THE INFINITE LINE ACTIVE BENDING PAVILION: CULTURE, CRAFT AND COMPUTATION

VERNELLE A. A. NOEL[1], NILOOFAR NIKOOKAR[2], JAMIESON PYE[3], PHUONG 'KAREN' TRAN[4] and SARA LAUDEMAN[5]
[1]*University of Florida*
[1]*vernelle.noel@ufl.edu*
[2]*Carnegie Mellon University*
[2]*nnikooka@andrew.cmu.edu*
[3,4,5]*Georgia Institute of Technology*
[3,4,5]*{jpye7|ptran44|slaudeman3}@gatech.edu*

Abstract. Active bending projects today employ highly specialized, complex computer software and machines for design, simulation, and materialization. At times, these projects lack a sensitivity to cultures limited in high-tech infrastructures but rich in low-tech knowledges. Situated Computations is an approach to computational design that grounds it in the social world by acknowledging historical, cultural, and material contexts of design and making, as well as the social and political structures that drive them. In this article, we ask, how can a Situated Computations approach to contemporary active bending broaden the design space and uplift low-tech cultural practices? To answer this question, we design and build "The Infinite Line"- an active bending pavilion that draws on the history, material practices, and knowledges in design in the Trinidad Carnival - for the 2019 International Association for Shell and Spatial Structures (IASS) exhibition in Barcelona, Spain. We conclude that Situated Computations provide an opportunity to integrate local knowledges, histories, design practices, and material behaviors as drivers in active bending approaches, so that structure, material practices, and cultural settings are considered concurrently.

Keywords. Situated Computations; craft; wire-bending; active bending structures; Trinidad Carnival; dancing sculptures.

1. Introduction

Active bending structures are an approach to creating three-dimensional (3D) curved geometry and forms from two-dimensional (2D) planar or linear elements using stresses and elastic deformations in the materials (Lienhard, Alpermann, et al., 2013; Nicholas and Tamke, 2013). The close relationship between geometry, material properties, and forces in these structures make predictive modeling very complicated. Vernacular structures based on active bending usually take

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a behavior-based approach that is intuitive (Lienhard, 2014). Because of their complexity, most active bending projects today employ highly technical, complex computer software and machines for design, simulation, and materialization. For example, the ICD/ITKE pavilion made from thin birch plywood strips used finite element method (FEM) simulations and robotic manufacturing; the AA Hybgrid project used special software built for design and analysis of fiber-composite strips; the twisted-arch plywood structure used special algorithms, FEM analyses, and CNC precision milling (Laccone et al., 2020); and Isoropia which used Isogeometric Analysis (IGA), a physics solver, and CNC knitting (Tamke et al. 2019). Some projects more sensitive to local material practices and skills include the ZCB and TOROO bamboo pavilions that use physical prototyping and hand-tied knots (Crolla, 2017, 2020), and an installation "Timespace," that employed mesh optimization, physics simulation and weaving of polycarbonate pipes for construction (Huang, Wu and Huang, 2017). Software subscriptions, computational power, technical knowledge, and training required for engagement with contemporary active bending projects can limit the design space and who participates.

1.1. SITUATED COMPUTATIONS

Situated Computations is an approach to computational design that grounds it in the social world by acknowledging the historical, cultural, and material contexts of designing and making (Noel, 2020). The approach asks that we not remain ignorant of the social and political structures that drive design. It facilitates an understanding of cultures, people, and traditions; creates design spaces for interactions between different people and knowledges; and amplifies the stories, histories, and innovations of groups and cultures often left out of computational discourses. Our active bending project is framed within a Situated Computations approach with "The Infinite Line" pavilion demonstrating what this might mean for research and practice in active bending structures.

1.2. THE TRINIDAD CARNIVAL

Carnival in Trinidad and Tobago was borne in the 1780s when French planters introduced it to Trinidad. Enslavement of Africans started in Trinidad in the 17th century, but after its abolishment in 1834, the formerly enslaved reinvented the Carnival, making it a space to release psychological tensions from oppression and violence at the hands of white systems of control (Liverpool, 1998). In this reinvented Carnival, people showcased their creativity by using easily accessible materials to make elaborate costuming.

1.3. DESIGN AND MAKING IN CARNIVAL IN TRINIDAD & TOBAGO

People and communities continue to create dynamic dancing sculptures for Carnival with easily accessible materials for performance in public squares and streets during parades and design competitions (Noel, 2017). Skills and embodied knowledges from art, crafts, dance, and design make these artifacts a reality. One integral craft is wire-bending, in which wire, fiberglass rods, rattan, and other linear elements are bent and shaped to create 2D and 3D structures (Noel, 2015). Wire-bending inscribes a milieu of interactions between community, senses, and the moving body while designing and making with static and dynamic linear materials for concurrent expressions of each in three-dimensional space (Noel, 2020). Most tools and machines used are manual and include hacksaws, hammers, adhesive tapes, pliers, and drills (Fig. 1). Fiberglass rods are used in the making of elaborate and dynamic costuming. In 1984, carnival designer and artist Peter Minshall used fiberglass rods for an active bending approach to dancing sculptures by inserting them into the hems of t-shirts, creating textile hybrid costuming (Fig. 1). He continued this design method for the Barcelona and Atlanta Olympic opening ceremonies in 1992 and 1996, respectively.

Figure 1. Tools used in Carnival and dancing mobile by Minshall in 1984.

In this study, we employ Situated Computations to design and construct a lightweight structure built on the culture of Carnival for an innovative structures exhibition at IASS 2019 in Barcelona, Spain. The design brief called for an experimental installation of max. dimensions 4x4x4 meters, resting on the ground with all materials fitting into max. six (imaginary) boxes of max. dimensions 1x0.75x0.65 m per box, each box weighing max. 32 kg (70 lbs.) for transportation by airplane. In this paper, we investigate how a Situated Computations approach to active bending might amplify rich social and cultural practices of people with limited access to high-tech infrastructures. We design, build and exhibit an active bending pavilion that acknowledges and amplifies the historical, cultural, and material contexts of design and making in the Trinidad Carnival.

2. Situated Computations Framework for Active Bending Structures

Our framework for a Situated Computations approach that grounds active bending structures in their context is shown in Figure 2. It begins with understanding traditional and contemporary knowledges in a setting, the materials available, and cultural design and making practices in which communities engage. Based on this understanding, we can develop design interventions that connect local material practices with active bending and culture. After design, simulation is required to get feedback on the geometry, structural behavior, and material properties. In regions with limited, highly technological resources, simulation might involve physical prototyping for feedback that informs structural decisions. In areas with high levels of technological infrastructures and resources, structural simulation software and custom algorithms can be used and developed by those with expert knowledge. Materialization of active bending structures in a low-tech setting might involve manual and hand-powered fabrication and assembly methods. In contrast, a high-tech community might apply advanced fabrication techniques and robotics.

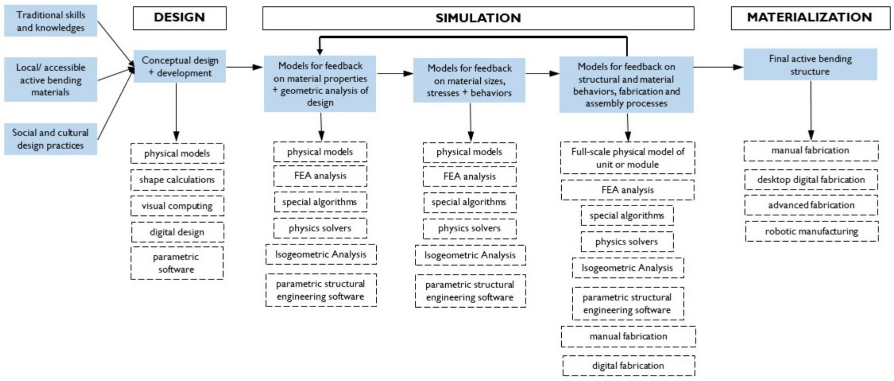

Figure 2. Situated Computations Framework for Active Bending Structures.

3. Materials and Methods

Our motivations in this project were: (1) employing knowledges in the Trinidad Carnival context; (2) creating an active bending structure with limited high-tech infrastructures; (3) using materials, tools, and techniques in wire-bending for fabrication; and (4) designing for easy assembly, disassembly, transportation, and reuse. The Infinite Line's design emerged from an analysis of a previous pavilion built by our team (Noel, 2019). The project was made using a CNC wire-bender, hand tools, wire, fiberglass rods, and adhesive tapes - industrial strapping tape and industrial duct tape. Based on that study, we took an active bending approach to this proposal due to the potential advantages of material behavior, packaging, curved geometries, structural stability, and transport. We used fiberglass rods because of their local accessibility, availability, affordability, their ties to costuming in the Trinidad Carnival, and their use in wire-bending.

3.1. PHYSICAL FORM-FINDING

3.1.1. Conceptual Design model

Since limited access to complex computer software and machines would inform our approach, physical modeling was our primary method for design, simulating appearance, material behaviors, fabrication and assembly processes, and failures. We took a geometry-based approach by creating and manipulating circular geometries from clear polycarbonate rods. We used the computational design method shape grammars to calculate design possibilities visually (Knight, 1991). Four of the 12 design studies are shown in Figure 3.

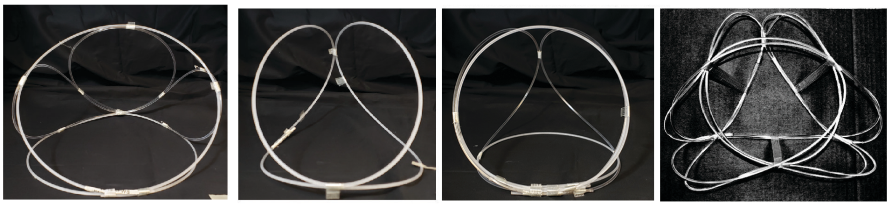

Figure 3. Conceptual designs and form-finding. (L-R): 3A, 3B, 3C, 3D.

3.2. PHYSICAL MODELS #2 (1/6TH SCALE)

Based on our conceptual studies, we explored two designs at 1/6th scale and made from 1/8" diam. fiberglass rods to observe how our ideas behaved at larger scales (Fig. 5A). After analyzing their design, behaviors, and geometries, we proceeded with the design in Figure 3D, which comprised three modules that we called "pringles" (Fig. 4). In the design, each module is rotated 120 degrees from each other. This design was selected for its modularity, geometric simplicity, and coiling possibilities for packaging and transportation.

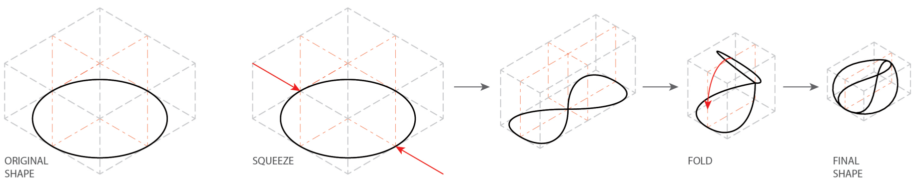

Figure 4. Steps for construction of the 'pringle' module.

3.3. PHYSICAL MODELS #3 AND #4 (1/4TH SCALE)

We built our third model at 1/4 scale with two 1/4" diam. fiberglass rods bundled together. At this scale, the rods' stresses were very high, requiring extra force to control them during taping, bending, and compressing. The high flexural stiffness caused rods to buckle and crack. After analyzing its material failures, stiffness, and assembly, we built a fourth model of same scale. This fourth model was made using bundles of two 3/16" diam. fiberglass rods, and resulted in a less stressed, easier to assemble model (Fig. 5C). After feedback from the models on sectional diameter, we built one pringle module at full-scale.

3.4. DIGITAL MODELS AND SIMULATION

While building physical models, we also employed digital modeling and simulation methods with Rhino 3D and the Kangaroo2 plugin. Minshall's textile hybrid costumes and our models were reminiscent of minimal surface geometries. Our digital models leveraged this similarity and were constructed from a series of rods and surfaces contracted together to approximate the physical model. Using the Kangaroo2 plugin, we employed a minimal surface method for modeling and applied a pre-tensioned mesh to discretized rods pulling them into shapes approximating the physical prototypes, and based on the internal tension of the rods and the minimal surface bounds of the mesh. Three of these forms were intersected to match the physical model. Due to complexities involved in digitally modeling these structures, we decided to construct ours so that: (a) each pringle was modeled independently such that there was no structural relationship between the three; (b) bundled rods behaved like a single rod of the same diameter, and (c) the flexural modulus was constant at 6.0x10ˆ6 psi. Construction of the digital model in Kangaroo2 mimics the physical method with rods independently folded, assembled, then joined. The second and third decisions helped simplify the modeling process. However, by modeling bundled rods as a single rod, we exclude potential internal friction forces within bundled rods.

3.5. PHYSICAL MODEL #5 (FULL-SCALE SINGLE MODULE)

We bundled four 10-foot long 1/4” diam. rods for a one-inch sectional diameter to build our full-scale pringle module. This allowed an understanding of material and geometric behavior and stresses and our fabrication and assembly strategies (Fig. 5D).

Figure 5. Figure 5. (L-R) 5A: 1/6 scale model (left); 5B: 1/4 scale model from 2 No.1/4“ diam. rods; 5C: 1/4 scale model from 2 No.3/16” diam. rods; and 5D: full-scale ‘pringle’ model (right).

4. Fabrication and Assembly

One 10 ft. rod was placed beside another with both ends at each other’s midpoint. This process of placing and securing one rod beside the other to form a pair was continued until the entire length measured 80 ft. After two sets of paired 80’ bundles are fabricated, both pairs are bundled together to create an 80’ long bundle of four rods. We used 1/2” wide industrial strapping tape and 2” wide industrial duct tape for bundling, since they performed best during our tensile experiments (Noel, 2019). Industrial strapping tape was wrapped 12”-16” apart, and industrial duct tape at 5’-0” apart. After fabricating the four-rod bundle, we built the circle and followed the steps shown in Figure 4. To reduce sliding and slip between rods, tape is first wrapped around one rod with some excess, then adhered to itself before wrapping it around the adjoining rod and securing both. This strategy was employed for all bundles, i.e., bundles of two and four, using both the strapping and the duct tape.

5. Full-scale pavilion

After fabricating and assembling the three full-scale pringle modules, and building the pavilion, we observed the structure sagging under its own dead load. To counter this, we created three structural members made from fiberglass rods. Each was a circle of circumference of 25 ft. built from two 1/4" diam. rods. These circles were secured with industrial strapping tape at the tops and bottoms of the pavilion at three locations 120 degrees apart. We then squeezed these 8' diam. circles to apply upward forces to the structure and further stabilize it (Fig. 6). Only a partial understanding of the effects of dead loads was possible with one module of the design. A fuller understanding through physical modeling could only be achieved after building the entire pavilion.

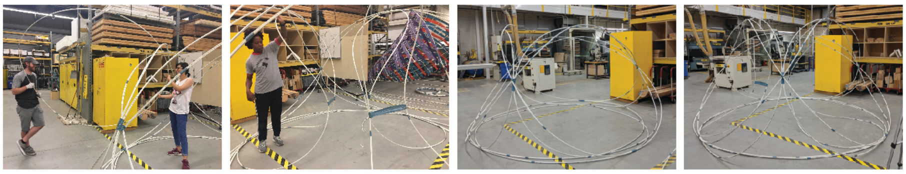

Figure 6. Installation of tensile struts to resist dead loads.

6. Results

Circular geometry allows us to leverage the flexural properties of the fiberglass rods, linking the physical form to the material properties, permitting experimental determination of 3D forms, which in turn inform the developing digital model. We used a 32" diam. base drum case to pack and transport our structure and additional rods should replacements be necessary (Fig. 7). After fabricating, installing, and testing our pavilion in Atlanta, GA., we de-installed, disassembled, and packaged it for our flight to Barcelona, Spain (Fig. 7B). The entire process - unpacking, bundling pairs, assembly, and erection in Spain - took approximately three hours, with the whole pavilion weighing less than 30 kg (66 lbs.). This mode of travel supports the mobile, temporary nature of Carnival with quick construction, disassembly, exhibition, and transportation of its artifacts.

Figure 7. 7A: Coiled pavilion structure in drum case (left); 7B: Drum case at the airport (middle); and 7C: Pavilion in Barcelona, Spain (right).

Communities come together to make artifacts from locally accessible materials for Carnival. By developing this active bending pavilion with a Situated Computations approach, people can make active bending structures as architecture and costuming for the Carnival. Second, children, adults, crafts persons, and other professions can come together to design and fabricate these structures that include traditional craft and costuming skills embedded in the Carnival. Third, through these structures, communities can showcase their creativity as they have done since the 1830s. Fourth, the ability to repurpose and create multiple design options using modular units ties back to the histories and innovations of people who use ordinary materials in extraordinary, creative ways. Figure 8 shows a rendering of the pavilion during the Carnival celebrations.

Figure 8. Render of Infinite Line pavilion during Carnival in Trinidad & Tobago.

7. Analysis & Discussion

We investigated how a Situated Computations approach can broaden the design and research space into active bending structures by computationally designing and building an active bending pavilion from local techniques in wire-bending, available materials, and design in the Trinidad Carnival. Our results show that by bringing together traditional crafts, cultural practices, and shape computation, we can develop novel approaches to active bending structures and contribute to scholarship. One practical challenge encountered in physical modeling was that feedback on deformation from dead loads was only observable when the entire structure was assembled at full-scale. This underscores a shortcoming of our digital model as it did not indicate a need for additional supports. Two limitations are that this structure was exhibited inside and did not have to resist external wind loads. Second, continuous coiling and uncoiling of rods for disassembly and packaging weakens rods over time.

Employing a finite element method and other advanced software and computational resources for digital design, simulation, and fabrication may have given extra information for predicting behavior. However, these methods turn a blind eye to the social, cultural, and technical knowledges of its setting. Second, they limit who can participate in design and scholarship by catering mainly to experts. Third, they restrict the fields and practices in which active bending can be explored with preference given to those largely resourced. Emphasis on highly technological methodologies limits advancement in design and research at the intersection of active bending, computational design, and cultural making practices. Although this project focuses on employing low-tech approaches to designing, simulating, and materializing active bending structures in a specific social, cultural, and technological context, other computational methods can be integrated for a hybrid approach. Parametric software can be used to generate design possibilities (Fig. 9), digital design and 3D printing technology can be used to fabricate connectors like previous projects (Noel, 2016, 2017), and structural simulation software in Rhino and Grasshopper can be combined with physical modeling for material and geometric feedback and analysis.

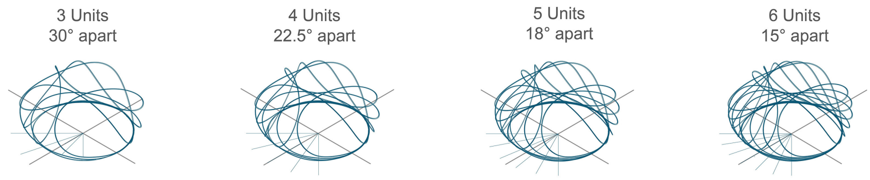

Figure 9. Digital designs of variations.

By building on existing knowledges and skills in Carnival, and facilitating creative expression using tools and materials at hand, a Situated Computations approach can (1) strengthen social and cultural connections, (2) link and advance culture, craft, and computation, and (3) employ the tensions and elastic deformations in society and materials to drive and generate form. A Situated Computations approach in active bending provides an opportunity to integrate local knowledges, design practices, and material behaviors as drivers in active bending approaches, so that structure, sociality, material practices, and cultural settings are considered concurrently. Future studies will continue to develop low-tech computational methodologies for design, simulation, and materialization in active bending discourse. Situated Computations opens the design space so that research in active bending is not driven solely by highly technological tools and skills but includes low-tech computational tools and knowledges and creates practices where both can work together and engage in mutual learning.

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