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Conference Paper · September 2019

DOI: 10.5151/proceedings-ecaadesigradi2019_103

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Weaving physical-digital networks:

Brazil-Germany integration experience

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The idea of a network weaved this project in a conceptual as well as in a physical way. A network in the sense of an intangible connection between people, and a network in the sense of a materiality, woven to constitute the skin of a building according to different techniques associated with the ancient culture of covering to provide shelter. We seek to integrate old cultural identities with new digital methods. In the time of the fourth industrial revolution, we might think about a network as something fully accomplished, as if the availability of an internet connection was synonymous with effective communication. In our methodology, we face network challenges at the intersection of human communication and the physical and material domains. The challenge is to discover what to exchange and how to do so. Through the Brazilian-German program 'Connect', we tested our research in two practical workshops in two continents. The result suggests that is possible to weave a network incorporating local building traditions and analogue and digital processes of form-finding. The report describes our findings and shares critical reflections opening future research possibilities.

Keywords: Network, Brazilian-German, Traditional construction, Gridshell, OCA, analogue-digital

RESEARCH CONTEXT

The fourth industrial revolution is about to bring profound changes in building technology, challenging a re-thinking of local building traditions and associated cultural identities. Schwab (2018) highlights the relevance of collaborative networks to find meaning and purpose in technology. Our Research addresses a local/global gap bridging local building technolo-

gies with algorithmic design and digital evaluation. It relies on collaboration to integrate technical and cultural knowledge to find innovative design solutions.

The Research started at a bilateral scientific Conference, where different fields of research, i.e. Sustainable water management, sensor automation technology and digital fabrication for building construction were brought into contact. The confer-

ence was part of a meeting organized by Gabriela Celani and Olfa Kanoun at the UNICAMP in Campinas in 2016 (Celani, and Kanoun 2017). The authors presented their research to an audience from different scientific fields during the conference (Henriques, 2017). The first two authors of the paper saw an opportunity to establish a collaboration to combine their research connecting traditional structures and digital building techniques. In South America, there are previous references of the combination of local tradition with new technology as Sperling (2015), and Herrera (2016). Additionally, the collaboration intended to weave a network in two ways:

Firstly, to establish a network to connect people with different cultural backgrounds and practices to incorporate different traditions with current tools in architecture. How to establish a network, what aspects are valuable, how to benefit from the exchange? In the information network it is decisive to reflect about what information can feed the network and how. The scientific exchange triggered the idea to establish a partnership between the two countries; the dialogue would complement our individual ideas and could result in a joint vision.

The second aspect of the network is the physical weaving of material. Based on initial research we decided to re-interpret the construction of a gridshell, a construction principle that has a tradition in Germany - and the OCA, a Brazilian indigenous tradition. We proposed to combine aspects of local traditions between the partner's countries, testing the implementation in a different context. What can Germans learn from Brazil and Brazilians from Germany? How can we cross-fertilise traditional construction principles? How do we join material / physical practices and form-finding with new tools?

Supported by the Alexander-von-Humboldt Foundation - whom we thank for their generous support - the authors established a collaboration between Universities, industries and professional practice. Our proposal suggested that each partner would visit the other, bringing a traditional technique to test in the foreign context using new tech-

nologies. The paper describes this experience in five steps:

1. The exchange program and preparation of activities;
2. The first workshop - "Tropical Gridshell experience" and its results
3. The preparation for the second workshop;
4. The second workshop "OCA Traditional Brazilian Construction reinvented" and its results;
5. Synthesis of the results of both workshops and future research potential.

RESEARCH AND PREPARATION FOR THE FIRST WORKSHOP

At the scientific meeting, choosing a partner was somewhat like a speed dating. The partners did not know each other before. They get familiar with each other's research at the presentations and the social meetings at the conference. In a scientific universe, issues of affinity and compatibility also inform the decision regarding collaborations. Nonverbal and intuitive criteria also influenced the formation of the partnership, which we started with communicating from the distance.

After the conference, the partners discussed how to collaborate and analysed different possibilities of traditional German techniques to develop during a workshop in Brazil. They found potential in the analogue construction technique of gridshells, which we could explore, with the help of digital technologies. Gridshell structures, first used by Shukhov in 1896 (Chilton, 2016), are lightweight constructions that use a low-ratio of material/weight and bare the potential for re-use in a circular economy. We examined in detail the gridshell applied by Frei Otto for the Mannheim Multihalle pavilion. During conversations, we decided to combine the German technique with bamboo as an abundant material in Brazil. Bamboo is a fast-growing material that is light and very resistant but despite its properties rarely used in construction in Brasil. The use of Bamboo is not part of the University program and students do not re-

Figure 1
Tropical Gridshell
Experience,
workshop at Rio de
Janeiro Federal
University, March
2018. Trefoil
Pavilion, a parabolic
hyperboloid
gridshell,
constructed in
bamboo.



ceive a formal education. Therefore, we had to start our own research regarding bamboo properties, processes and suppliers. We looked for a local architect experienced in traditional building using bamboo and an advanced engineer that could use structural programming.

WORKSHOP TROPICAL-GRIDSHELL

The Workshop generated interest from students, teachers and professionals from different states in Brazil and Argentina. We select 14 participants balancing their interests, origin, knowledge and digital experience. The Workshop started with lectures introducing gridshells, explaining the design challenge and methodology. We had lectures from Celina Llerena (Ebiobambu), the bamboo specialist and Felipe

Tavares (UFBA) a structural engineer, so both also guided project development.

The introduction focused on gridshell construction and form-finding techniques. The reference was the Mannheim Multihalle (Frei Otto, 1975) with 85m span, 7400m² roof area, half-meter thickness and a ratio of span to shell thickness thinner than eggshell. Gridshells are three-dimensional self-supporting structures based on their geometry. The grid patterns replace a homogeneous distribution of material in shell constructions resulting in a “grid-shell”. We examined the construction process, starting with a flat layout of grids, the design of joins and other details and launched a design challenge. The participants formed five groups of three people each. Each group developed a proposal. All together, we developed and constructed the most suitable one.

The challenge was to design a shelter in bamboo, 1:1 on the University grounds, inspired by the gridshell technique, with special attention to the articulation of geometry/technique/material. We suggested possible sites outside or inside the FAU-UFRJ University Building. The site for the project could take up different shapes according to the project design, a polygon, circles or irregular shapes but had to have a maximum diameter of 10m. Each project should define a shelter, referring to a grid or tessellation, defining the geometry of cells and their connections type. Based on previous studies and budget experiences we selected bendable bamboo slats to enable free-curved forms, acquiring 200 slats, 4m x 4cm with 4mm thickness (average). The consulting architect trained in traditional bamboo techniques was astonished we did not know the exact material number and form at the beginning - we told her about algorithmic design and form-finding techniques to apply in the process.

The act of weaving proceeds human constructions in the nest-like constructions of birds or other animals. Associated with the idea of using a grid is the idea of surface tessellation. Both concepts are associated with the act of binding materials using a material pattern. Binding is also present in

the ancient crafts as stonemasons, carpentry, weaving or metalsmiths constituting what Semper claims as archetypes of the innate human building culture (Semper, 2004). The repetition of cells creates different patterns - regular, semi-regular, periodic, aperiodic or non-periodic. The tessellation pattern changes according to the cell’s material and geometry, i.e. squares, triangles, hexagons, or others. Gridshells employ flexible rectangular grids that are associated with a specific behaviour of the grid, that starts flat in the ground and can acquire freeform surfaces.

In respect to gridshells, we identified three relevant factors to define the final design: the global geometry of the proposal, which is defined by the external shape of the proposal, the local geometry that is the type of local divisions or cells. Finally, the type of local articulation or nodes relating global and local geometry. The configuration of the nodes, the material and the cell’s disposition affects the global geometry. The material bamboo was an unknown material for most of the participants. Thus during the workshop we stimulated hands-on empirical testing to predict behaviour besides the use of digital models using visual programming (Grasshopper) and load simulations (Karamba).

TROPICAL-GRIDSHELL RESULTS

Over the course of five days, five groups with mixed abilities developed a proposal through physical and digital models experiencing form-finding in a mixed cycle, digital-analogue. Participants presented unusual gridshell proposals coordinating geometry-structure-material - the entire group developed and built the selected gridshell solution.

We built a ‘Trefoil Pavilion’ in the entrance lobby of the FAU-UFRJ University, a paraboloid-hyperbolic gridshell 5 x 5 x 5m exploring form through tension and compression. The folding and unfolding process stimulated participants’ geometric and material thinking and the ideas of structural assemblage and erection. The material bamboo proved to be a real challenge even after the try-out of a dozen physical models in different scales and their digital

evaluation. We assembled the gridshell flat on the ground and then lifted it with the help of temporary support structures. However, the bamboo structure challenged our predictions and the digital simulation. We had to keep part of the support structure to avoid the gridshell to collapse. Based on this failure, we started a partnership with the civil engineering department to deepen our knowledge about the material and its behaviour. This led to the development of a new solution to remake the trefoil installation. We understood that bamboo is as a complex material that even with empirical testing through implicit knowledge and digital evaluation might not be as appropriate for gridshells as materials with more predictable behaviour.

Results discussion. In the development of their design proposals, it proved to be difficult for the participants to resort to form-finding. Although they had an intuition on how to handle and to bind bamboo elements, and despite some experience in modelling, they generally had difficulties to tessellate or divide surfaces and establishing a part-whole relationship, both in digital and in material models. It turned out that the majority of the proposals started from a priori forms. The attempts to adopt these for a gridshell resulted in some cases in polygonal meshes of planar surfaces that were too rigid, difficult to assemble and structurally not gridshells. Finally, three groups adapted flexible grids with different degrees of success. The grids tested were periodic or semi-regular, quadrangular (diagrid), triangular, or hexagonal. The grid cell was primarily obtained from a surface, and the geometry of the cells affected the type of structures proposed. Many structures had rigid connections, few presented flexible connections, which are necessary to employ the idea of assembly used in gridshells. The material applied for the models used for testing was initially paper and cardboard, then strips of wood, wire and rope. It was only when the final construction was selected that the bamboo connections were more actively tested, as the connections in the previous phase were more dependent of the grid type and of cells geometry.

Reflecting on the methodology, we can approach design based on the idea of form-making or form-finding, in the first process, form or global geometry is defined first, in the second local geometric behaviour defines the final form; during the project these two processes can be combined. Participants explored an abstract definition of grid and of tested different combinations to develop their structures. We introduced the participants to the idea of form-finding by physical and geometric behaviour of the material and through computational simulation with the software Karamba. For the participants of the first workshop in Brasil the idea of a gridshell was something new. At first, they choose different geometries thinking about the global form and only then looked into options for cell division. Thus, they imposed a structure to a form, which represents the inverse reasoning. Something similar occurred with the structural simulation, due to their limited experience and the urge to define the global form, the participants used digital simulation only in a later stage of their design.

Reflecting about the difficulties of using form-finding, we can interpret this as cultural difference, which would suggest the application of a more didactic methodology, starting with a deeper understanding of an existing model and the introduction of several ways to model and build a grid. Especially the reference to the legacy of Frei Otto (Nerdinger, 2005) is more known in Germany and we would need to address in detail to overcome the different cultural backgrounds.

Our conclusion is that the explanation for both cross-connected groups, should explicitly include the participants cultural background.

PREPARATION SECOND WORKSHOP

After the conclusion of the workshop in Rio, our interest in the use of bamboo increased, but we also realised that due to the complex nature of the material the technique of how to use it structurally needed a more solid preparation. Therefore, we formed a study group at UFRJ, which conducted regular meet-

ings. We thought of this as a research and a preparation for the upcoming workshop in Germany. As topic for the second workshop, we selected the OCA, indigenous traditional constructions that were popular in Brasil, although most of the participants of the group had never visited one or had any idea about the construction. The material we collected included drawings, but was not sufficient to construct an OCA (among other books by Lengen 2013, Weimer 2012, Montezuma, 2002).

The material about the OCA is vast but disperse, which led us to organize our search in respect to understanding what the more important aspects. The OCA traditional indigenous constructions are foreign even to Brazilians, so we decided to address the following topics working in groups:

The OCA house typology and its urban organization: we identified and systematized a geometric vocabulary with visual programming as found in vernacular indigenous constructions. We defined plans, sections and structure as focal points. Defining primitive and attribute values generated a range or spatial solutions. Plans were circular, elliptical, semi-elliptical, rectangular and polygonal; Vertical sections triangular, ogival and semi-circular. The support structures applied were central pillars without perimeter columns, with singular perimeter columns and two or more rows of perimeter columns. Structures with more than one central pillar had rectangular, polygonal or semi-elliptic plants. To erect these shapes structure included a table made of pillar-beam supporting the shell cover. House unity changed according to tribe and region in Brazil. We found three urban organizations: the horseshoe, circular or single houses.

Building Technologies: we studied foundations (above ground, buried, semi-buried), materials, connections (longitudinal, transversal, others) and enclosures (metal, wood, grout, straw, canvas) and synthesized the examples in an overview table. A visual study using sketches to document the connections and the construction assembly applied in different cultures (Horning, 2009).

Structural Systems can be classified in 7 types according to Engel (2015). We found that the OCA uses four of them: Form Active, Vector Active, Section Active and Surface Active Structures. We tried to adapt an OCA to other structural types seeking to define new possibilities. We collected examples of around 40 bamboo pavilions and analysed them according to the previous subjects. This intend was to combined traditional-contemporary solutions, to understand differences, challenges and opportunities.

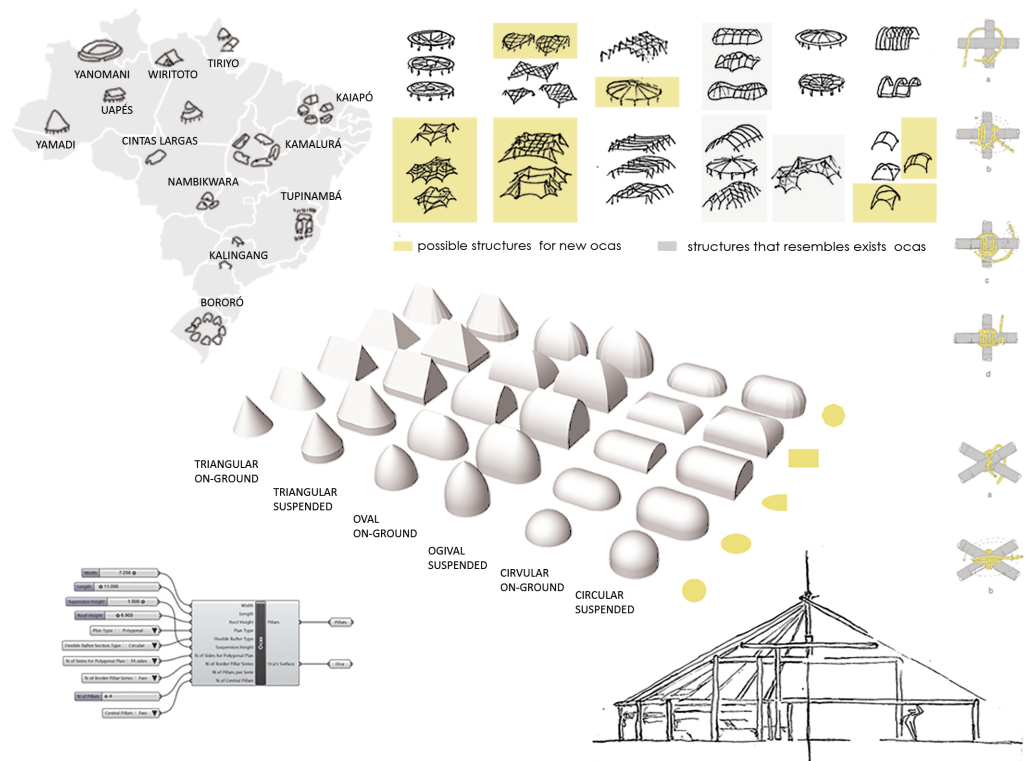
We found that OCAs often had an internal table structure, which supports the outer covering, and that the table supports the outer curved shell. One of the challenges was how to eliminate the table, creating self-supporting surfaces - that could act like a real shell in the structural sense - such as gridshells - or how to hybridize them, to obtain a more integral construction system.

After completing these studies, we tested the construction of OCAs with physical models, but there was a short time before the workshop to develop these models. Looking at this aspect now, an in-depth study of grid models would have been very useful to support the development of an OCA based structure and would have increased the conceptual clarity of the three-dimensional elements of the structure.

Another result from the preparatory research was the material to use for the workshop in Germany. Originally, we envisioned to use bamboo as studied in relationship with the OCAs. While only some of the original constructions employ bamboo we were interested to continue with the material bamboo after the first workshop. In the process of preparation, we found that to work with bamboo in Germany, we would need to import the material from another continent, which proved not to be feasible. Therefore, we considered using wooden slats. Economic and easily available elements are 4x4 cm slats with a length of 6m. They are frequently used in roof constructions in Germany, but with the experience we had exploring the design of the OCAs we realised that this would limit the geometry to stiff wood, or pitch-roof like

Figure 2

OCA preparatory research: urban settlement typologies of indigenous camps; structural types used in OCA; Bamboo constructive tiding studies, cross-section of traditional example. Parametric model developed combining the type of horizontal and vertical sections that define an OCA grammar. The grammar documents existing solutions so we can identify complementary solutions and future improvements. Drawing by Amanda Ribeiro and Christian Jesus.



structures. We considered sliding the slabs in halves, but the nodes of the pinewood affect the homogeneity resistance and might break if we apply too much bending in the slat. Finally, we found a suitable substitute, which we would latter call the German bamboo in the application of PVC pipes used for electricity installations. They are light, resistant, equipped with connectors, are cheap and easily bend. Therefore, facing a difficulty we had jointly discovered a creative solution to come closer to our goal.

WORKSHOP OCA

The challenge of the workshop was to connect the new students form the academy in Stuttgart to a

group of Brazilian students that participated in the preparatory research and had come to the workshop with DAAD support. We had to introduce the new participants to the concept of an OCA. Following long discussion about what to present from the research, we introduced operative concepts of the OCA as typologies, building systems, materials and structure. However, some of the Brazilian students argued that it was far more than that this, as it forms part of a nomadic and ecologic way of living and a cultural expression and art. We solved this difficulty presenting the OCA in a more open concept as a shelter and construction, so participants from diverse cultural backgrounds could appropriate it.

During the introduction, we presented the

preparatory research. An OCA possesses an inner nature of protection and establishes a social and spatial relation with the space it organizes. We presented diverse types of group organization of the OCA buildings. As in the previous workshop, we introduced some constraints and remembered participants to articulate geometry / technique / material. We organised complementary lectures about digital fabrication, simulation and calculation, by Tobias Schwinn (ICD), Arnold Walz (Design to Production) and Thomaz Vieira (Detmold) who later on supported the workshop with the application of digital form finding in Karamba.

OCA RESULTS

We conducted the workshop with participants from Brazil and Germany from diverse study programmes and experiences. During five days, four groups developed proposals with the help of several physical and digital models. This continued the first workshop form-finding process. Several proposals articulated the combination of geometry/structure/material successfully.

The participants incorporated the idea of shelter relating an inner and outer space. The constructive process of the OCA structure was not as defined as the Gridshell. This difference has two reasons: an OCA constitutes a different system and we might need extensive research to understand the OCA construction techniques in depth. Especially because the proposal set out to avoid a table system to support the OCA. The participants developed revolution structures that followed rail curves with free forms; some proposals incorporated the idea of bending tubes to attain curved surfaces, and others thought to use the tubes in combination with wooden slabs. Defined by the overall form there was a challenge to think how to connect the portal frames that in the majority of cases would require the development of three-dimensional complex joints. The selected form to construct is based on a set of petals that are arranged in an array, creating a space of relationships between the exterior and the interior where a pro-

tected patio is created, which would be the place where the Indian tribe would gather, to light the fire.

The built pavilion yields a new typology combining process, techniques and cultural experiences.

The pavilion is a group of five rotational "petals", organizing a central void for the fireplace surrounded by benches. The rotation and intersection of the petals creates niches in-between. The petals size decreases to the center, inviting to enter and sit. Each petal is a separated grid with PVC bended pipes connected with a standard male-female plumbing. We crossed the main bended arches with complementary smaller elements of bended tubes in the other direction to create concave-convex double-curved fittings that we fixed with cable-ties, resulting in a ruled double-curved grid. We carved wooden pegs and stacked them in the ground. We slot the pipes arches in the wood stacks. We made use of a traditional German carpenter measure tool to carve the different angles. We tested covering the petals with plastic film to increase the OCA protection effect.

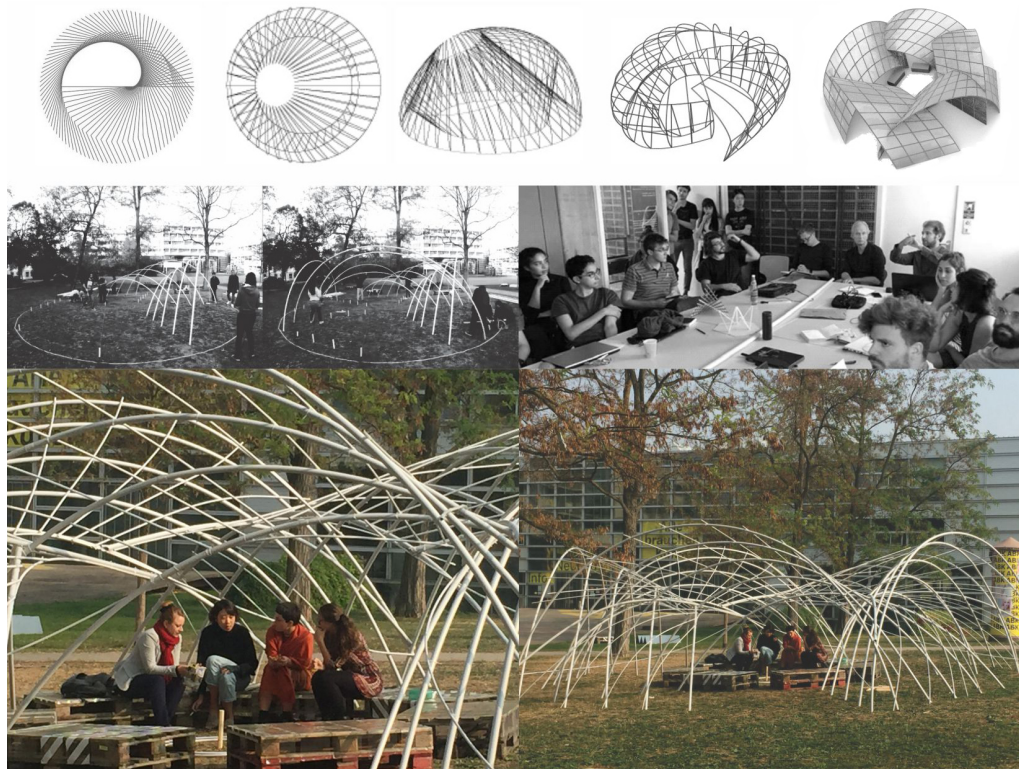
COMPLEMENTARY WORK

To foster collaboration, and get in touch with state of the art, technologies we visited different universities and research centers, with meetings and lectures. We visit UDK Berlin University Arts, Prof. Norbert Palz/Sven Pfeiffer; ICD Universität Stuttgart, Prof. Achim Menges, Tobias Schwinn; ABK Stuttgart. We visited Franken Architekten GmbH, Frankfurt; LAVA Offices Stuttgart, Berlin; NOWlab/BigRep Jörg Petri, Berlin; in Stuttgart: Design to Production, ILEK Lightweight Institute Frei Otto, and Mercedes-Benz Museum. Professors visit places in Frankfurt and Berlin, and then the all the group visit places in Stuttgart.

DISCUSSION

The purpose of the collaboration was to exchange knowledge in the fields of technical, cultural and human aspects. Learning by doing with others in a combined empirical-technological process. On one hand, the context of the Brazilian Lab 'LAMO' with

Figure 3
Workshop OCA
traditional Brazilian
Construction
reinvented, October
2018 at
ABK-Stuttgart-
Solutions
developed during
the workshop,
construction
process and the
final pavilion that
interlaces
bended-pipes to
form a ruled-grids
structure with a
central gathering
void.



its highly motivated group used to an informal working process stimulating creativity. Students improvising to overcome obstacles, making intuitive and empiric use of material and techniques. On the other hand, the German Lab very well equipped with a formal structure, run by experienced professionals, but with limitations to use of the facilities for foreign students and time constraints for the local students during the workshop period. German students used to solve problems interacting with seniors, something new for the Brazilian students.

The structure of the OCA is a vernacular construction that makes the best use of the most abundant material that exists in the place in an expedite con-

struction. It uses a table to support the outer shell. In this sense, it has a different nature from the grid-shell that is engineered, in an erudite development, which has no additional support elements as structure. One construction is optimized by the available materials, while the other is optimized in the search for the best structural solution, based on the study of minimal surfaces as found in nature. This does not mean that we cannot combine these two types despite their different natures. We believe that a complete fusion of these two constructions needs further research.

In the first workshop, we built a new type of grid-shell with a novel material. We then studied tradi-

tional OCA structures with the aim to eliminate the table as a structural support system inspired by the gridshell. During the second Workshop, we developed a new type of structure combining OCA shelter with a gridshell introducing a different material. We do not develop the technical aspect of the construction in depth, as this was not the research focus.

Students remember the workshop for learning multiple factors that affect architecture, how to develop multiple aspects of a design and how to test various design options in a quick way with the help of analogue and digital modelling techniques. Through the research of traditional techniques and materials and their combination with construction elements from a different continent, the project created new ways of connecting people. During the short time of five days each workshop provided a special experience containing discussions, digital simulations, hands-on making and in the end the celebration of the erection of a 1:1 prototype. The high-speed joint development of a piece of architecture by strangers. At the end their eyes blinked, we had fulfilled the purpose of creating multiple networks.

CREDITS

Workshop Tropical Gridshell experience / FAU-UFRJ Rio de Janeiro, March 2018. Coordination: Tobias Wallisser and Gonçalo Castro Henriques; workshop support by Daniel Lenz, Felipe Tavares. Lectures: Tobias Wallisser (ABK/LAVA), Celina Llerena (Ebiobambu), Felipe Tavares (UFBA). Participants: Amanda Ribeiro, Christian Jesus, Cristian Fagundes, Erick Maiworm, Francesco Milano, Isadora Tebaldi, Karen Antorveza, Leonardo Pate, Mariana Chalhub, Nicolle Prado, Pedro Teixeira, Pedro Engel, Rafaela Engler, Sol Ztt, Thatilane Loureiro, Thomas Anjos.

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Participants: Adriane Ossaille, Amanda Ribeiro, Christian Jesus, Erick Maiworm, Isadora Tebaldi, Leonardo Pate, Rafaela Engler and Ronaldo Lee. Collaborators OCA research: Lais Kaori, Pedro Teixeira and Thatilane Loureiro. German participants ABK Stuttgart: Andreas Klatzka, Felix Joachim, Frida Ruppe, Hari Wolfer, Lu Chéng, Isabella Altemani, Tobias Haas.

ACKNOWLEDGEMENTS

BRAGFOST Connect programme, Alexander-Von-Humboldt Foundation, DAAD, FAU-UFRJ/LAMO-PROURB, ABK-Stuttgart/LAVA

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