Recently, prototyping enabled by CNC technology has found its way into design practice where concepts can be quickly and economically tested through multiple design iterations that closely approximate the realities of one-to-one construction. This has lead to the promise of renewed research in tectonics and constructional techniques where the traditional concepts of craft and the joint, that were once married to the hand, can be rediscovered through the agency of mass customization. If we apply the lineage of the trait—a representational and cognitive tool to marry complex form with the exigencies of construction—pedagogical approaches can be developed that extend the current interest in intricate surface, structural morphology and geometry towards a robust materiality rooted in componentry, the joint, and part-to-whole relationships. This paper will introduce several threads from the twentieth century that have informed these tendencies in contemporary design practice, emerging from the well spring of Viollet-le-Duc. The thesis is supported by undergraduate model-based research employing digital design and fabrication techniques.
1 Provocation

In his remarkable essay, “Drawn Stone,” Robin Evans discusses stereotomy—the cutting of solids—through the technique of the trait. Developed in the sixteenth century, “traits were layout drawings used to enable the precise cutting of component masonry blocks for complex architectural forms, especially vaults. Thereby accurate fabrication of parts could be achieved prior to construction. Traits are not illustrations and yield little to the casual observer. They are orthographic projections, but they are not like other architectural drawings” (Evans, 1995). Evans argues that this method was required only in extraordinary conditions and was at the limits of mathematical geometry, technical drawing, structural theory, practical masonry, and military engineering. More than an early form of shop drawing, the trait can be seen as both a representational and cognitive tool to marry complex form with the exigencies of construction.

Analyzing the highly complex fan vaults at Henry VII Chapel, Westminster, Evans writes that the apparently contradictory principles of structure and ornament are inseparable, having been developed through the geometric and jointed logic of the trait. “The filigree of liernes and ring ribs is nothing more or less than the generator of the fans and the loci of their rotation repeated over and over. The pattern is a diagram in the way in which the surface was construed” (Evans, 1995). He then goes on to argue that the components of the vaults were in all likelihood precut or prefabricated before being installed by the masons.

The extraordinary effect at Westminster can be described as the union between construing and constructing or the production of discourse and the act of building through the agency of the detail (Frascari, 1996). Details and by extension joints have been described by Marco Frascari “as the minimum units of signification in the architectural production of meanings. These units have been singled out in spatial cells or in elements of composition, in modules or in measures, in the alternating of solid and void, or in the relationship between inside and outside” (Frascari, 1996). If we look at the biological definition of trait as a genetically determined characteristic or quality that is physical (hair color or the shape of a leaf) or behavioral (nesting in birds or burrowing in rodents), details and joints can be also seen as the genetic material that constitutes a work of architecture. Architectural performance begins with these concepts of the trait, where part-to-whole relationships are generative and catalytic, and feedback is developed between varying scales of material and spatial joints.

Recently, prototyping enabled by CNC technology has found its way into design practice, where concepts can be quickly and economically tested through multiple design iterations that closely approximate the realities of one-to-one construction. Michael Speaks argues for design intelligence through design prototyping based on what MIT Media Lab’s co-director Michael Schrage terms, a spreadsheet way of knowledge (Speaks, 1995). The design process becomes less about producing a one-off building and more about dynamically developing a product using contemporary business practices as a model. Because the prototype can be analyzed, adjusted, and remade quickly throughout the design process, it “becomes a tool of innovation and not just a version of the final design” (Speaks, 1995). This way of working also allows architects to actively reengage with the complexities and logics of construction as a direct extension of their design practice. This has lead to the promise of renewed research in tectonics.
and constructional techniques where the traditional concepts of craft and the joint, that were once married to the hand, can be rediscovered through the agency of mass customization. If we apply the lineage of the trait to these new ways of working, pedagogical approaches can be developed that extend the current interest in intricate surface, structural morphology and geometry towards a robust materiality rooted in componentry, the joint, and part-to-whole relationships.

Many of the digital modeling techniques we have seen in the schools of architecture beginning in the 1990s strive for formal complexity at the expense of material and assembly related research. In a recent interview about one-to-one CNC fabrication, Fabian Scheurer of Designproduction suggests that architects typically confront fabrication only after their designs have been completed, not as an integral part of the process. Scheurer notes that “all of this top-notch modeling software out there effectively hides the complexity of the geometry. But the complexity is back as soon as you try to break it down into segments and manufacture it” (Byles, 2007). Having consulted with Zaha Hadid and UN Studio on fabrication strategies, Scheurer’s experience points to a gap between fabrication processes and design pedagogy.

An emphasis on component modeling and the joint can be seen in the work of Konrad Wachsmann and Pier Luigi Nervi. A common thread links this work that originates with Viollet-le-Duc and Structural Rationalism. These ideas would have an impact on architecture at the edges of the modern movement and are still influential today in work that embraces prefabricated constructional techniques and material research in the service of expressive tectonics.

The theoretical promise of Viollet-le-Duc’s L’Entretiens sur L’Architecture was “an unprecedented architectural code created out of the articulation of constructional logic” (Frampton, 1983). As a reaction to Neo-Classicism, Viollet-le-Duc argued for the establishment of critical and interpretive play with regard to the past. It was not stylistic but was governed by unlocking the technical and constructive principles behind what was already built. His thesis suggests how emerging building technologies in concert with structural research could lead to a new tectonic expression in architecture. Art Nouveau, Jugendstil, and the Arts and Crafts movements grew out of this approach, and much of it resided in the study of structural and geometric analogues found in nature. The lineage of the tension between structure and ornament that Evans unlocks at Westminster is a marked quality of Art Nouveau, where the articulation of a structural logic is conflated with the continuity of the surface through elaborate tracery. This tendency can also be seen in the work of Wachsmann and Nervi.

Wachsmann’s Study of a Dynamic Structure started as a research studio project at Chicago Institute of Design in 1953 with aim to produce a novel construction system using factory produced components. Working as a team, the students developed interlocking “three-legged, wishbonelike members” that operate as both column and beam and connect at midpoint locations where the structure is horizontal (Wachsmann, 1961). The joint becomes the generator of the project where the modules intertwine at nodes that provide vertical and horizontal contact and distribute the loads in converging diagonal lines. Also known as the Grape Vine Structure in Wachsmann’s archive, the components are organized from the bottom up and aggregate into a complex 3D lattice that is analogous to a botanical system. The material for the modules was never defined, although there is a study that shows the members as continuous tube or channel sections that could be made from steel.
or precast concrete. The study also shows that the modules could be broken down even further as triangular sections forming either corrugated sheet steel members or light weight trusses. Thus the part to whole logics would be consistent across scales of construction and jointed modules would be formed of jointed parts.

Nervi had been experimenting with prefabrication for long span structures as early as the mid 1930s but his great innovation began a decade later when he began developing ferrocement vault and dome structures. Prefabricated pans were arranged on scaffolding with four inch channels between them where cement would be poured in situ creating dense lattices. The pans were, effectively, material and formal joints where multiple variations in size and shape would develop a complex geometric tracery of voids, creating light-weight, thin shell structures. This is best seen in the coffered ceiling of the Gatti Wool Factory or the Small Sports Palace where the ribs map the flow of forces along the interior surface of the spaces. Nervi describes in his book Structures that many of the forces were impossible to calculate without the aid of a large scale models (Huxtable, 1960). Nervi used this method of material analysis throughout his practice to test and measure loads and stresses under various conditions. Partial full scale models were also used to layout and construct the prefabricated pan systems. Nervi was actively involved in prototyping across scales as a rehearsal for one-to-one construction; his methods of construing are literally embedded in the surface of the architecture.

## 2 Pedagogy

The pedagogical heuristic of the model traces a line through the research in two ways: 1) as a material practice and 2) as a cognitive tool. The first employs the model as a working method to unlock material and structural performance—the scalability of the prototyping process becomes a rehearsal for the realities of one-to-one construction. The second harnesses the model as a tool for conceptual thinking—both the drawing as model and the model as prototype marries the “cognitive-perceptive with the figurative-operative” (Moldonado, 1987).

Tomás Moldonado describes the feedback between the act of drawing and the physical model, where drawing is a type of cognitive model-making which anticipates the object and its construction. It is this productive tension between construing and constructing which is unique to the model as a design tool. He clarifies the difference between classical iconic model-making and drawing that represents a proposed building or object, and non-iconic models that are diagrammatic. Non-iconic production targets how an object works; its function and structure are important, not its form. Moldonado calls this class of models analogous and includes mathematical models as an example. Interestingly, prototypes—“models that serve to facilitate preliminary or final decisions about a product that will be mass-produced” – fall outside iconic production because “one can talk about prototypes in a construction-related industrialization system, but not in the case of traditional building” (Moldonado, 1987). Although his research was published in 1987, before the introduction of digital fabrication into design practice, it is prescient in that it points to the shift in thinking that the discipline is taking regarding mass customization. Moldonado anticipated the current trend in digital practice that blurs the distinction between building and product.

Over the last three years, two model-based approaches using digital fabrication techniques have been tested in an undergraduate research seminar and degree project studio at Pratt Institute School of Architecture—component invention using analogues from nature specifically botanical models, and component mutation interrogating preexisting architectural systems. The model based approach emphasizes the development of part to whole relationships through jointed assemblies and privileges expressive tectonics as a means to confront scale and the exigencies of construction. Although 3D printing has proven itself to be powerful tool to visualize
complex form, its use has been discouraged because of its lack of materiality and its tendency to produce smooth surfaces with no tectonic differentiation. The laser cutter is the tool of choice because by default, assemblies have to be made of modules. The limitations of the tool also demands that 3D form be geometrically constituted from sheet stock with a restricted size. Tectonic innovation using off-the-shelf materials was privileged over new material technologies.

3 Coursework: Research Seminar (co-taught with Aaron White)

The ambition of the seminar was to interrogate digital prototyping as a working method and form of research that differs from classical iconic models of representation. Working within two parallel forms of inquiry—the design/fabrication of laser cut wood models and the analysis of selective readings—the potentials of contemporary digital modeling was exposed as a speculative practice that embraces iterative making as design intelligence. Critical to this method was the scalability of the prototyping process—each consecutively scaled model raises questions about material performance and constructional specificity.

Assuming that the two prevalent taxonomies of laser prototyping are the intricate surface (single cut and/or folded sheet) and the fuselage (framework of ribs forming tubes of space), a third alternative strategy was investigated—digital tracery. Using the logic of Gothic architecture’s jointed 3D lattices as a departure point, digital tracery marries the contour between column and beam to create surfaces that have the potential to both develop topological variation and confront the laws of gravity. Working in teams, students tested multiple design variations by fabricating ¼”=1'-0” scale jointed lattices and ¼ full scale joint details using a 18”x32” laser cutter. The intent was to limit the size of the components that form the lattices, so students would have to confront the economies of assembly and structure, while still maintaining the effects of continuity and lightness.

At the beginning of the semester students were asked to independently analyze a particular flowering plant with an emphasis on organizational and geometric characteristics. From their research, students attempted to trap, or intensify a particular trait(s) of their plant through notation drawing and detail modeling by developing simple modules of assembly and building complexity from the bottom up. Students then broke into teams to research techniques and fabricate prototypes to draw out larger organizational principles and structural details. Simple “programmatic” pressures in section such as compression vs. dilation, cantilever vs. vault, light vs. dark, introduced variability and adaptability in the aggregation logics, structural morphology, and joint details.

After the completion of the seminar in the spring of 2009, a team of two students were selected to perform an independent study over the summer to further develop their proposal for a full-scale installation at Pratt later in the year. After building a digital parametric model and full-scale detail prototypes, Textile Helix was milled on a three axis CNC machine and was assembled using four primary part types with no mechanical connections. From issues of material performance and tolerance, to geometry and assembly sequencing, the process proved to be far more complex and intense than anticipated by the design team. This, however, was in keeping with the pedagogical objectives of the seminar and provided critical research and development experience for the students beyond what is typically taught in the design studio.
4 Coursework: Degree Project Studio
(co-taught with Daniela Fabricius)

Beginning with the topic of “market economies”—whether it was a market for pirated goods, a real estate market, a food market, or a virtual system of exchange like Ebay—the studio research grew out of the architectural systems that constitute these programs at multiple scales.

From the gondola shelf, to prefabricated enclosure systems, to vehicular infrastructure, a given system of componentry forms a culture of assembly within the marketplace. These systems and subsystems are typically seen as being beneath the discipline of architecture and in the service of efficiency, marketing, and sales. In contemporary practice, architects have been experimenting with BIM (building information modeling), just-in time-production techniques, and mass customization that mirrors the trends of the marketplace with the goal to achieve spatial complexity that is both efficient to build and cost effective.

The ambition of the studio was to interrogate the logics of these systems as a material practice to unlock a tectonic strategy tailored to each student’s market program. Because the components were constituted from readymade parts, they were charged with cultural content particular to their market program. Any operation on the parts demanded a programmatic response not just formal one. This approach pushed the components into new territory and generated novel tectonics and part to whole relationships by demanding that the components do more than one thing.

Students analyzed components particular to their market program to develop systems of infrastructure to interface with both the specific (the inner workings of their market e.g., storage, display, pedestrian circulation, structure, etc.) and the general (urban
scale processes e.g., vehicular distribution systems, services, etc.). By mutating and hybridizing components, inventive formal, programmatic, and organizational systems emerged. In this way, both the tectonic and the programmatic interfaces could be related through selected characteristics or parametric modeling. Students worked with RhinoGrasshopper and physical model-making using the laser cutter, to economically introduce variability and adaptability in these systems.

The final part of the assignment asked students to develop, in a 3D drawing, a conceptual organization that was either structural (addressed gravity to support smaller component assemblies) or distributive (addressed pedestrian or product circulation). As the semester progressed, each student developed these assemblies in concert with their cultural research into a comprehensive architectural proposal.

5 Conclusion

The work from the fabrication research seminar and the degree project studio develops a robust materiality rooted in componentry and part to whole relationships. The method of conceptualizing the work is embedded in the surfaces of the architecture to form a code of constructional logic. These technical and conceptual joining principals can be seen as the traits of each project, where feedback is developed between varying scales of material, spatial, and programmatic detail.

References