# Adaptive Fabrications: Rapid Directions in Design Build

"As the complexity of our physical and social systems make the world more unpredictable, we have to abandon our focus on predictions and shift into rapid prototyping and experimentation so that we learn quickly about what actually works."[1]

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**STRATEGIC PLANNING IS DEAD**

The statement above comes from a recent posting by The Stanford Social Innovation Review, an online journal dedicated to non-profit business management. The statement calls for business leaders developing strategic plans to abandon them in favor of rapid prototyping, the underlying message being it is no longer effective to devise a 5-year strategic plan and wait to see how it goes. Rather one must establish immediate goals and act on them now since the future won't wait. Citing several examples of businesses whose markets quickly changed while they stuck to their long term business models, think Barnes and Noble in relation to Amazon, or Blockbuster video to Netflix, the authors argue for having a mobile strategy capable of rapid response and adaptation.

To do this, one must rethink strategic planning, as fat binders, which sit on the shelf, in favor of a new attitude towards a practice of rapid prototyping. Strategic planning is really just military strategy which can be described as, "…setting objectives, collecting intelligence, and then using that intelligence to make informed decisions about how to achieve your objectives, take that hill, cut this supply line."[2] Historically, intelligence was difficult to gather and relatively speaking the world wasn't a fast changing place. As a result strategic plans were effective for a great number of years.

Yet to markets and business leaders the future is more unpredictable now than ever before, as a result of technological change, climate change, and social media. The old method of devising a strategic plan based on some concrete notion of the future is dead.[3] The flaw in this old model is that the target is now moving, and just as we didn't plan for climate change 100 years ago, we can't adequately plan for a future unknown with a static plan, the implication being that the past is no longer a good indicator of the future.

As a result strategic thinking shouldn't be frozen, rather focused on the present with a strategy for being adaptive and directive, that emphasizes learning and control and reclaims the value of strategic thinking for the present world in what's termed an Adaptive Strategy.[4]

Architecture is a historically based discipline based on codes, strategy and intelligence gathering, whose strategies take the shape of plans which typically take several years to be implemented much like a strategic plan.

If architecture can benefit and more quickly adapt to contingency through prototyping, what are its historical evidence and future directions?

In many ways Design/Build pedagogy provides the perfect platform to incorporate new interactions with disciplinary thinking in the built environment. Just as the tools and conventions of representation and fabrication have begun to quickly evolve with each next service pack of software, so too can building in addressing and testing new potentials and practices.

If anything Design/build allows one to invent new couplings as the designer is also the builder, and typically there is some divorce between these two roles. As a result of this divide, architects must rely on a series of historical progressions and standards which can constrain the outcome of a design process. Design/Build offers the opportunity to operate outside the constraints of historical models, an Idea that Jan Knippers,explains as the shift "From Model Thinking to Process Design."[5] Knippers argues that the introduction of computational design processes, recasts the roles across the design team, and offers the opportunity to break from the barriers of conventional model thinking to embrace process thinking and new forms of interaction.

Knippers defines conventional model thinking, as the practice of thinking in discreet typologies, using the example of the hinged arch's calculability verses that of the cable-stiffened arch. He states that although the hinged arch is not more efficient than the cable-stiffened Arch, it has allowed an exact and reliable calculation of internal forces. So even at the end of the previous century, when the limitations of calculability was no longer an issue, nearly all large exhibition halls still use three-hinged arches. He argues that this is the negative result of Model Thinking, which defines individual models as a set of well-defined rules for the development of geometry and calculation of internal forces. Clear boundary conditions and limitations only allow for solutions within a specific framework, in other words thinking in discrete typologies.[6]

## NOT ALL DESIGN BUILD EXCHANGES ARE CREATED EQUAL

In the text "Who's afraid of Fabrication?" the author Brennan Buck distinguishes between the two types of design build programs at Yale University, one titled the Yale Assembly Project, and the other the Yale Building Project. The Assembly project acts as a counterpoint to the building project utilizing more advanced digital fabrication tools and processes while the Yale Building project utilizes conventional stick frame construction. Noting the differences in approach between the Yale ASSEMBLY Project and the Yale Building Project, the text documents the shifts in scale and priority. There exists a marked difference in that the YBP prioritizes site, program and urban issues, waiting until later in the semester to incorporate issues of detail and material generally progressing from large scale to small scale in chronology, as Buck states it, "from the apparently important concerns of site and program to the less consequential questions of character and environment." Alternately the Assembly project lacked a coherent scalar progression, "…what became clear during Assembly was a complete loss of both scalar and temporal sequence. The massing of the project was reinvented countless times as the material, detailing, or even the paint job changed." Buck goes on to refer to this state of fabricated flux as the state of "unstable interdependence."[7]

While both these programs are design build projects, one is a top down sequence of zooming in, while the other is a simultaneous series of operations which provide feedback across scales. As new prototypes are developed at small scale they influence the large scale composition of the whole. In this sense the Assembly project approaches the definition of a new strategic plan, one which privileges the prototype, not by layering at different scales, rather by deep simultaneous incorporations and integrations of the various prototypes feedbacks and vicissitudes.

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This paper presents a series of graduate courses and a resultant case study pavilion, which embodies rapid and situational design methodologies demonstrating a shift in tendencies from something static and ideal to something adaptive and reactive to prototyping, feedback and re-evaluation. Perhaps in the context of design/build, buildings can be liberated from the clear boundary conditions of discrete typological thinking through rapid prototyping and feedback, better allowing us to embrace new forms of interaction by testing what works, and adapting our frozen strategic plans by dissolving the temporal progressions of design phases across multiple scales.

Figure 1: The Unflat Pavilion assembled on site.

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## TWO PEDAGOGICAL SETTINGS FOR FABRICATION

Digital fabrication allows for design customization in the tradition of DIY, and provides a more adaptable means and methods for working with non-standard construction and assemblies allowing a more extensive interaction with materials and performance.  Whereas off the shelf components and systems approach materials from a perspective of standards, averages and mass-markets, rapid prototyping allows for the personal, the non-standard and the non repeatable.

Two graduate level university seminars, offered at the Massachusetts Institute of Technology, demonstrate two complimentary approaches towards utilizing digital fabrication as design research. These complimentary modes of fabrication each situate prototypes within a pedagogical context suggesting how Digital Fabrication functions as a model for research by combining new tools and techniques with a more nuanced approach for understanding and mediating materials and their behaviors in relation to design.

## PERSONALIZED FABRICATION

In the class titled How To Make Almost Anything, offered annually at MIT's Media Lab Professor Neil Gershenfeld teaches students how to use a vast suite of digital fabrication tools for the purpose of being able to digitally fabricate anything.

This pedagogy engages students with direct and hands on experimentation with materials and technologies that leads to developing a different type of knowledge and judiciousness.  In this class it isn't enough to simply have an idea for a design, rather the design must be fully operational in order to be successful. According to Gershenfeld, the humanist distinction between the "liberal arts" and "illiberal arts" separated the making of ideas, from the making of things, a divide which needs to be reconnected.[8]

Given the tools and support in the class, students learn many of the fabrication technologies used by large-scale corporations and manufacturers, reconnecting the end user with the manufacturing of the products themselves.  This represents a more personal relationship between user, technology, and products as a bottom up approach to innovation that Gershenfeld refers to as Personal-Fabrication.[9]

The course advances the idea of a more active rapid learning environment by what he calls just-in-time education. He states: "You can view a lot of MIT's

Figure 2: Molded plywood profiles, testing the material to find its failure point.

instruction as offering just-in-case education; you learn lots of stuff in case you eventually need it. What I'm talking about is really just-in-time education. You let people solve the problems they want to solve, and you provide supporting material they can draw on as they progress."[10] In this course the potentials of the tools and various processes of engagement with them represent a new type of capability whose feedback influences what one might design for themselves. Instead of waiting for a mass-market product which may address ones individual needs, students are asked to quickly identify a personal problem, and adapt fabrication techniques in service of their own desires. This shift in market size represents a shift in the strategic plan for addressing mass-market end users in favor of what is needed now, not what might be needed in the future.

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## SOFTWOOD

A second course titled Softwood was offered at MIT's Department of Architecture in the spring of 2011 co-taught by Nick Gelpi and Sheila Kennedy. Softwood was a workshop/seminar conceived of to reexamine wood as a material with properties ranging from hard to soft. Wood is typically something viewed as a rigid material to be used in hard applications with a disregard for the variety of soft attributes that wood possesses. 3 Soft objectives laid the foundation for the course. First the distinction between the families of Soft woods and hard woods encouraged students to look at the deep structures of wood, as not all woods are created equally. Softwoods are usually the non-decorative species coming from the Conifer family, most often used in the back-of-house applications. Typically softwoods are not exposed, but rather used as subflooring or sheathing for their performative values, as opposed to their decorative cosmetic potentials. While Softwoods are Low-cost and more quickly regenerative, the course also investigated the Soft Energy Path, a discourse articulated by Sheila Kennedy referencing Amory Lovins' text advocating a soft approach to energy consumption favoring renewable sustainable options as opposed to the Hard paths which rely on fossil fuels and ultimately nuclear power.[11] The last of the 3 Softs is the use of Software to interact with wood, articulating a shift from the hard tools and industrial equipment used to manufacture wood products towards computation and the processes of digital fabrication asking what new potentials existed across these three conceptual territories. Students examined a range of furniture projects from the 1940s-60s in which wood bending and deforming first occurred on a massive industrial scale, and looked to at how to isolate and redeploy various soft woodworking processes in a contemporary context.

Softwood asked students to reimagine larger scale means and methods based on small scale prototyping with these soft iteneraries in mind, as a type of pavilion

Figure 3: Plywood Flexure Prototype.

or system of assembly. In these cases the rapid prototype was the observed ability for wood to behave in a range of positions, and these detail observations were speculated upon at a large scale. While How to Make Almost Anything encouraged feedback of the personal type, Softwood coupled design with the feedback of various materials and their behaviors. Both types of feedback and prototyping were combined in support of the design for a pavilion project constructed on MIT's campus in the spring of 2011.

## UNFLAT PAVILION

The Unflat-Pavilion is a large scale inhabitable pavilion designed and constructed based on the observation of a certain materials ability to behave, in this case plywood's ability to flex. A small size / full scale mockup was conducted to demonstrate a range of positions for a thin plywood membrane digitally perforated and then flexed to allow flaps to open up in relation to bending. This sketch of performance suggests a material property and the range of geometries it is capable of. Great effort was taken to scale up this range of behaviors, first as small sized objects, and then again at the scale of building form. Careful observations and iterative studies led to a relative definition translated into digital form which was able to link the tangential strain relief pattern with the bent position of the membrane as something reactive. As the bent section was redefined the flaps would respond to different positions based on a relative tangent angle to the curvature of the section. As the plywood flexed the pattern would expand and allow greater transparency.

The physical flexing of material became the generator of the pavilions shape. Present from the beginning the ambition was to construct a pavilion utilizing the physical range of behaviors of a given material, privileging physics over optics. Careful study of flexing occurred at a small scale, after which the design development phase increased the scale of this behavior to the size of an inhabitable pavilion where it was merged with a familiar house section shape. Various advanced modeling and analytic software were utilized in support of the design, with an anticipation of material behavior present from the beginning.

The design and fabrication of the pavilion combines characteristics of both personalized fabrication as well as an understanding of material potential energies and techniques for capturing these behaviors. The design of the pavilion is a large scale generic house section mediated through the behavior of the material which it is constructed from. The house section was revised several times based on the physical ability to bend plywood into its shape. What results is a mediated shape, a negotiated condition blended from the specific geometry, and the plywood's ability to define that shape based on the physical behavior of material. Several times the section needed to be redrawn based on the observed bending radius of materials at various scales, and then finally at full scale based on the specific wood-species of tree used.

## WOOD IS A TREE

Materials were tested for their ability to be both flexible enough to bend and also rigid enough to support load. Indeed multiple species of woods were tested, Marine Grad Merranti, Rotary Cut Lauan, Verticle Grain-Douglas Fir, Flat Sawn-Ash, Italian Poplar, Rotary Cut-Okoume, and finally settling on Baltic Birch. Various species demonstrated a range of capabilities and behaviors. Several of the discarded species were able to bend to the shape of the pavilion, but were too flimsy to prop it up.

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Figure 4: Full scale flexing of roof peak sandwich panel for the pavilion.

Several other species were too rigid to accommodate the bending radii of the sections, so they had to be revised. Baltic birch was the most resilient, able to be bent, although requiring greater force, but also able to support load on its edge condition. All of these wood specimens look approximately the same with slight variations in grain and tone, but while they look more or less the same, they perform with radical difference. Some buckled, some sagged, and some shattered into pieces, all symptoms of specific performance unrelated to the image of the building.

In the introduction to Mike Cadwell's book, *Strange Detail*, Nader Tehrani discusses the scenario in architecture where the architect has significantly been disempowered by a divorced relationship between the means and methods of construction and the image of a building. Tehrani states,

> "The architect is charged with the design; the builder is responsible for the means and methods of its construction-as long as it remains faithful to its 'design intent'. While this legal provision may seem a guarantor of design implementation in general, it significantly disempowers the architect and presents several theoretical predicaments….First, the law effectively severs the architect from the "specific" relationship she or he can construct between the technical specification of an artifact and its corollary effect-the assumption being that the architects investment is in the image and its rhetoric, not in its constructive makeup. Second, it further problematizes the relationship between design intent and material construction…as if to suggest that any detail or any material will suffice, so long as the general effect is delivered."[12]

There is a strong argument here for forging stronger relationships between design as the production of images and actively engaging the means and method of construction by which that image is translated into reality. This pavilion takes the deformations of specific materials as its generator of shape. The flexing becomes not the representation of shape, rather a posture or a position selected from a range of possible positions which aren't flat.

Observed in the small scale mockup of flexing and bending, strain relief flaps unflattened at tangent angles to the surface, this unflattening of components occurred in relation to the flexing of the bent plywood. Likewise at the scale of the pavilion, there exists a reciprocity, where the shape of the house effects the position of the flaps as they unflatten. The plywood flaps act as structure, column, buttress, windows and vents, gaining their independent roles only as they unflatten and find their position in space.

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Compositionally and structurally the plywood skin demonstrates a role reversal across its elevation, on one end being hung on a structural frame, and on the other actually lifting the weight of the frame with its precise tangent angles to the ground, inverting the normal relationship between curtain wall and frame. The skin which is normally hung like a curtain, actually lifts and suspends the frame, rendering the support as an excess of the system. While the appearance remains consistent there is a radical difference of force occurring within the skin of the pavilion, shifting from tension to compression. Several key details were developed to reinforce this moment of Force inversion.

**ADAPTIVE FABRICATION**

The pavilion pioneers a flat to form fabrication methodology, which links the unflattening of parts to the demands of structure and shape. Individual panels

Figure 5: Unflat Pavilion exterior skin suspending the frame above the ground.

were unflattened, as part of an automated process of designing between 2d and 3d, and prepped for readiness to be milled on a computer numerically controlled (CNC) milling machine. Custom tabs and slots were designed to allow the frames to be able to capture the bending skin at various positions. These details were coordinated to be able to slip-fit together secured with minimal set screws. Of course most projects utilize details which allow for materials to cycle through their various phase states, think of expansion joints, control joints, gaskets…etc, however in these cases details are deployed to mitigate the deformative effects that the material properties may have on the ideal image or shape of the project. In this application, considerations of panel length, curvature, flap location and fastener coordination were combined into the process of design and the automation of fabrication output, with full scale behavior anticipated from the beginning by sketching with material performance. Individual sheets are fastened to the inside or outside of a frame with each side creating a double layer sandwich, connected at the edges and at the flaps. Individual sandwich panels are stacked horizontally and vertically constructing a vaulted structure and space.

### UNFLAT

As a result of preliminary mockups and prototypes, this pavilion project is different from many other projects in that it doesn't' go through the standard flattening procedure of manufacturing. Typically even complex shapes and forms are rationalized into flat planes…a process called penalization. These planes are then arranged on site to build up complex geometries, but at the scale of the panel, everything is flat. The Unflat pavilion never goes through the flattening process, in fact it takes flat material stock and pre cuts it using a combination of computer modeling and projection in space. A 3Dimensional model is built in the computer simultaneously as a flat sheet and an unflattened form. These panels come out of the fabrication lab and go directly into the field where they are literally unflattened into shape. This process is contrasted with the conventional stick framing of wood construction. As in the Yale Assembly project, the curvature of the skin produces feedback which redefines the shape of the frame and the configuration of the multiple apertures.

The pavilion is titled "UNFLAT" because it refers to the process of taking the design off the flat page of representation. Without waiting for the years of construction to see how it will perform, this design is quickly mocked up instrumentalizing behavior and performance from the beginning. The drawings are also uniquely unflat here, similar to a Hologram, where 3Dimensional information is embedded in a 2dimensional plane. Each of the buildings features, columns, buttresses, windows and vents are embedded on the flat sheet, finding their position as the wooden skins are unflattened on site.

### RAPID DIRECTIONS IN DESIGN BUILD

Prototyping provides us with a model for rapid collaboration with materials and performance. The practice of rapid prototypes and the feedback at multiple scales constitute a shift towards a new design practice which allows for adaptation and feedback as a result of the fabrication process. As contemporary practice evolves technologically and new tools of digital fabrication evolve, the very nature by which we test and materialize our designs can also shift. These rapid directions in design build are suggestive of new forms. Certainly observing the mechanical and physical properties of matter aren't all that's required to adapt to an uncertain future, but perhaps these insights into the nature of materials and the behavior of the world can help assure new collaborations between design and how we imagine the built environments we inhabit. This suggests that feedback and prototyping plays as large a role as our discursive sensibilities, and as one changes so too must the other. This evolving collaboration with prototyping does the work of fine tuning form for environment and material, and this work is the focus for understanding the new possibilities for adapting to the feedback we gain in the process of design/build which isn't ideal, rather contingent and always changing.

## ENDNOTES

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