Pavilion: Geometrid

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+ Purpose

The Geometrid, borrowing its name from the insect family of a moth larva it resembles (both in form and in movement) represents a proof-of-concept for a specific kinetic typology – circular scissor linkage. The pavilion is part of a larger, ongoing line of research and practice in the field of kinetic structures by Thornton Tomasetti [2]. It is intended to serve as a close simile to real architectural application, employing mechanisms that can reasonably be scaled to function as a large kinetic roof and/or facade structures (or other) without fundamentally augmenting the approach.
Criteria

With this in mind, we set a number of other criteria for the Geometrid. To be successful as a scalable simile to large roof structures and to be manageable as a transportable pavilion it must be lightweight and long span to more closely realize a full scale application of kinetic architecture. For similar reasons it also needed to be discretized into components of 1 meter or smaller dimensions to comply with the rules of the IASS Expo competition. Working within a short time frame it was necessary to use widely available parts and fabrication processes. Similarly, the short time frame for installation required a simple flat-pack-like assembly utilizing repetition to achieve the overall form. In addition to being kinetic we also intended to program a responsive behavior to react to sound within the space, though this was later ruled out to avoid the unreliability of sensors over long periods of time (the pavilion needed to run continuously for 2 months without stop).

Concept design process

Our process explored a number of design avenues while refining the design criteria over time ultimately settling on a kinetic pantograph mechanism that suited the aforementioned constraints. Early studies explored a bending truss arrangement where the upper or lower chord members could be actuated. This ultimately proved hard to stabilize while managing the expansion and contraction. This led to an investigation of pantograph mechanism that could be actuated by pushing or pulling neighboring nodes together. These were attractive because only a small movement in the actuator is multiplied into a much larger movement in the overall truss. As an open-ended truss these were similarly hard to stabilize, but in a closed, circular arrangement they could be stabilized and actuated with more reasonable force via struts triangulated to a central axis. This circular scissor form from a series of pantograph mechanisms also exhibits an intriguing geometric behavior that we found attractive.

<<Early concept renderings of the pavilion>>

<<Early scaled kinetic study models>>
The main rings of the pavilion are comprised of universal scissor components, pairs are pinned to their neighbors at their ends and together as a pair at their middle [1]. Each boomerang arm makes up one side of a 4-sided diamond form. This diamond form becomes long or thin as the boomerangs rotate and the rings expand or contract. In the interest of building a structure that provides support or enclosure with such rings, they must be fixed in some way. However, all nodes are in motion relative to all other nodes. Therefore, only one node can be fixed in space – as in, to a supporting structure. This leaves the rest of the ring completely free and relying on bending in the axle at each node to keep it in plane. The triangulated struts solve this issue by fixing three points in a coordinated expansion as well as providing significantly more reliability in actuating the ring at 3 equally spaced locations at 120 degrees apart. Our prototype models proved that actuating the ring from only one location was sometimes unreliable and tended to bind the movement of the entire ring. The struts all lead back to a single node which travels along the central axis of the pavilion, driven by stepper motors spinning an ACME threaded rod. This node slides on three finely honed steel rods which give it stability and reduce friction. As the node plates move laterally the scissor rings will expand or contract in diameter as the struts move the ring’s nodes radially.

For reliability when working with movable components, the spanning structural system is separate and distinct from the kinetic system. The structural functions as a beam with a 6 m clear span and a 1 m overhang over each support. To keep the structure lightweight and stable, a tri-chord truss is used. The chords are composed of 1m segments of aluminum round tube with a 25 mm OD. The web is made of vertical PVC diaphragm and post-tensioned threaded rod. The structure was analyzed for a variety of boundary conditions, to allow discretion during the erection process. The skin around the structure is translucent exposing the structure and mechanisms inside, so any deflection would be very noticeable. The tension in the threaded rod could be adjusted to minimize the deflection for service conditions.
The electronics system consists of an Arduino plus two CNC controllers each capable of controlling 4 axis. The Arduino is programmed with a series of choreographed movements that get transmitted over serial connections to the CNC controllers. The CNC controllers each handle the synchronization of 4 industrial stepper motors. Upon startup the CNC controllers calibrate the sculpture by moving each kinetic section to its limits to zero out, or “home” the machine. Once calibrated the controllers notify the Arduino that they are ready and the preprogrammed sequence begins.
Construction Design Process

Once the design process for the kinetic geometry was completed in Rhino and Grasshopper the model was imported to Catia for a more detailed assembly and digital mockup. By utilizing the online library of 3D parts from the online industrial parts store, McMaster-Carr, we were able to quickly mockup the assembly with the exact parts required to construct a complex kinetic system. This assembly includes even the smallest of items so that every part could be reviewed before construction. This digital mockup was used to check for clashes between moving parts, confirm that the total weight was within our original design assumptions, and then generate a full BOM (bill of materials) for ordering.

Fabrication Process

The fabrication was a combination of digital fabrication and traditional methods. Parts that could not be sourced directly from a manufacture and contained geometry unique to the design of the pavilion were fabricated in one of these methods. Where geometric complexity, high tolerance, and/or high part counts were required CNC methods were used. Waterjet CNC cutting was used for all two dimensional parts (main PVC vertical diaphragms, struts, scissor shaped boomerangs) while three dimensional parts such as enclosures for retaining the acme nut on the linear motion assembly and limit switches were 3D printed. Various aluminum brackets and couplings were fabricated by hand, leaving the rest of the pavilion largely as off-the-shelf components.
Assembly occurred in two stages, both after air transport from the United States to Amsterdam where the pavilion would be erected. All parts were transported via checked luggage in ‘raw’ form. The first stage, occurring off-site, involved semi-completion of the 8 identical major components. Of these there are 2 parts, the rings and the structural core, transported to the site separately to keep size reasonable for transport by taxi and avoid instability. The rings were bolted together with low torque to keep friction low and transported in their contracted state. The 8 identical segments making up the structural core were assembled, including motors, the actuation axis, but excluding diagonal tension members. The second stage, occurring on site, saw the application of the rings to the segments, coupling of the segments, and addition and final tuning of the diagonal members. Final wiring was completed and skin was applied as the last step before hoisting.

+Thoughts on full scale applications

The challenges of designing large scale kinetic structures are compounded by the complexities of simultaneously maintaining structural stability of the main structural support system through the entire movement of the kinetic assemblies, a smooth (minimal friction) and predictable kinetic movement of the assembly itself, and the need to accommodate overall structural movements as load paths change and external forces are variable. Furthermore, the relative scale (weight and volume) of a kinetic system drive mechanism and the kinetic assembly becomes a critical factor in providing kinetic reliability. Based on our design development and installation of the Geometrid kinetic pavilion, we believe that similar typologies of large scale kinetic structures and facade systems are achievable and with intelligent planning and testing, they can be extremely reliable and economical as well.
<<View from balcony looking over the IJ>>
<<View from balcony (lower left), view from NE corner(lower right), view from below (upper)>>
+References