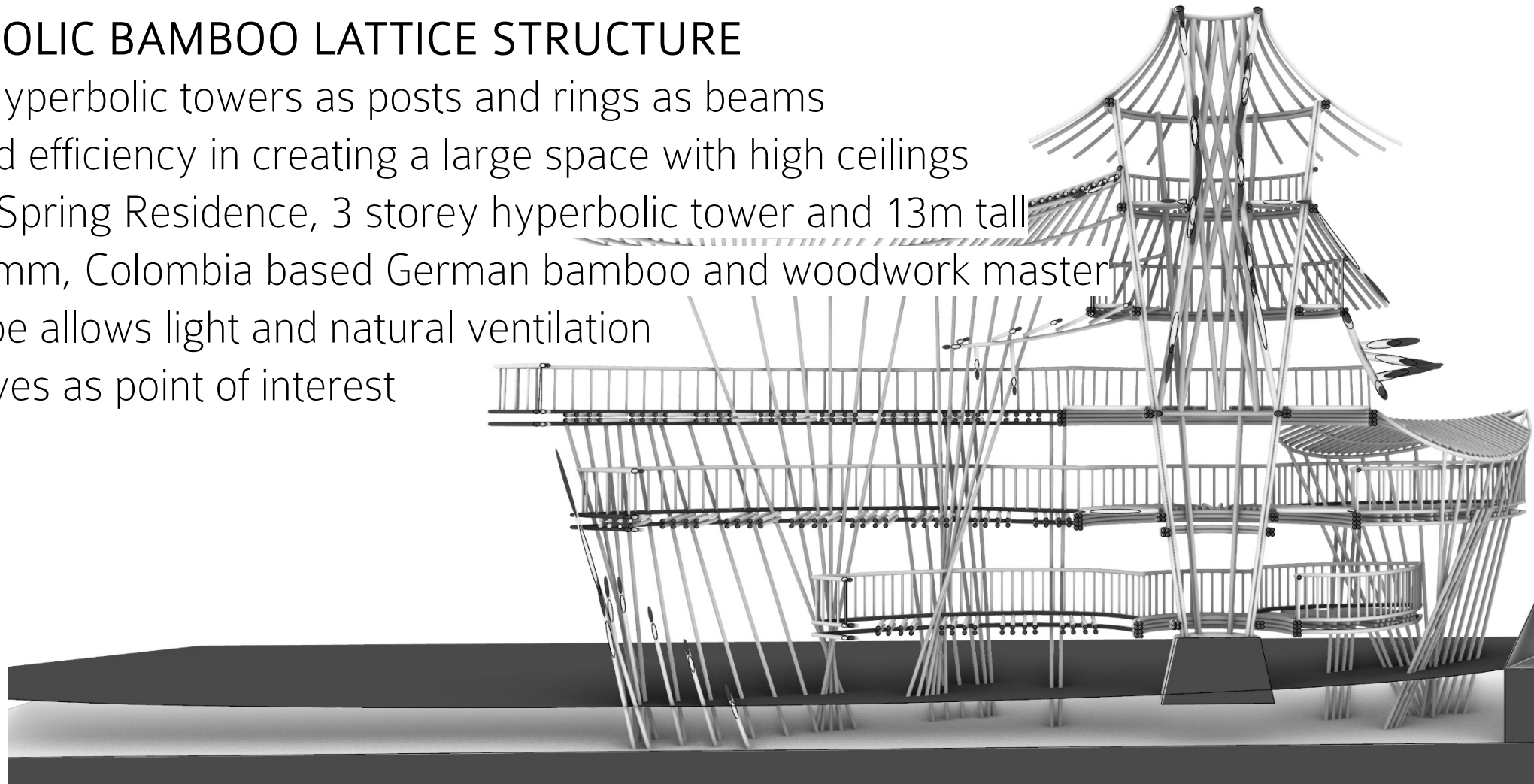


Sharma Springs Residence
Pic courtesy of IBUKU

LITERATURE REVIEW

3: HYPERBOLIC BAMBOO LATTICE STRUCTURE

- Central hyperbolic towers as posts and rings as beams
- Increased efficiency in creating a large space with high ceilings
- Sharma Spring Residence, 3 storey hyperbolic tower and 13m tall
- Jorg Stamm, Colombia based German bamboo and woodwork master
- The shape allows light and natural ventilation
- Also serves as point of interest



METHODOLOGY

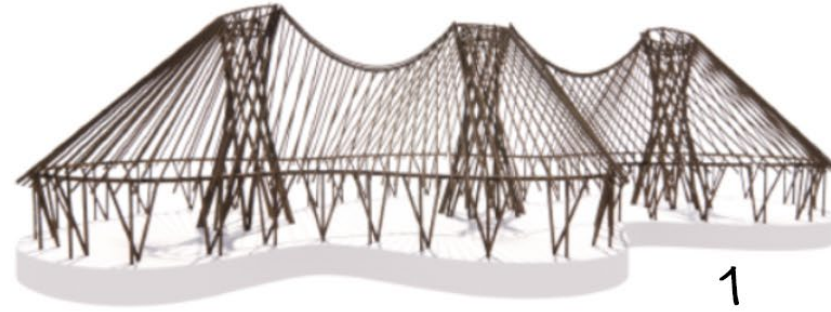
MULTIPLE-CASE STUDIES AND INTERVIEWS

Seven design precedents and two interviews with bamboo experts

Observations during bamboo course

Green School, Kulkul Farm (BambooU) and IBUKU

No	Name	Completion year	Floor Area (sqm)	Overall height (m)	Function of the structure	No of hyperboloid element	No of storey
1	Three Mountains	2006	1200	15	Multi-purpose functions	3	1
2	Aldo's kitchen	2007	500	14.5	Design studio office	1	3
3	Kindergarten classroom	2008	155	7.5	Classroom	1	1
4	Heart of School	2009	2740	18	Central admin building	3	3
5	Sharma Springs	2012	750	23.5	Residential	2	6
6	Princess Tower	2019	12.56	12	Lookout tower	1	1
7	Dragon Kitchen	2022	200	12	Kitchen	1	1



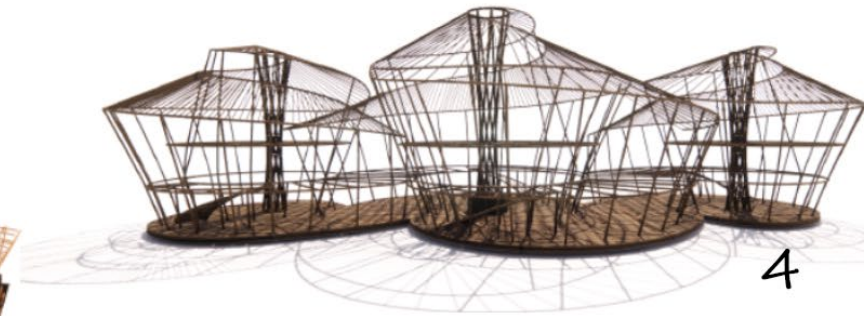
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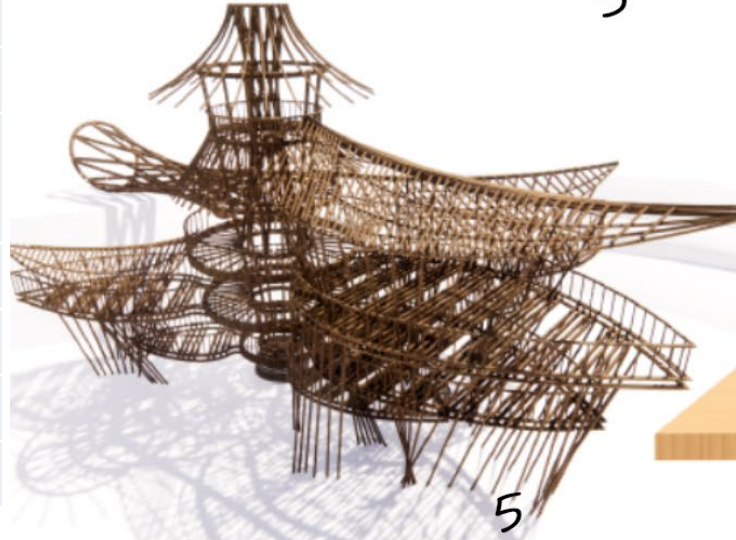
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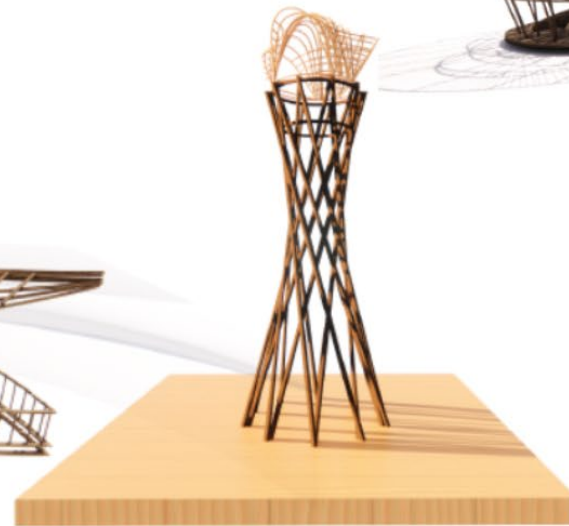
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6



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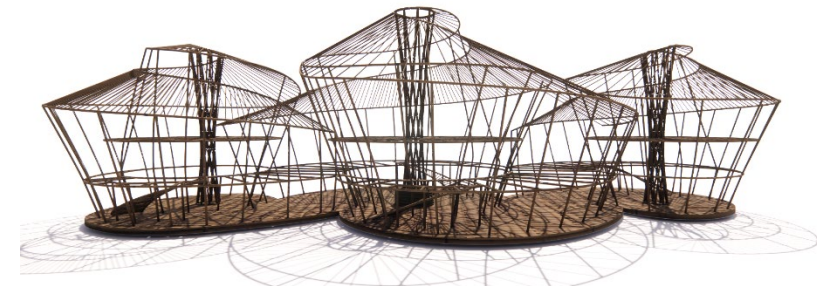
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7	Dragon Kitchen

AR experience: <https://miatedjosaputro.com/2022/06/07/ar-bamboo-structures/>

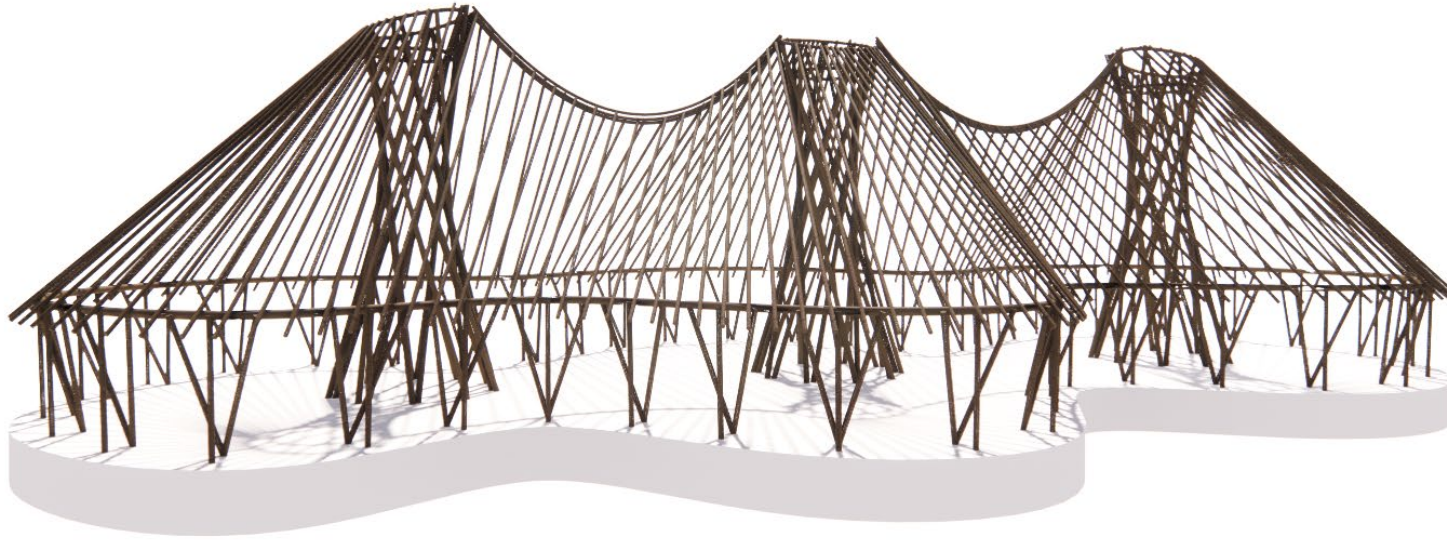
Conceptual 3D are generated from online data provided by IBUKU, BambooU and Green School by author



Heart of School (2009)



RESULTS



First application in Three Mountains (2006)



Dragon Kitchen (2022)

Only one case precedent uses tower typology

Also commonly called 'reciprocal tower' or 'spiral tower'

Advantages:

Disadvantages:



Three Mountains (2006)
Pic courtesy of KulKul Farm and Kura-Kura Island

DISCUSSION

Three central themes of classical tectonics:

1. *Technique*, represented by *construction, technology* and *representation*
2. *Culture*, represented by *art* and *handcraft empathy*
3. *Material*, represented by *structure, science* and *ontology*

DISCUSSION

- Low-tech construction
- Minimal number of joints between straight members
- The 'waist' in single storey and multiple storey structures
- How elements are connected with other main structural system, there are two considerations: top ring and ground attachment
- Aesthetic and expressional purposes
- Vertical load and horizontal load
- Changes over 15 years: multiplication in two directions (horizontally and vertically)

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top ring



ground attachment



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DISCUSSION

- Balinese bamboo carpentry
- Handicraft empathy
- Construction method is maintained (low-tech) and nearly 100% bamboo
- Balinese architecture and mistakenly typical bamboo architecture
- *Tri Hita Karana* in Balinese architecture
- Forms to follow nature
- Hyperbolic structure as environmental cooling strategy

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Three Mountains (2006)

Left image: The view of Three Mountains (Mount Batur, Mount Abang and Mount Agung)

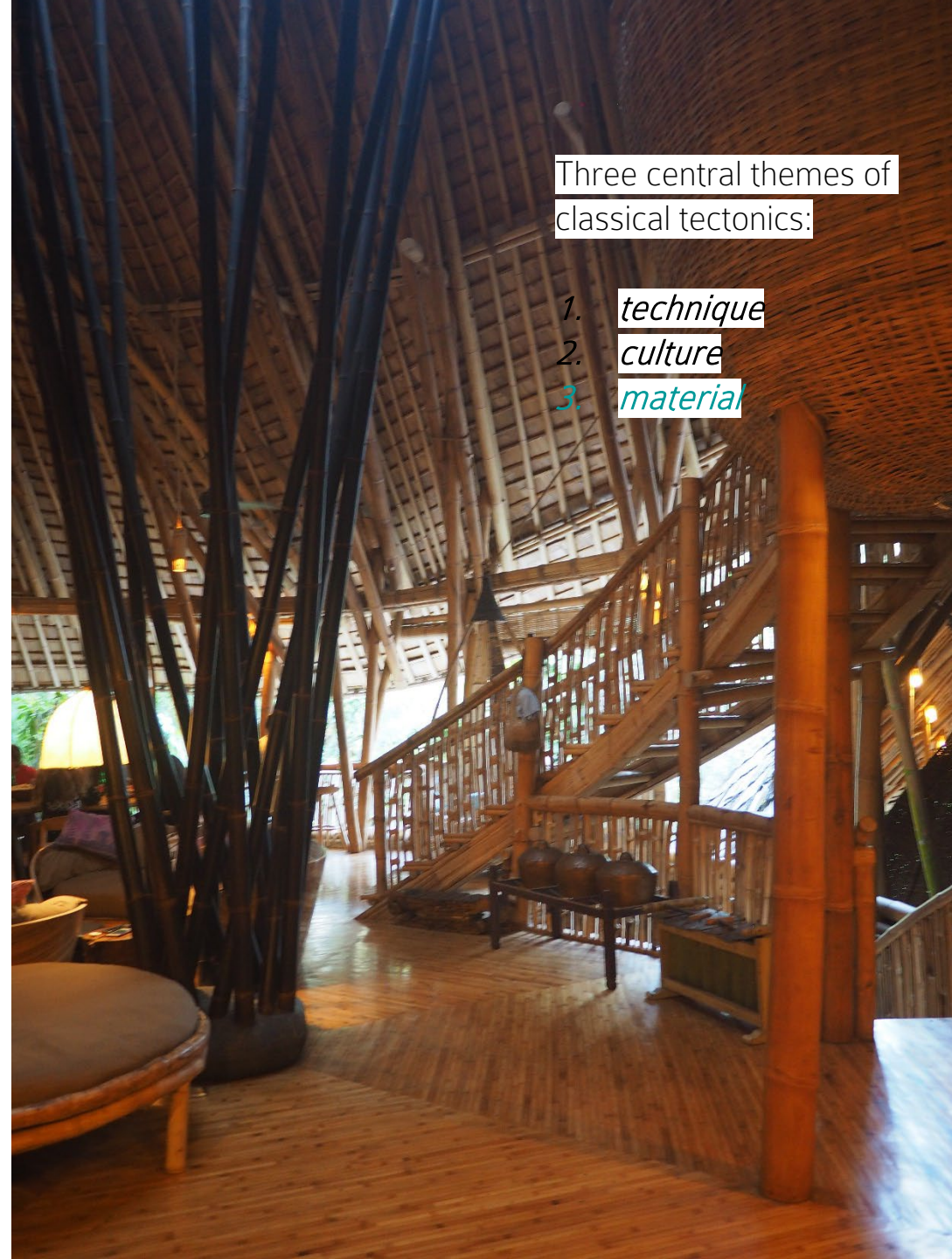
Right image: courtesy of Jorg Stamm

DISCUSSION

- Full culm bamboo: tapered at the end
- Commonly used local species, *Dendrocalamus Asper* 'Bambu Petung' and its black tinted version.
- Up to 30m long, 8-20cm in diameter
- Tallest bamboo structure in Bali, case study #5 (Sharma's Springs), 6 storeys
- Changes in 15 years: guess work and redundancy of material
- Suggestion: rule of thumb can be developed based on structural calculations
- 6 design parameters
- Slightly different with Shukhov's intention

Three central themes of classical tectonics:

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DISCUSSION

Suggested **6 design parameters**, adapted from Beckh:

- Bottom radius
- Top radius
- Height
- Number of members
- Rotation angle
- Number of spanning storeys



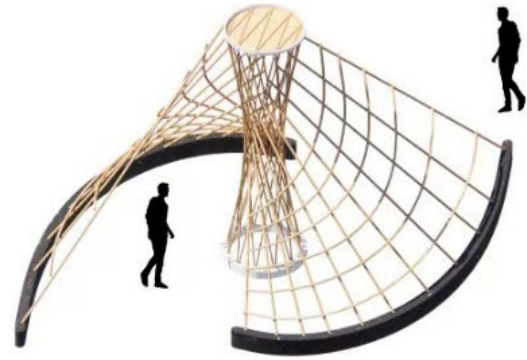
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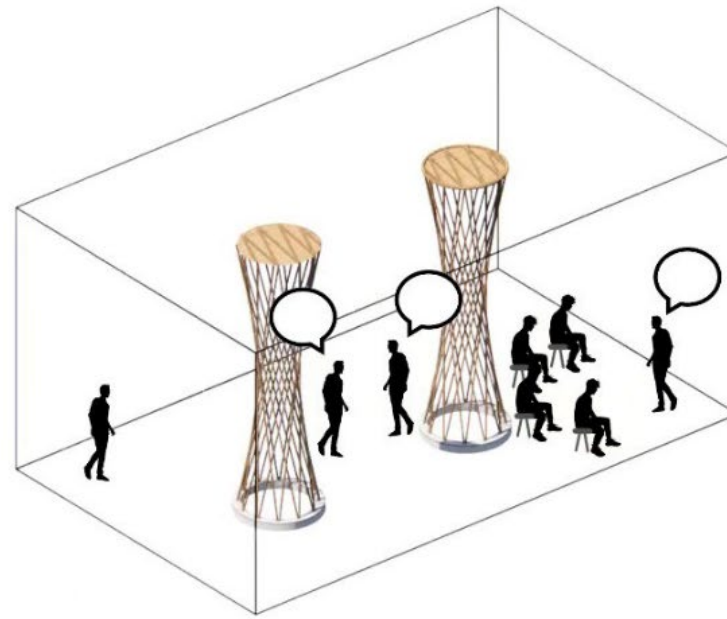
CONCLUSION AND FUTURE WORK

What is the role of the hyperboloid structures in bamboo architecture?

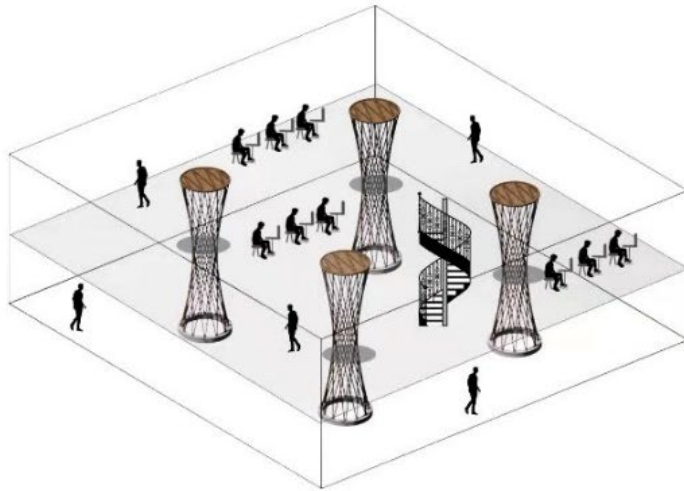
- It was derived from Shukhov's lattice tower although in 1899 he did not anticipate the application in bamboo
- In bamboo application, it aims to provide a different solution. This load bearing element substitutes columns and commonly used as central column
- Aesthetically works with organic shaped bamboo structures
- Straight members are replace-able >> DfD (Design for Disassembly)
- 6 design parameters
- Potentials to bring the system to mainstream construction made of natural material



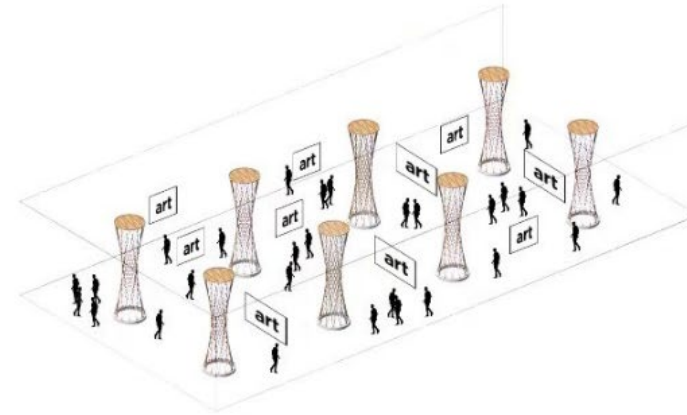
1 unit can be used as a pavilion



2 units can be used as meeting point or seminar space



4 units can be used as two-storey office



8 units can be used as a gallery