Figure 1: Rendering of an InterLattice structure. Hypothetical form shows vertical and horizontal rotation.

**InterLattice**

Lauren Johnson, Design Machine Group, University of Washington Department of Architecture

**Abstract**

*InterLattice* is a three-dimensional fastener-free joinery system composed solely of interlocking flat pieces. The *InterLattice* system is made up of vertically oriented triangular modules that connect to each other in a manner inspired by conventional brick and mortar construction, updated to take advantage of digital technologies available in an era of mass customization. Connection gaps between the triangular modules act as flexible joints, connecting the modules together while allowing for a wide range of angles between adjacent modules. With the *InterLattice*, double curvature in form is possible without the typical need for tiling or major alteration of module geometry. This enables material sheets to be nested and CNC cut simply and efficiently; tabs and slots are unique to their position, but the overall size of pieces remains consistent. The parametric model of *InterLattice* allows for control of lattice geometry and automatically updates connection conditions, paying attention to patterns and constraints within the
Through this modeling process, CNC-ready InterLattice designs are simultaneously generated and visualized. InterLattice systems are highly flexible and have many potential applications including interior walls, self-supporting awnings, and as a part of weatherproofed exterior structures.

Introduction

The buildings of the Industrial Revolution relied heavily on brick and mortar construction, a technique utilizing a standard unit of construction, the brick, assembled in a seemingly standard fashion. However, tremendous variety in surface texture (coursing) and overall geometry (curved walls, vaults, and domes) have been demonstrated through variations in the joints between units without changing the fundamental technology. Digital technology “updates” to the brick include “smart bricks” (Engle et al., 2004), robotic brick placement (Bonwetsch et al., 2006). The InterLattice project examines the space between modules—the joint.

As digital fabrication becomes more prevalent in the field of architecture, new design and construction details are being explored. Details for approximating curved surfaces with two-dimensional digitally fabricated material are being researched (Kilian, 2010, Kolarevic et al., 2008). Analyzing the relationship between materials and manufacturing tools and then developing methods to design for the new technology, as opposed to simply using it, is necessary for innovative design. In the InterLattice project described here, the goal is to develop a methodology for generating surface curvature using a standard unit and a system of variable interlocking connections or joints. By designing the principles of a joinery system it is easy to incorporate control of other design priorities from the initial design phases. In this instance, the problem is approached from the smallest piece forward. Final geometrical form is unearthed from within the system rather than being the focus of the design. Joinery pieces are developed for readily-available sheet material and utilize flat cutting technology in consideration of time and economy. In contrast to many digital fabrication examples, minimizing material waste is of high importance. In addition, the development of a general connection methodology and parametric model shifts the design from being manipulated by one architect to being accessible to many. The InterLattice is more than a unique design; it is a new joinery system capable of producing highly varied forms.

InterLattice

InterLattice is a fastener-free space defining joinery system assembled entirely from interlocking two-dimensional pieces. Composed of triangular modules of alternating orientation, the delicate lattice-like structures can be imagined as fulfilling various typological roles. The system builds off of the integrity of a brick and mortar system and at the same time, takes advantage of customization potential inherent in contemporary design and fabrication technologies. In a traditional brick and mortar system, mortar is the vehicle that both connects the bricks together and allows for gradual movement within the assembly of rigid modules. In the case of the InterLattice, gaps between planar modules act as the mortar joint; double curvature is achievable through the gaps.
Each triangular module can be broken down into three rectanglularly-bounded flat pieces which lock together with tabs and slots (“fig.” 2). The overall equal sizing of the modules enables the unique pieces to be unrolled and nested in a materially efficient manner (“fig.” 4). An InterLattice structure with double curvature can be constructed with the same material specifications as one that approximates a flat planar surface. As envisioned, the InterLattice is to be fabricated out of plywood using a 3 axis CNC mill. Since the focus is on the joinery, as opposed to simply the final form, material waste resulting from irregularly shaped pieces is avoided.

![Figure 2: Diagram showing module connections.](image)

![Figure 3: Diagram showing vertical and horizontal rotation joints.](image)

**Defining Curvature**

The connections of the InterLattice are what enable the creation of flat, singly, or doubly curved surfaces. While enabling the emergence of curved forms, there are limits to how sharply curved the forms can be. It is necessary to understand the system’s limits and rules in order to develop a parametric model. Each triangular module is connected with four adjacent modules: top, bottom, and either side. The modules are attached through six connection points, although it is more accurate to describe the system in pairs rather than singular triangles. The repeating modules can be visualized (“fig.” 2) as having a tip-down triangle on the left with a tip-up triangle connected to the right at the midpoint of the first’s side piece. In other words, the right side of the first triangle’s center point, A in figure 2, is coincident with the bottom left corner of the second, point B. Amongst other things, the amount of curvature is proportionate to the gap dimension (mortar joint). The larger the gap is, the larger the
possible degree of curvature. To better understand the system, properties of vertical and horizontal curvature will be discussed separately from complex curvature.

Triangle pairs share the same axis and degree of vertical rotation; however each module can independently rotate in the horizontal direction ("fig." 3). The axis of vertical rotation is located at the bottom of the tip-down module. Vertical rotation is limited by the necessity to connect with the module directly below. Module depth affects vertical rotation; deeper modules provide a larger surface area for intersection. In order for the lattice to maintain structural stability, all triangles must have secure slotted connections.

Horizontal rotation is centered on the point shared by both triangles in the pair. In this location, the center left of the top piece is connected to the center of the adjacent module’s left side piece. Limits on horizontal rotation ensure that the modules do not rotate to the point where the neighboring side pieces collide ("fig." 5). The maximum angle of horizontal rotation is a function of ½ module depth, shown as A in figure 5, and the tab length plus ½ material thickness, dimension B. Top piece geometry is cut to match each piece’s angle of rotation; this is shown by the right edge of the module in figure 5.

In order to define double curvature, rules that ensure top and bottom module connections and those that prevent side piece collisions still hold true. Yet the exact limits established for single curvature situations will not result in a structure that adheres to the project goals. Employed together, vertical and horizontal rotation angles compound and further limits must be put in place for a structurally sound lattice. If limits are not tightened, a common place for failure is where module rows become disconnected from (i.e. do not intersect with) the rows beneath them. Failures are, of course, dependent on the parametric modeling technique. Tailoring the limits to favor either a higher degree of vertical or horizontal rotation can be instrumental in generating a doubly curved InterLattice form with a primary axis of rotation.

Throughout the process of defining the joinery rules, interplay existed between connection and curvature analysis and feedback from the generative model. Certain partially developed traits were rewritten as hard rules. Also, a few rules were loosened in order to support greater degrees of
curvature. For instance, closer examination into the workings of the vertical rotation joint revealed that it was unnecessary for modules to pivot along a single point, the bottom connection in figure 2. In this case, the origin was redefined to include any point along a specified arc.

Parametric Model

InterLattice structure geometry is generated through the parametric model. Geometry is also converted to labeled fabrication drawings in a file-to-factory process. Module height, width, depth and material thickness are variable. In addition to manipulating size, users have direct control of module rotation. Slider limits, tab size and bottom tip spacing dynamically update in accordance with the input parameters.

The parametric model is built using Grasshopper, the generative modeler for Rhino, and is based on a linear progression of actions. Initially the master triangular module, rotation angle domains, and connection points and planes are created. Subsequently, the triangle surface geometry is transformed, together with necessary connection points and planes. In generating cohesive interlocking rows and columns, transformations must occur in one specific order. Each new triangle is an instance of the master triangle. Information is stored within each instance allowing direct manipulation of vertical and horizontal rotation for the specific triangle. The order of setting up connections (order of transformations) is configured in a way that vertical rotation is cumulative. This provides the ability to create twisting forms with the limited the range of curvature. While this methodology offers direct control over surface generation, the copy and paste approach to transforming and generating new instances, a necessity with Grasshopper, can become tedious in the generation of very large surfaces. A parametric model that supports iteration and recursion could offer an elegant approach for structures composed of many modules.
Future Work

Work has begun on a second methodology of using the InterLattice joinery to create form. In this area of further research, an array of modules are placed along a vertical plane and virtually joined together at their connection points. Using a physics simulation engine, a pushing force is applied to a selected module. The force is able to travel through the adjacent modules thus affecting movement across a larger area of the lattice than just the selected triangle. The user can fix the location of specific triangles and continue the force application process until a desired form is reached. This methodology is entirely programmed; but like the existing method, a display window records change and allows for direct interaction. In both of these parametric modeling techniques, user interaction is highly integrated into the system and near real-time updates makes these approaches possible.

Architectural Application

Up to now, the InterLattice has been described in regards to material efficiency, tabs and slots, surface curvature, and the ways in which the parametric model enables these. In this section, the InterLattice will be discussed as part of its many possible architectural applications. Two scenarios will be drawn: in
the first the InterLattice will be imagined as a partition wall in a gallery, and the second a landscape pavilion.

The InterLattice’s “flat pack” slot and tab assembly make it a clear candidate for a temporary installation. With no permanent fasteners, it can be assembled overnight in preparation for a gallery exhibit, illustrated in figure 7. At the same time, it can be easily dismantled for reuse. The variable form provides many visual options and the ability to fulfill different spatial agendas. For example, an expansive gallery could be divided into discrete zones by a semi-transparent snaking wall. An intimate gathering area of its own could also be created by wrapping part of the end of the lattice wall back towards itself. Finally, as in any gallery application, lighting plays an important role in illuminating the lattice and heightening the shadow patterns across the triangles.

Figure 7: Rendering of a possible InterLattice structure.

In the second scenario, the landscape pavilion illustrated in figure 1 exemplifies the ability for the joinery system to create a fully sheltered space. Properties of strength and symmetry, integral to the alternating orientation of triangles, can be used to develop a vaulted structure. In this instance, vertical rotation is the primary source of curvature. In addition to simple shelter, a sense of privacy is desirable in a public outdoor setting. The depth of the numerous lattice triangles obscures views toward the pavilion while maintaining clearly framed views out. Breezes are also able to permeate the interlocking surface.
permanent applications such as this, the lattice can easily be secured to a foundation. Cladding is also an option. Same sized triangle pairs are connected and laid out along the InterLattice surface in ruled curves. In cases where no vertical rotation exists or the origin location of vertical rotation is limited to the top/bottom connection point, all tip-down bottom points will be located at the outer edge of the surface. This creates possibilities for cladding the ruled surface with flat strip material, lapped to shed rain. The flexibility of the InterLattice joinery system allows it to be thought of as a stand-alone architectural piece or as a substrate to a larger system.

For any application, assembly is simple and straightforward. Pre-labeled pieces help to organize the assembly process. Since modules fit together by hand, the crew and toolset of a typical construction site is not required. The precision fit of the slots makes it so pieces are secured at the time of connection, resulting in little need for temporary scaffolding.

Conclusion

The InterLattice prototype pays attention to progress in manufacturing technologies and the material response. A system that may look fairly simple to the human eye is often made up of complex relationships. It is a challenge to decompose a system to its core principles in order to recreate it with new parameters, often in completely unexpected ways. Yet the excitement of the generative joinery system comes from the many undiscovered possibilities of form and use. There is room for future research on the InterLattice, specifically furthering the capabilities of the parametric model, and producing simulations and large-scale prototypes.

Acknowledgements

Development of InterLattice was begun in a course under the leadership of UW Professor Rob Corser. Colleagues in the UW’s Design Machine Group offered insights and suggestions. Travel support was received from the Department of Architecture. Thanks also to Professor Brian Johnson for help in preparing this paper.

References

