GENETIC STAIR

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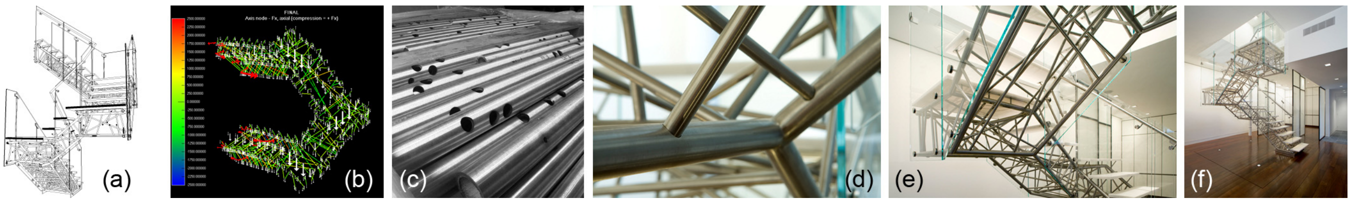

Figure 1: (a) Sectional cut of digital parametric model. (b) Screen capture of FEA software. (c) Laser cut structural pipe components. (d) Detail showing typical rod-to-tube connection and four-way miter joint. (e) (f) Final stair in space.

Introduction

Designed, fabricated and installed by a single team of architects and metalworkers, the Genetic Stair represents the culmination of a fully integrated generative design process. Digital design techniques formed the heart of the research and development process from the earliest conceptual stages, through performative analysis and onwards to fabrication.

1 Design

The design intent of the Genetic Stair was to arrive at configuration of simple elements that would be expressive of the complex set of forces at work in the structure. To that end, a cross-platform generative design program was developed that married the precision and adaptability of the 3D CAD environment Rhinoceros 4.0 (Rhino) with the analytic power finite element analysis (FEA) software. This program implemented a specialized genetic algorithm (GA) that integrated project-specific fabrication constraints into the generative process in Rhino while utilizing FEA to assess structural performance and assign evolutionary fitness to individual stair configurations.

The first step in the design of the stair was the development of a script (in Rhino) to create the overall three-dimensional layout. This was essentially a function to set the stair's bounding volume based on variable input such as building code requirements, fabrication constraints and on-site measurements. The result was a three-dimensional parametric digital model with line elements representing all components excluding the diagonal rods used to stiffen the stair and distribute the forces within it. The layout of these connecting elements was the focus of the GA.

To create the initial generation of stair configurations, rods were distributed in a random process that nonetheless required adherence to programmed fabrication constraints. The configurations in this population, while structurally entirely inadequate, still followed rules which allowed any of them to be built using predetermined construction methods.

Once a population of three-dimensional configurations was created, it became the genetic material for the creation of a new generation. To this end, each stair configuration was imported from Rhino via custom-formatted text files into the FEA software. Then degrees of freedom were assigned to its nodal connections, units of force were applied to the nodes and specific material properties were assigned to the linear elements. Then the FEA model was solved and structural performance data was exported to form the means of assigning the probability of that individual's genetic information being passed on to the next generation.

The final step in the cross-platform loop that formed the core of the GA was to create a new generation of configurations based on weighted selection of information from the previous population. Once two individuals were selected for reproduction, a crossover point was assigned randomly at some point along the length of the stair layout. Rods located below the crossover point on the first individual were added to rods located above the crossover point from the second individual to produce a new configuration that was a combination of the two. Further operations carried out on the new configuration included auditing for constructability and occasional statistically-determined mutation functions.

2 Fabrication

Fabrication methods were developed and tested concurrently with the design and development of the stair. In the end, though the generative design process was highly automated, its actual construction was a combination of digital and traditional techniques.

The Genetic Stair is made of 48 unique stainless steel pipes with 1400 holes and 253 connecting steel rods cut to length. Using five-axis CNC laser cutting equipment, these holes could be cut with enough precision in both position and angle to allow the pipes themselves to act as a kind of three-dimensional jig for assembling the stair. One quickly identified limitation of laser cutting technology was the relatively small range of incidence angles (< 15°) that can be precisely cut into polished stainless steel due to refraction of the beam. This constraint led to the development of highly specialized design and detailing solutions, such as fabrication-conscious generative processes and hybrid digital/analog templating procedures.

Though the laser cut pipes themselves were fabricated with a high degree of dimensional and angular accuracy, the way in which these components were joined one to the other (structural welding) was significantly less precise. To bridge the gap between the precision of digitally fabricated smart components and traditional metal shop fabrication techniques, custom jigs were made using additional digital equipment such as a CNC router, on the high end, and a standard office laser printer on the low.

3 Conclusion

The result of this process of design, analysis, and fabrication is a complex yet understandable architectural experience in steel and glass in which every component works together as a unified whole to push and pull the stair upward through 270 degrees with no intermediary supports.