TURNSTIJK OUTCOME A: NORTH BI-SHOT* (NORTH SHORE, BI-LEVEL, SHOTGUN)

ABSTRACT

This work presumes that integrating modeling tools and digital fabrication technology into architectural practice will transform how we build the detached house. Single-family houses come in all shapes and sizes, and in doing so, imply variation as well in certain materials, methods, and lighter classes of structure. Ultimately, houses are extensions, if not expressions, of those dwelling within, yet our attempts to produce appealing manufactured houses have prioritized standardization over variation and fall short of this ideal. Rather than considering new offerings born of the flexibility and precision afforded by digital production, sadly, today’s homebuilders are busy using our advancing fabrication technology to hasten the production of yesterday’s home.

In response to such observations, and drawing upon meta-themes (i.e., blending and transition) present in contemporary design, this study proposes a hybrid SIP/Lam framing system and a corresponding family of houses. The development of the Cannoli Framing System (CFS) through 3D and physical models culminates in the machining and testing of full-scale prototypes. Three demonstrations, branded the Turnstijl Houses, are generated via a phased process where their schema, structure, and system geometry are personalized at their conception.

This work pursues the variation of type and explores the connection between type and production methodology. Additional questions are also raised and addressed, such as how is a categorical notion like type defined, affected, and even “bred”?

RICHARD AECK
December 2007
Everything made for the greatest number is ugly, dreadful, misleading, and fraudulent. That’s what I think is so serious. They want anything at all as long as it looks like something they know.

Jean Prouve

Charles had clearly learned that if you were designing for mass production, you had to discover how to make the tooling - not just the end product - yourself.

Eames Demetrios

Shall I call that wise or foolish, now; if it be really wise it has a foolish look to it; yet, if it be really foolish then has it a sort of wiseish look to it.

Herman Melville

Idealism is a contemporary form of hope. The future is the projection of the past conditioned by the present.

Georges Braque
To Erin Lindley
ACKNOWLEDGMENTS

In addition to the Thesis Committee, many have contributed to my education and creative efforts over the years. For this I am deeply grateful, and would like to thank Nathalie Lewis, Robert Bricker, Monica Ponce de Leon, Nader Tehrani, Franca Trubiano, Tristan Al Haddad, Russell Gentry, Alathanossos Economou, James M. Hull Jr., Karl Brohammer, Leonard Lowrey, Vishwadeep Deo, and Richard Taylor (II & III), all of whom have played important roles.

Also special thanks to my family, Antonin Aeck, Frank Hull, and Molly Aeck.
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INTRODUCTION

This work presumes that integrating modeling tools and digital fabrication technology into architectural practice will transform how we build the detached house. Single-family houses come in all shapes and sizes, and in doing so, imply variation as well in certain materials, methods, and lighter classes of structure. Ultimately, houses are extensions, if not expressions, of those dwelling within, yet our attempts to produce appealing manufactured houses have prioritized standardization over variation and fall short of this ideal. Rather than considering new offerings born of the flexibility and precision afforded by digital production, sadly, today’s homebuilders are busy using our advancing fabrication technology to hasten the production of yesterday’s home.

In response to such observations, and drawing upon meta-themes (i.e., blending and transition) present in contemporary design, this study proposes a hybrid SIP/Lam framing system and a corresponding family of houses. The development of the Cannoli Framing System (CFS) through 3D and physical models culminates in the machining and testing of full-scale prototypes. Three demonstrations, branded the Turnstijl Houses, are generated via a phased process where their schema, structure, and system geometry are personalized at their conception.

This work pursues the variation of type and explores the connection between type and production methodology. Additional questions are also raised and addressed, such as how is a categorical notion like type defined, affected, and even “bred”? 
PART I – TYPE TO MASS CUSTOMIZATION
CHAPTER 1 | TYPE, PROPERTIES, AND SCHEMA

Webster’s Dictionary states that distinguishing type depends on “the morphological, physiological, or ecological characters by which relationships between organisms may be recognized.” This is a common approach, known as “taxonomic essentialism,” that may be traced to Aristotle’s hierarchy (genus, species, individual), from which the empirical resistance to classical idealism was derived. It is a reasonable place to begin a discussion of type, because it conveys the internal-external division involved and suggests that type is discernable through the systematic collection of properties. Even so, we should keep in mind that the biological analog is not wholly adequate for architectural purposes, because it assumes an a priori organic relationship between internal morphology and external form. Our architecture, unfortunately, does not naturally grow and must undergo an atomic transformation as it moves from idea to its physical realization.

For some necessary introductory terminology, we turn to American philosopher C.S. Peirce who contributes to the discussion a crucial distinction between object types,

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tokens, and instances. Of this, William Mitchell explains that, “a token instantiates or is an instance of a type.” Nearby, he adds that tokens are “unique physical entities that we find located at a particular place at a particular time. Tokens may be of the same type by virtue of having something, for example, shape, in common.” The significance of this is the separation of actual occurrence from category (i.e., types), and most importantly, again, that membership in the category depends on shared properties.

As our preliminary objective is to understand type more clearly in order to begin to conceive its variation, a closer look at the specifics of its formation is required. William Mitchell’s characterization of the “basic empiricist assumption” offers some further insight into this:

_Type is an abstraction formed by dropping details which vary idiosyncratically from one exemplar to the next and retaining only the residue of commonality._

What Mitchell describes is a procedural distillation during which the selection and omission of properties define type. The “abstraction” part is particularly pertinent to the diagramming exercises to come, but the phrase “residue of commonality” is rather vague and poses some immediate difficulties. Questions of this statement immediately abound, such as how during the stripping away of variation does a linkage become apparent? Additionally, how is a definition stated or recorded, and in what way are comparisons made between types? These are all valid (and anticipated) concerns; however, the notion that we define type through some kind of systematic reductive process is very misleading and must first be addressed.

If we realize that with “residue of commonality” Mitchell is also referring to shared properties, things finally start to become a clearer. In turn, we may recognize that the identification of common properties is actually a positive process and is not a reductive

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6 Ibid, p. 98.
7 Ibid, p. 94.
act. This is a crucial observation because it reveals those properties not shared between type tokens as a source of variation. Supporting this, a statement from E.H. Gombrich contests Mitchell’s suggestion that the varying details are simply “dropped” during the type recognition:

The principle of sacrifice admits and indeed implies the existence of a multitude of values. What is sacrificed is acknowledged to be a value even though it has to yield to a value which commands priority.8

Sir Gombrich’s phrase, “value which commands priority,” is meaningful because it clearly insinuates that some ordering of properties exists for type. In addition to type’s dependence on common properties, we now also know that there is a structure to them. This raises the issue of the need to distinguish between essential and accidental (or non-essential) properties, to which the concept of the absolute essence is bound.

Within the discipline of architecture, two figures are commonly used to introduce the dialectic of essences: Marc Antoine Laugier and A.C. Quatremère de Quincy. The former is known for his deliberations on beauty, and his anecdote about the prototypical “primitive hut,”9 which for him was a universal architectural prototype. The essence of a type, according to Laugier’s methodology, is revealed by distinguishing between those parts that are “introduced by necessity” and those “added by caprice.”10

The latter, Quatremère, saw a difference between a model that is “exactly” imitated, and a type, with an “elementary principle” that is “more or less vague” after which we “conceive works which do not resemble each other.”11 Such thinking implies variation about some fixed point, and in both cases, the essence is understood as intrinsic to the nature of the token.

11 Quatremère de Quincy, A.C. “Type” In Dictionnaire historique d’architecture. Paris: Librairie d’Adrien le Clere et Cie., 1832, p. 629.
Immanuel Kant, takes different route, eschewing the notion of absolute essences and using the term “schemata” (singular: schema) to define the conditions for the existence of a type. Below, he prescriptively situates the verbal schema relative to its diagrammatic representation:

\emph{In truth it is not images of objects but schemata which lie at the foundations of our pure and sensuous conceptions.}^{12}

Rather than adopt Kant’s rigidity, we will opt for a looser interpretation where “schema” is used when stating the necessary conditions for a type’s existence, and to verbal or diagrammatic representations of said conditions. The principal difference between Kant’s relativist mode of operation and an absolutist approach is, as Mitchell tells us, “properties are of the same basic kind, and what we take to be of the essence of something depends on our interests of the moment or the quirks of vocabulary.”^{13} This is a linguistic argument against essences, which suggests type is a function of what has been stated or defined outright. In this modality, a number of conditions can be specified for the existence of type and the accidental vs. essential divide is purely nominal, and not defined by nature. As the work presented here involves organizational logic, topology, and is heavily reliant on virtual means of representation, a relativist approach was favored over the absolute.

By now, if has been well-enough established (or belabored) that type recognition depends upon common properties, this is sufficient to begin speculating about how we may consciously create variation. With all the talk of essences, or schemata rather, how can we help but think of these as attractive targets for manipulation in the name of variation? If the schema is the highest-level property of type, as in the relativist modality, operations performed upon it (…or them) should presumably yield the most dramatic results. In particular, at issue is: To what extent does type endure if non-schematic properties are manipulated, and what results when schemata are combined?

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To set forth explicitly the Neo-Kantian convention used in this work, three elements are consistently presented whenever defining type. These are the (1) verbal schema, (2) its associated diagram, and (3) a programmatic quantity. It should also be emphasized that although both the program and the schema are both essential properties, only specific propositions are treated or referred to as *schemata* in this work (e.g. a house must have program generally). For the sake of clarity, all that is vital before moving on is to arrive at a conceptual understanding of type as a *category*, i.e., a metaphysical construct based on the conjunction of shared properties, whether these are logical, physiological, morphological, organizational, or otherwise. In this way of thinking, type is categorical, may have some hierarchy of properties, is mind-dependent, and exists in abstraction.
Though useful for establishing a critical language, we should remain aware that typological thinking is a top down approach. Philosopher Manuel DeLanda cautions us of the shortcomings of taxonomic methodologies and additive essences saying, they “will obviously not account for emergent properties since the latter, by definition, is that which goes beyond any simple addition of parts.”\textsuperscript{14} This emphasizes for us that the relationship between type and its properties is not linear (i.e., type is not exactly the sum of its properties). In his most recent work, DeLanda introduces a new term into the fray stating that, “capacities do depend on a component’s properties, but cannot be reduced to them since they involve reference to the properties of other interacting entities.”\textsuperscript{15}

This last quote is evidentiary of a theme, the connection of properties and capacities, first encountered during 2006 Uniformity & Variability symposium at Georgia Tech. There, the example of a knife was discussed and an argument made connecting the material’s properties to its capacity for sharpness. The key point being that it was the metal’s capacity to hold an edge, and not simply that it is metal or a knife that allows the variation. Elsewhere, and discussing a knife, DeLanda states, “what matters from the philosophical point of view is precisely that toughness or strength are emergent properties of a metallic material that result from the complex dynamical behavior of some of its components.”\textsuperscript{16}

Such thinking, considered in the context of our discussion of type, leads us to the epiphany that there may be more involved in variation than simply the manipulation of non-schematic properties or operation upon schema themselves. It is increasingly the case that advancing technology is playing a role in the conscious production of variation.

\textsuperscript{15} DeLanda, Manuel New Philosophy of Society. 2006, p. 11.
To describe the houses proposed by this work in DeLanda’s terminology, one of their properties is that we make them on and by equipment that has a greater capacity for precision than has existed before. More specifically, this increase in capacity facilitates the affordable cutting of curves, something that previously required patterns, patternmakers, or some other sequence of elaborate steps and/or tools (e.g., French curves in drafting). In the case of the Exercise 3, this increase in capacity allows the articulation of the structural seams to such an extent that literally every piece of the house becomes unique. Although many of the pieces are self-similar, no two are actually identical - this is true at least for those located within doubly curved portions of the structure. This geometric variation is literally mass customization, which again, is possible because how the houses are made is itself a property whose capacity for variation has increased.

More than a local revelation, this kind of causal explanation draws on Assemblage Theory, as reconstructed by DeLanda, where entities previously conceived to be heterogeneous nests of instances are now wholes. To quote DeLanda, “Entities ranging from atoms and molecules to biological organisms, species, and ecosystems may be usefully treated as assemblages, and therefore as entities that are products of historical processes.”¹⁷ This thinking, developed from fragments of Gilles Deleuze and Felix Guattari’s work, speaks directly to the connection between production methodology and variation. A quote from their A Thousand Plateaus may help to clarify things further.

*Take the example of the saber, or of crucible steel. It implies the actualization of a first singularity, namely the melting of iron at high temperature; then a second singularity, the successive decarbonations; corresponding to these singularities are traits of expression [like hardness, softness, and finish]… We may speak of a machinic phylum, or technological lineage, wherever we find a constellation of singularities prolongable by certain operations, which converge, and make the operations converge upon one of several traits of expression.*¹⁸

In Deleuze’s terminology now, digital production methodology relating to houses is a “singularity” of the assemblage. The houses are part of a “machinic phylum,” and as such, all assume a specific technological lineage . . . one that is digital and whose trait of expression is precision. This precision is (bear with me now), a property of a singularity and is where the increased capacity for geometric variation comes from. This however, is also not the only such trait being expressed.

Architect Bill Massie identifies another when he states that “advances in electronics and computer processing found in CNC technology allow us to move from computer model/computer drawing to built form. This technology […] eliminates the distance between virtual architectural hypotheses and the physical test of construction.”

Back with DeLanda, what is going on here is by virtue of proximity, we have naturally begun “tapping into morphogenetic capabilities in the process of producing.” This affirms Massie’s thinking, and suggests that both material properties and software will play greater roles as the architect evolves to become part fabricator and part process engineer. It also causes us to consider the architect’s facility with the new equipment in terms of capacities. Depending on one’s view of the state of the profession, or rather, the new generation of practitioners themselves, this is cause for celebration or for alarm.

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CHAPTER 3 | HOUSE TYPOLOGY

The detached house, itself a typological category, contains familiar types like the ranch, the split-level, the duplex, the bi-level, and the shotgun shack. Nominal differences aside, many commonalities exist between these groupings such as material (wood), framing method (balloon/platform), structure class (sheathed frame), location (suburbia), and even cladding technique. We should not, however, just interpret by default these shared properties as prerequisites, for they are not all schemas for the type. As we start to differentiate the types mentioned above, perhaps the most meaningful distinctions can be made about the organization and quantity of program.

Figure 3.1 The Shotgun

The Shotgun

Let us consider the example of the shotgun shack (“shotgun” hereafter), a house typology tied to mill-towns and early twentieth-century industrialization. These houses are famous for one extremely simple detail - an occupant could conceivably stand on the front porch and fire a shotgun down the straight hallway through to the backyard. Whether its “shotgun” moniker came from the difficulties of policing the mill neighborhoods, or from workers returning home to catch their spouse’s lover fleeing through the rear door will not be resolved here. Whatever the case may be, these curious elongated houses possess the simplest of schemas: straight circulation.
Quantitatively, they also typically had one bedroom, a common room (frequently doing double duty as the second bedroom), and a kitchen and bath grouped together in the back (1 BR, 1 BATH). Prior to air conditioning, the narrowness of the house had the practical advantage of aiding ventilation. Other factors, from the shape of a subdivided lot, to the ease of extrusion of an orthogonal framing system, may also account for the straight, single-loaded circulation of the shotgun. Each of these factors is circumstantial, but may be argued as having influenced its initial development. Either way, this vernacular structure clearly illustrates the schema, and again raises the issue of a hierarchy to the properties of type.

It can be problematic to consider the schema within the context of architecture because the organization of space has historically been plan-driven. Among other things, this seems to have precipitated an overly-topological, two dimensional understanding of it. For most people, “schematics” are synonymous with plans and any distinction made otherwise is trivial at best. From the vocabulary of practice, the first phase of project delivery known as “Schematic Design” certainly involves plans, but does not refer to them exclusively. With this, and the work to follow in mind, “SD” might more effectively summarized as the first effort to represent the idea to scale. As a deliberate affront to strictly planar or “flattened” interpretations of the term, the level-changing schema has been included in the Turnstijl houses (see Exercise 2).

Types Compared

Beyond the shotgun, the initial survey of house typology included two other types selected for their contrasting schemata. Split-level houses have a level-changing schema (mentioned just above), and the first-level property of duplexes is their two-program schema. Figure 3.2 below illustrates the comparison between their quantitative properties and typical plans. Occupying the gray area, at this scale, a duplex arguably qualifies as a detached house because “single family” and “detached” are not synonymous. (…this would be harder to claim for a Triplex.) For brevity’s sake, the anecdotal histories of the duplex and split-level have been omitted, but may it suffice to say that the differences in their organizational logic are the significant schematic
properties that need to be recognized. The convention used in Figure 3.2 appears again in diagrammatic form in Figure 8.2 to serve as the starting point for an inventory of sub-types.

**Figure 3.2 | Program Quantity & Schema - Aeck**

**Framing**

Depending on the age of any instance of the three types just mentioned, usually one of two basic framing typologies are encountered - either balloon or platform framing. Popularized during westward expansion according to Giedion, the balloon frame developed prior to the standardization of lumber dimensions, and before improvements in fire regulations required blocking.\(^{21}\) As shown by the representations of each in Figure 3.3 below, the continuity of members relative to the intermediate floor is the most obvious difference. A more subtle difference between these two exists in how each is sheathed (not shown). The development of plywood hastened the obsolescence of the

\(^{21}\) Monteyne, David: JAE “Framing the American Dream” 2004 p.24-31
diagonal non-structural “board-sheathing” used in balloon framing. By comparison, a 4’x8’ sheet of plywood performs the same task in the platform frame but is structural. The plywood’s advantage of rapid application eliminated the need to inset dimensional lumber as permanent lateral bracing having made this redundant. Today, workers affix diagonal studs temporarily to the bents before the sheathing is applied, and once the sheathing is complete, the workers remove the diagonal studs.

These observations are meaningful to this research because technically what we actually have are actually two classes of structure. The balloon frame pictured is a “braced frame” structure and the platform frame pictured is a “sheathed frame” (a.k.a. shear panel) structure. Put another way, as the result of technological innovation, the popular wood framing typology changed states from one structure class to another.

While there may be little meaningful difference at this scale in structural performance between “braced frame” and “sheathed frame” structures, the platform is recognizably

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22 Ibid, p. 25.
easier to assemble and therefore better suited to its task. In addition to the tedious board sheathing, the need to cut and install blocking at the floor joists was another repetitive task that doomed the balloon frame. From this, we recognize that ease-of-assembly is a significant elephant in the room when considering alternative framing systems - especially ones involving self-similar, but unique parts.

These six images in Figure 3.4 illustrate some common classes of structure, most of which are either discussed or referred to within this work. This mode of representation occurs from this point forward when representing structural class graphically or verbally.

Figure 3.5 below represents a comparison of two framing typologies based on material, structure class, span, and system proliferation. In contrast with the wood platform framing system, the metal framing system has a greater spanning capacity, but a reduced capacity for subdividing space. Literally modeling each framing typology in detail served as a crash course in the assembly and proliferation of each. The inability to modify the radius of the Quonset’s stamped sheet is a constraint tied to its production, and unlike the platform, does not lend itself to field modification. The typical effect of this constraint is that a second class of structure is used when to partitioning, or otherwise dividing the space within. A simple example of this occurs in Figure 3.5, but it
may helpful to think of the office in an automotive garage or a supervisor’s booth at a factory.

Such observations aid in the realization that classes of structure have radically different capacities based on both their material and tectonic properties.

A further example of how a framing typology’s tectonic capacity to order space influences type is shown in the center-right row of Figure 3.5. Here, the platform frame easily extrudes for the shotgun and slides past itself on both X- and Y-axes to create different size spaces and change levels. Observing the metal system’s comparative deficiency at both, it is not such a leap to infer its connection to the emergence of split-level houses. To accommodate a similar level change using the balloon frame, a builder would have to create notches on both sides of a continuous member, or most
inefficiently, have a redundant member. The former technique is inferior because of its difficulty, but also because it causes weakness if the notches are local to one another.

Figure 3.6 | Wartime Framing Systems

Figure 3.6 shows a familiar metal framing typology commonly associated with both World Wars. Engineered in Canada originally for the British government, the Nissen hut served as a model for the U.S. Military’s “T-Rib Quonset.” The principal advantages of the structure were that it could be assembled "in 1 day by 10 men," and “it came in 12 crates” and “required no special skills to erect.” In hopes of redistributing labor off site, the proposed system depends upon more pre-assembly where workers make tube-to-tube connections on site. The George A. Fuller Co. and Stran-Steel were the corporations that held the military contracts, yet to this day the name “Quonset” has endured and serves as a catchall for similar such systems. The name “Quonset” refers to the location of the production facility at Quonset Point, Rhode Island that came to serve as a kind of ad hoc brand. Rather than allow the branding to evolve naturally, the development of the branding for both system and product has been considered integral to the task.

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26 Ibid, p. 2.
There is a striking amount of variation in the design, application, and production methodology of the arched-metal structure during wartime. These structures served at many scales from barracks to blimp hangar. In a particularly divergent case, Frank Hobbs designed the all-wood “Pacific Hut” in response to metal shortages and to the tendency of metal Quonsets to corrode in tropical climates.\(^{27}\) Of anyone, perhaps Hobbs would most readily agree that the metal house, as will be seen with Prouve, Fuller, and Strandlund, is something that only the military will ever really love.

Structurally speaking, the Nissen and Quonset huts were corrugated metal panels supported over a steel frame; however conceptually and formally, similar long-spanning metal “surface structures” exist where the articulation of a single skin is the only structure. A famous, but atypical example shown below, the Orly hangar has a corrugated surface structure made in precast concrete.

![Figure 3.7 | Orly Hangar](image)

Home from the battlefield, but relevant structurally, Frank Lloyd Wright’s Usonian houses used a structural panel consisting of three layers of plywood though they were not insulated otherwise.\(^{28}\) A further derivative structural classification closely related to the “surface structure” is the “stressed-skin panel,” or with insulation, the Structural Insulated Panel (SIP).

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“SIPS” as they are most often called, emerged in the interwar years and predate Gropius’s General Panel. Alden B. Dow, son of the founder of the Dow Chemical Company, experimented with SIPS under Wright, later lamenting their omission from the Usonian Houses just mentioned.

Typically, a SIP is 1/2” to 5/8” Oriented Strand Board (OSB) with either an Expanded Polystyrene (EPS) or Urethane core. In the U.S., SIPS are available from an ever-increasing number of manufacturers; some the most well known are Winter Panel, R-Control, Premier, and Fischer. Regardless of brand, all of these competing entities use mechanized means to cut “custom” panels (meaning two-dimensional and not square in profile). Despite having already integrated CNC equipment into their production streams, manufacturers have not translated the capacity of this equipment into a next generation product.

This may be in part due to procedural issues. The EPS block used for the core of the panels is typically either cast first using Expanded Polystyrene (EPS), or Extruded Polystyrene (XPS). After creating the core, the OSB faces are pressure-laminated after the application of adhesives. A bonding agent, rather than the natural adhesive properties of the curing foam, is used to attach the OSB facing after the foam has

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cured.\textsuperscript{30} As such, the foam always comes first, and these systems do not break from this established constraint. To whatever confluence of factors this may be attributed, to date, industry focus is on competing with established framing typologies, or as SIP manufacturers tell it, on “replacing the platform frame.”\textsuperscript{31} At risk of putting the cart before the horse, casting foam, rather than plating pre-cast foam plays a significant role in the offerings to come.


\textsuperscript{31} Ibid, p. 3.
Standardization

The postwar housing boom yielded a wide variety of proposals from the likes of architects, engineers, fabricators, and some less merciful entrepreneurs. Out-producing the enemy had just won the war, and in turn, it is no great surprise that an industrial strategy would be put forth to resolve the housing crisis. Aside from innumerable differences in origin and detail, the efforts below all employ the now-familiar “Fordist” methodology of standardization and mass production in their attempts. An irresistible quote used by Kieran & Timberlake when critiquing mass production, Henry Ford is famously to have said that “you can have any color as long as it is black.”

Figure 4.1 | The Packaged House (none made) - Gropius & Wachsman

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Walter Gropius and Konrad Wachsman formed General Panel (GP) Corporation in 1946 with a loan from the Reconstruction Finance Corporation (RFC) - the government sponsor of their collaborative work. The image shown above in Figure 4.1 is from 1942 and represents their initial collaboration. A subsequent effort, the Growing House, allowed for unlimited growth in its plan, yet this “open proliferation” lacked flexibility and was strictly orthogonal.

Encumbered by both political and personal issues, delays mounted and the effort “ceased to function” in 1950 with the expiration of the contracts with the Veterans Emergency Housing Program. There is currently a General Panel Corp operating, but it has no advertised lineage relating it to Gropius’s defunct one.

Mass production raised upon pilotis, Prouve’s inclined axial windows are more than we get from the duo of Gropius and Wachsman. Apart from looking vaguely like subway cars and an over-reliance on metal (forgiven as he was a blacksmith’s apprentice initially), Prouve had much of it correct. Because of the sheer volume of his work it is

Figure 4.2 | Maisons Meudon (25 made) - Jean Prouve

unfair to represent Prouve with one image. This is especially so, as the Muedon houses are just a part of a persistent string of interrelated prototypes. At Atelier Prouve, variation was the mode (especially in section) and for this reason that an inventory of his prototypes and diagrams is included in Appendix A.

Figure 4.3 | Wichita House (2 made) - Buckminster Fuller

Truly visionary, “Bucky” Fuller is a geodesic spaceman of the atomic era, the Wichita House is literally a Beechcraft airplane turned into a house. The form recalls a molten aluminum droplet, looking as if an Airstream trailer has just fallen from of the sky. The Wichita has high-embodied energy, radial panelization, and epitomizes the machine in the garden.

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All surfaces inside and out of the Lustron houses have a porcelain-enamel coating; the color of this coating changes *sometimes*, but mostly it chips just enough for the visible metal to rust and streak. Industrialist and inventor Carl Strandlund began by manufacturing gas stations, and he produced the Lustrons from a plant in Columbus, Ohio.

In 1948, Strandlund began delivery of 1,800 Lustrons (of the 2,560 total) to Quantico, Virginia, however would eventually file for bankruptcy protection in 1953.37 One unforgettable quote from a experienced fan states that living in one was “like living inside a lunchbox.”38 The recent documentary from architect-historian Bill Ferehawk takes a swipe at the Lustron with the tongue and cheek title: “Lustron: The House America’s Been Waiting For.” For those in the Atlanta area, an aging Lustron with the exact color scheme shown above sits on Northside Drive 2 blocks north of Interstate 75.

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The Levittown Houses built in the mid-twentieth century feature significant variation in plan topology and quantitative program . . . and are thankfully not metal. Over the years, Levittown’s inhabitants have gone about their additions and renovations in such diverse ways that the most meaningful variation has actually occurred post facto. In those built after 1950, a TV set (12.5") was included in the space under the living room stair. Deployed in bulk like the Lustrons, the Levittown Houses are located at a former potato farm on Long Island outside New York City.

With the exception of the Wichita House, these are all what Robert Kronenberg calls “demountable buildings” that are “transported in a number of parts to the site” and “may be further divided into deployment categories.”39 This terminology is important because prefabrication, a property of each house shown, does not necessarily imply a portable structure. The association of prefabrication with mobility is partly to blame for many curious proposals where privacy and, partitions have been flatly dismissed. During the sexual revolution of the 1960s, such programmatic leaps in reverse might have played well, as pneumatic houses even did for a bit.

Laugier himself might approve of such domestic primitivism, but he too would grow weary of the parade of huts, yurts and igloos that continue to be proposed.

It is in reaction to our tendency to test our prefab ideas on the pod that the houses presented in this work eschew the tradition of portability and are not portable capsules for the American dream. The Turnstijl houses are happily static, demonstrating how custom prefabrication does not have to so thoroughly mobile as mid-century prefab was. Although the pre-assembled components are not quite “grand blocks” on “the goliath scale of shipbuilding,” they do come in “chunks” just portable enough to be brought to you.\textsuperscript{41}


Admittedly, some of the best of these mid-century efforts did move a few thousand units, but the real legacy of the factory-made house is inexorable from with the now-apparent shortcomings of Modernism. Traditionalist Stephen Mouzon captures this sentiment in a chapter appropriately titled "Story of Languages of Arch."

*Modernist architecture on the other hand, has always been focused on the machine. Much of the idealism was based on the notion that mass produced buildings would save the world’s working classes from their perceived miserable existences at the time by providing cheap, quickly produced housing. The actual buildings were based more on the aesthetic of mass production, which is a crucial difference. The only manifestation of true mass produced buildings is the ubiquitous mobile home, which might therefore be considered the highest form of Modernist architecture.*

Begrudgingly, a degree of what he says is sadly true - the “singlewide” and “doublewide” are the most prolific manufactured houses of our time. When observed by most, these are not at rest, but are polyethylene-clad on the way to a KOA site somewhere.

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My habitual digression aside, Mouzon accurately identifies that rooted within the recurring dream of prefab is the fallacy that some universal system may rescue us from more helpings of the same. A physical manifestation of this same ideal, appropriately named the “Universal Joint” was used in General Panel partitions and is a quintessential artifact of standardization – due to its maximum complexity and minimum impact. As much as we agree with the characterization that the dream of the manufactured house can “be the silver bullet that solved social problems by providing quality affordable houses for the common man,” we must adjust our tactics for the present. It is, rather, that this dream remains valid, but the aesthetic and basic modularity of Fordism that has been proven unsound.

Mouzon’s usage of the mobile home to lament Modernism reveals his avarice, but the real foes he should be engaging are mass production and the production methodology of that era. In fact, the commercial success of such inferior products is proof of nothing if not healthy demand! Avoiding the wonton historicism Mouzon would likely espouse, it seems more worthwhile and productive to spend time on where we are heading. The reasoning behind this being that the potential of digital production methodology and mass customization cannot be lumped in with past results, and this tandem is due their chance to shine. At the advent, it already seems unlikely that they will yield the same aesthetic objections, for they deliver only variety and form in places where only uniformity once reigned.

CHAPTER 5 | DIGITALLY MANUFACTURED HOUSES

If the studios of architecture schools (from Columbia and Yale to Georgia Tech and Texas) are legitimate leading indicators, there has been a resurgence of interest in the manufactured house lately. The Sears & Roebuck catalog is, of course, no longer the venue and has been supplanted by the internet. Prefab fan sites that rank, collect, comment, and publicize the efforts have sprung up (e.g., prefabs.com, fabprefab.com, and inhabitat.com to promote some of the best). Beyond academic speculation, this is actual competitive behavior whose observable excess is more than just another passing trend. The myriad of offerings, in fact, echoes, rhetoric issued over a decade ago by B.J. Pine.

\[\text{In this new frontier, a wealth of variety and customization is available to consumers and businesses through the flexibility and responsiveness of companies practicing this new system of management}^{45}\]

Although Pine directs this quote from 1993’s *Mass Customization* at the corporate community, it emphasizes that the burden of “responsiveness” lies with the producer. Indeed we now have “prosumers” (a term Pine coined to describe a more participatory consumer) seated at their PC, but they must be activated by the product being offered.\(^ {46}\)

From the point of view of the producer, this breed of consumer can only exist if the variability of a given offering is sufficiently integrated with production to enable the prosumer’s behavior.

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46 Ibid, p. 194.
One of the most well known, but woefully mid-century, of the contemporary prefabrication efforts is Flatpak. Named for its shipping method, it uses the 4’ x 8’ and 4’ x 4’ panels as its primary modular component. Generally, these houses feature less metal, more wood, and may be more fairly characterized as being a revisionist take on the modernist aesthetic. The debt in spirit to the Eames’ Case Study No.8 is obvious, but there are in fact some significant originality including a site-cast concrete base and the sales methodology via the elaborate animations on Flatpak.com, to mention a few.
In stark contrast with Flatpack, the Embryological House (Figure 5.2) creates brand identity through the global formal variation and local variation of the “shredded” skin. In the prologue of Architectural Laboratories Lynn states that “no two houses are ever ‘identical’ and that there is no “ideal or original.”47

Nearby Lynn issues a specific critique of Modernism saying that “the banal Modernist notion of generic housing involved the invention of a mass-produced existence minimum structure to which customizations, additions, modifications, or alterations could be made by the addition of parts of components.48 Such thoughts emphasize how individuality does not have to be purely an additive act, and may result from intentional variability that is built-in.

Figure 5.3 | Parish House - SYSTEMadarchitects

The Parish house was conceived via an iterative process using a lasercutter, featuring slotted prefabricated parts and an exterior envelope of plywood stressed-skin panels. Wartime opportunism and housing shortages drove the midcentury round of prefabs; hurricane Katrina, flood insurance premiums, and long hours in SketchUp (a guess), drove this one.

48 Ibid, p. 12.
Stephen Holl’s Turbulence house is a slightly crinkly example of custom prefabrication used in a residential application. It is a 900 square foot guesthouse in aluminum (i.e. not wood) and was erected in only six days from 24 stressed-skin aluminum panels.

Bill Massie’s Big Belt House (Figure 5.5) was cast both on and off site using both milled-foam forms and machine-scored OSB formwork. The house’s name is derived from the interlocking precast ribs (the principal prefabricated element) whose detail recalls an extruded jigsaw puzzle piece or belt clasp. The impressions left by the machined foam on the sink, and the form ties on the beams adorn the surfaces of the concrete castings. Throughout this field of contemporary precedent, we find the architects using pre-assembly and digital fabrication technology to achieve customization. With the exception of Lazor Office (Flatpak), each architect has also chosen to update the form. Lazor’s take is probably more fiscally realistic, and is not as much of a “one-off” as some, but it does not take sufficient advantage of the assets of modern production methodology. Having what Ulrich and Tung would call “common components” with only “bus modularity,” Lazor Office simply fails to engage the same challenges as the others.50 A harsher admonition of this behavior is offered in the Atlas of Novel Tectonics, which best articulates the architectural tendency to update the theory and not the product.

*The Apologists for Modernism [...] are in grave error. In their minds the shifting paradigm is simply yet another shift in discourse, it doesn’t affect the object, and the object has no effect on it.*51

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A new book on mass customization, Growing Modular, examines the popularization and development of Mass Customization following Pine’s 1993 book. In the preface, author Milan Kratochvil offers some complimentary how-to advice.

*The fast lane to mass customization of complex offerings is the definition of modular product packages, and their subsequent configuration on demand, to fit customer specific needs. This approach is usually called Configure-to-Order.*

Beyond instruction, these words also serve to remind us that the term mass customization really describes an effect and is not, itself, a specific strategy. Above, only Configure-to-Order is referenced, but later in the work Kratochvil discusses two other conceptual strategies for achieving customization. In Section 2.2, he details all three: Assemble-to-Order (AtO), Engineer-to-Order (EtO), and Configure-to-Order (CtO). These first two approaches are relevant to the extent that they resemble delivery strategies already familiar to the architect, i.e., mass production’s standard component modularity, and closer to home, the Design-Bid-Build project delivery method.

Without going too far into each (since you’ve made it this far), Assemble-to-Order (AtO) uses “standard level components that are pre-assembled to form large, high-level components. Consumer choice is usually restricted to a limited predefined set of product lines.”53 One example given is the car, in which “variance is kept small” causing us to recall Lynn’s objections about the limitations of strictly additive systems.

Of Engineer-to-Order (EtO), Kratochvil states that “cost and time estimates are kept hazy” and that many components are developed specifically for an order with little pre-

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assembly. The variant finally delivered is the result of a full-scale project."54 The hazy costs and deadlines sound a lot like the controlled-disorder of architectural projects, but the examples Kratochvil gives are vessels, defense systems, offshore platforms, and software packages - all items on a grander scale than houses.

Finally, of Configure-to-Order (CtO), Kratochvil asserts, “this concept uses components, often with some pre-assembly, and with variance built into the product, usually at the last steps of the production and deployment process.”55 The name, he says is meant to imply that we should “compete by customization, rather than trying to struggle with it.” At first glance, this kind of flexibility seems achievable for small-scale products (e.g. personal computers or cars), but can such a strategy operate at the scale of architecture? The systematic customization of a house seems a reasonable place to test such ideas. In any case, these are still just sweeping conceptual guidelines, so how exactly can we build variability into a house?

The short answer to this is modularity, but it is a more complex and diverse modularity that the mid-century prefabbers conceived previously. Early on, Kratochvil makes the delicate point that “product customization can be achieved through methods that range from ‘one of a kind’ design through to the adaptation and modification of a standard product to meet a specific customer’s needs.”56 In Section 5.6, he continues the discussion of different types of modularity and includes three different systems of classifying modularity, which may be found in Appendix D.

Looking at these attempts to parse modularity, we realize that our task is to debase the typical pluggable-swappable, or as he calls it, the “Lego Generation’s”57 interpretation of modularity. This can be translated into a preliminary design question, i.e., must modularity always, as the Lego implies, be a unit of construction?

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56 Ibid, p. 5.
PART II – PELIMINARY EXERCISES
CHAPTER 7 | TYPE DEMATERIALIZED

Now with a deeper conception of modularity in mind, we return to the shotgun and its properties, which we have already discussed at length. If one of its properties (i.e., material) becomes modular, how does this affect the type as we know it? If a straight single-loaded circulation schema is considered the only ontological (or essential) property of a type, will maintaining it alone be enough keep it seated within the category? If so, how far can we go? The following three figures show a typical shotgun where material is treated as a non-essential property that may freely modulate. These wood, metal, and plastic shotguns have, though only in a limited sense, been “Configured-to-Order.”

Exercise 1: Materially Diverse Shotguns

Figure 7.1 | Plywood Shotgun - Aeck
These "materially diverse" shotguns demonstrate type's resilience as well as the potential of reviving past types. The variation produced here is non-typological however, and the question of whether the increased capacity of new production methodology will yield its own unique schemas remains.
At this point, it is also important to recognize that much like production methodology, materials are undergoing a technological revolution of their own. The running theme of increased capacity allowing variation is also applicable to them. As an example, the forming that would be required to make figure 7.3 would certainly be inconceivable without thermoplastics. Just for a moment imagine a Bakelite shotgun, the only polymer that approaches that house typology’s age. To explain these three figures in terms of their structure class, the first shotgun remains a foam-filled “ribbed shell” throughout, while the second two figures show a state change from “sheathed frame” to corrugated “surface structure.”
The Turnstijl Houses have their own branding; the first part *turn*, refers to change, and the second, *stijl*, to their departure from the planar constructivism (think Schroder House) characteristic of early modernism. The neoplasticists were one of modernism's primary theoretical influences, and thus the reference to de Stijl (the style) in the branding. In contrast to the oppressive panelization, rigidly orthogonal plan topology, and kit-of-parts strategy of previous efforts, each Turnstijl house is created from unique parts and is formally organic. The acts of selection which occur during the generation allow each to be personalized at different points during the process. This exercise attempts to embody the Configure-to-Order approach (more fully than Exercise 2) by systematizing the creation of blended schemas and developing a means to involve the consumer in every decision along the way. Please refer to Appendix B for larger versions of the following Figures as well as a menu for finishing (page 85).
Exercise 2: Schema Variation

Figure 8.2 | Phase 1: Inventory of Sub-Type - Aeck

Figure 8.3 | Phase 2: Selection and Abstraction of Schema by Sub-Type - Aeck
Figure 8.4 | Phase 3: Breeding in Abstraction - Aeck

Figure 8.5 | Phase 4: CFS Application - Aeck
The variation created by this system is occurring on two levels; the first, on a typological level where the schema itself is manipulated. This begins with the inventory of subtypes, then in abstraction, diagrammatic representations of the straight circulation (shotgun), level-change (split-level), and two program (duplex) schemas are cross-bred with one another. Part in parcel to the manipulation of type is the specification of differing amounts of quantitative program. This aspect is included to demonstrate that schema blending is scale-less, and, to an extent, independent of program quantity.

The second area of variation occurs on the level of structure class. In each house, the public rooms and circulation paths were identified as areas where doubly curved surfaces would be most desirable, and are signified by the nodes in Figure 8.4 & 8.5. The public spaces are also the largest spaces in all three houses, so naturally correlate with the longest spans. The double blue lines in Figure 8.5 represent areas where the
system transitions to a doubly-curved “ribbed shell” structure. Additionally, there is
topological and geometric variation which could both be claimed as well, but these were
considered self-evident.

Exercise 3: Outcomes

Figure 8.7 | Turnstijl Outcome A: “North Bi-Shot”

Figure 8.8 | Turnstijl Outcome B: “Camel Side-Split”
Exercise 4: Structural-Aesthetic Variation

In this fourth exercise, variation is developed by manipulating the behavioral properties of the panelized system. The three examples below range from purely aesthetic in the first figure (i.e., random panelization) to practical in the case of the third (i.e., curvature-based panelization). This is a “structural-aesthetic” variation where the seams of the plywood formwork, which must exist anyway, are themselves designed. The variation of the system with respect to structure class has been eliminated for clarity in this case. Decisions such as what direction it runs, what percent curvature it has, and how it relates to the overall form all could all become parameters adjusted in advance by the inhabitant. In order to further reduce the number of variables in play (and avoid exhausting the shotgun), Outcome B from the previous exercise is used as the vessel for this final exercise.
Figure 8.10 | Random Panelization

Figure 8.11 | Diagonal Panelization

Figure 8.12 | Curvature-Based Panelization
PART III – THE CANNOLI FRAMING SYSTEM (CFS)
The enduring question that arises on this safari through type, house typology, and structure class is what may be conceived that can affect all three? Specifically, the final problem of this research is to design a plausible framing typology that is capable of both formal and structural variation. If defined using the specific definitions of modularity as outlined in appendix D, the system that is proposed would be a “variable component-dimension, standard component” with “sectional modularity.”\textsuperscript{58} A number of conceptual realizations became evident along the way and became the criteria for the system as Table 9.1 shows. In the second column, the motivation behind each is classified in order to reveal the diversity of the group.

### Table 9.1 | Conceptual Assumptions

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Motive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood ( . . . people want wood houses)</td>
<td>Materiality</td>
</tr>
<tr>
<td>Maximize the usage of thin materials 1/2” and under.</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Be capable of both typical &amp; long spans.</td>
<td>Structural</td>
</tr>
<tr>
<td>Closely approximate double curvature.</td>
<td>Formal</td>
</tr>
<tr>
<td>Avoid exhausting &amp; costly surfacing on the mill.</td>
<td>Fiscal</td>
</tr>
<tr>
<td>Be affordable.</td>
<td>Fiscal</td>
</tr>
<tr>
<td>Change structure state.</td>
<td>Structural</td>
</tr>
<tr>
<td>Be green wherever possible.</td>
<td>Environmental</td>
</tr>
<tr>
<td>Reduce usage of metal fasteners &amp; nails.</td>
<td>Efficiency</td>
</tr>
</tbody>
</table>

CHAPTER 10 | PROCESS (CFS)

Material Dimensions

The first in the series of considerations on the way to the final proposal were the dimensions of standard materials. The lengths of each component of the system are sized based on how they will fit on a 4’x8’ sheet (see Appendix C). Specifically, the pieces involved in the middle or “transition section” (where the change from stud-to lam occurs) never exceed 4’ (i.e., the short direction of a sheet). In the long direction, another example is that the both the “faces” and “ribs” of the tube are always under 8’. These considerations become especially significant in the aggregate after all parts are sorted by material thickness. Nesting software (RhinoNest) was used to mathimatically calculate minimum material usage. Were capital unlimited, these decisions could be modified for larger router beds or material sizes. For instance, 8’x24’ is a common panel dimension in the SIP industry. Nevertheless, what is presented here is based on standard retail materials and the equipment used to produce the mockups.

State Change

The CFS, though comically named, performs in several ways beyond its obvious capability of greater formal continuity. The most conspicuous area of “performative variability” is its ability to change structure state. This transition from a stud wall to “ribbed-shell” is practical for long span conditions and situations where the approximation of double curvature is desirable for either spatial, span, or formal reasons.

By contrast, the stud (or sheathed frame) half of the system is only capable of single curvature, but does have the advantage of being more or less dense for point loads or to framing openings. In certain conditions where no transition or curvature is needed (e.g., partitions and gable walls), the studs may simply become widely spaced serving as splines to join adjacent panels together.
**Insulation**

When in "ribbed shell" state, the 9" (6" in the hollow core) of rigid foam serves simultaneously as structure and insulation. The wood tube is essentially permanent formwork for sprayed foam, so the R-value of the section will clearly exceed current standards. For example, a conservative R-value for one inch of foam is roughly 4, so an estimated R-value for the section is 36. The best BATT insulation typically does is 22, and this assumes the myth of perfect installation with complete coverage. Expectedly, the tolerances of a digitally manufactured panel system would also exceed that of conventional framing, and presumably, infiltration would also be minimized.

![Figure 10.1 | Associative Branding](image)

**Branding**

The branding of the “Cannoli Framing System” is based on the analog of the rigid foam and plywood tube to the cream-filled Italian dessert as is shown in the image above. Of branding, activist and author Naomi Klein says, “In a consumer-driven society, brands are the main source of identity. The brand fills a vacuum and forms a kind of armor, taking over the part once played [by] political, philosophical, or religious ideas.”59 Developing an identity for the product does not fall outside the purview of the architect,

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and is far from needless commercialism. The favorable branding of an architectural idea may positively influence its consideration, and if anything, that positive influence increases the chance that an architectural idea may actually be realized. Even Klein relents when the branding is actually embodied by the product:

\[ I \text{ don’t think there is anything wrong with logos, with doing whatever is necessary to get your message out. Among some of the people who share my ideas, there’s an attitude that the act of selling is somehow dirty. But I think that if you’re actually selling what you are claiming to sell, then it’s fine. I have a problem when there is a betrayal of the message.}^{60} \]

Kratochvil also discusses branding as part of his strategy for achieving “customer intimacy” naming four related parts: “product supremacy, service supremacy, brand focus, and dialog focus.”^{61} The last of them, “dialog focus” represents the interaction of the consumer with the product - the diagrams in Exercise 3 represent the design dialog a consumer would engage when generating their own house. The actual means of making this process interactive would involve, presumably, some sort of web-based graphical user interface (GUI), which would have to be developed to deploy such a system.

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60 Sittenfeld, Curtis. “Fast company” Issue 38 August 2000
CHAPTER 11 | THE SYSTEM (CFS)

Please see Appendix C for full page sections and elevations of the proposed system.

Figure 11.1 | CFS: State Change

Figure 11.2 | The CFS
Figure 11.3 | The CFS

Figure 11.4 | The CFS
Figure 11.5 | Site Assembly 1

Figure 11.6 | Wall Panels - Site Assembly 2

Figure 11.7 | Assembly 3
Figure 11.10 | Component Assembly Order
CHAPTER 12 | PROCESS MODELS

The strategy for physically achieving the objectives found in Table 9.1 was attrition by way of recursive physical models and mockups represented by Figures 12.1-12.6. In all cases, fabrication geometry was extracted from the same three-dimensional models used to either render or conceive the prototype. Some minimal offsetting for material thickness was necessary to create toolpath-geometry for full-scale work, but for the most part, all three-dimensional work is scalable and multi-purpose.

Figure 12.1 | Three Tubes - Exterior @ 1/2”=1’

Figure 12.2 | Three Tubes - interior @ 1/2”=1’
Figure 12.3 | Transition - Joinery Closed

Figure 12.4 | Transition - Joinery Open

Figure 12.5 | Transition Detail
Figure 12.6 | Lam-Stud Joint
Digital Production Methodology

All-digital processes were used to create the models and mockups presented by this work. The chipboard models that follow were cut on a Universal Laser Systems (ULS) X-660 Lasercutter. The three-dimensional work was created using Rhino 4 and was rendered in V-Ray and Penguin. The Advanced Wood Products Lab (AWPL) at Georgia Institute of Technology (GaTech) made the time on a Morbidelli Author 3-axis router for the full-scale prototypes and final prototype.

In Rhino, the “FlowAlongSrf” function, RhinoNest, and ArchCut plugins were used together to create the geometries. Next, the “UnrollSrf” command with high tolerance was used to extract the geometry for machining the CFS. The labeling of parts was scripted and is based on material thickness, layer, and overall length.

Foam

The choice to use rigid polyurethane foam for the mockups was dictated by both the retail availability of this product, and the relative dearth of competitive green alternatives in sizes below the 55-gallon drum. Both were two-part foams; the 1.5pcf was low-expansion strength from “Foam Power Inc.,” and the 3.0pcf foam was the “Smooth-On” brand. The most likely green candidates to substitute are believed to be either icynene or a soy-source urethane, both of which are commercially available.

Materials

The full-scale mockups use four types of wood: 5/8” BC ply, 3/8” BC ply, most notably 3/8” bending Luan, and 1/4” Luan for the spacers inside the tubes. The bending Luan on interior and exterior faces is oriented so that its strong axis runs either perpendicular or near perpendicular to the length of the tube.

In this second of stage of physical prototyping, the different types of joinery and the assumptions made in chipboard were tested in the material from which they would presumably be cut.
Figure 13.1 | 4 Sections

Figure 13.2 | Beams A, B, C

Figure 13.3 | 4' Tube - Curved
Figure 13.4 | 8’ Tube - Curving and Twisting

Figure 13.5 | Detail 1 - Section Distorts

Figure 13.6 | Detail 2 - Variable Joinery
Figure 13.7 | Pin-Nailer and Foams

Figure 13.8 | Router Bits
CHAPTER 14 | TRANSVERSE LOAD TESTS

Testing - Round 1

The letters from in the previous chapter’s Figure 13.1 correspond with the following Beam and Column letters. More detailed full page drawings calling out material thicknesses and joinery details for each section can be found in Appendix C. Dr. Russell Gentry graciously ran the press despite overwhelming commitments on the Solar Decathlon house. The foam density, peak load, deflection, and observed failure cause of each section are located in Table 14.1.

Figure 14.1 | Beam A - Before

Figure 14.2 | Beam A - Local Shear Failure
Table 14.1 | Flexural Test Results

<table>
<thead>
<tr>
<th>Beam</th>
<th>Filling</th>
<th>Peak Load</th>
<th>Failure Description</th>
<th>Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.0 pcf Foam, Solid</td>
<td>7312#</td>
<td>Local Shear @ Face</td>
<td>.01”</td>
</tr>
<tr>
<td>B</td>
<td>1.5 pcf Foam, 4” Hollow</td>
<td>5897#</td>
<td>Local Shear @ Face</td>
<td>.04”</td>
</tr>
<tr>
<td>C</td>
<td>1.5 pcf Foam, Solid</td>
<td>3426#</td>
<td>Improper Filling @ Joint</td>
<td>.138”</td>
</tr>
</tbody>
</table>
Figure 14.8 | Beam B - Interior Detail (note failure @ top)

Testing - Round 2

Figure 14.9 | Beam D - Curved Beam w/ Bending Plywood Faces
Figure 14.10 | Beam D @ Failure - Local Shear Failure

Figure 14.11 | Beam D - Failure Detail

Figure 14.12 | Beam D - Loading Diagram
### Table 15.1 | Axial Test Results

<table>
<thead>
<tr>
<th>Column</th>
<th>Filling</th>
<th>Peak Load</th>
<th>Failure + Location</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>3.0 pcf Foam, Solid</td>
<td>30,000#</td>
<td>None</td>
<td>.001&quot;</td>
</tr>
</tbody>
</table>

![Figure 15.1 | Section D](image)

![Figure 15.2 | Section D - Loading Diagram](image)
Each practical test yielded something previously unknown about the performance of the system. In particular, the way the beams failed in the flexural test was generally favorable because the failure was not catastrophic as had been expected. Deflection was well within expected tolerances at (.01", .04", and .138" .001 respectively). The mode of failure was always local to the face of the exterior plywood and occurred around the feet of the loading fork. The force applied by the hydraulic press resulted in a staged failure that began with (1) local shear failure of the face and was followed by (2) crushing of the foam inside. In each case (even the improperly filled beam C), the section continued to perform at about two-thirds of its peak load after the initial failure. The horizontal portions seen in Figure 15.4 demonstrate this high post-failure performance, and suggest a safety factor with a ceiling at about two-thirds the peak load.

In general, this portion of the research is included not to represent the already well-established structural validity of SIPS in general, but to support some of the specific assumptions being made in model and on paper. The 9"x9" section is the smallest dimension the tube half of the system would ever become, so that dimension was chosen as the condition to test.
PART V - CONCLUSIONS
The attempts to create different types of variation in the exercises demonstrate the breadth of digital production methodology’s impact, but also challenge strict typological thinking. Whether or not combining a shotgun with a split-level house is a desirable thing to do may remain debatable, but in any case, such hybrids still have yet to occur. This must be, at least in part, because the results would have been monstrous, if not untenable, with the techniques and technology of their day.

Ultimately, two worldviews are juxtaposed here; the relative-empiricist view, as represented by the research into typological exercises, and the Deleuzeian-realist view, as represented by the discussion of capacities and assemblage theory. In the first, we are looking down on collections of objects and their relationships; indexing, sorting, and cataloging their sordid properties. In the latter, we are peering up at mind-independent, property-and-capacity hierarchies to explain the impact of technology upon our architectural constructs. There are merits to both views, and flawed or not, taxonomic methodology is well suited to the task of establishing synthetic (or virtual) vocabularies that may serve as analogs for construction.
Assemblage theory is distinct from the taxonomic approach because it is able to provide causal explanations for variation that go unexplained in alternative modalities. The drawback to this is that it does not acknowledge the existence of essences whether absolute, relative, or otherwise. Even so, accepting the existence of one does not have to be, as Gombrich has taught us, like “the exclusion principle” that “denies the values it opposes.”62 While it is correct to observe that the essence of an object, especially a building, may be purely logical or virtual, it seems more reasonable that this might be complement this with an acknowledgement of the structure and of the natural world which plays so completely into the act of making.

It is with this in mind that we return to marvel at the impact of digital production methodology. The fundamental technological improvement in the act of cutting, when coupled with the ability to pre-model everything virtually, adds up to an expansion in our capacity to produce. What we are experiencing are the repercussions of modeling and fabrication technologies that are radically more precise in not just two, but three dimensions. The potential for this singularity to affect the detached house by allowing unforeseen structural, formal, even typological variation is recognizably immense. As the formerly rigid seams of the built environment are now relaxed, it is now possible for architects to set their sights upon both type and typologies - instead of only the token.

The true object of the research, the component-based CFS system, is an initial attempt to use this new production methodology to reconsider one of the most fundamental systems of modern construction, light wood framing. In its current incarnation, the proposed CFS uses a layered modularity that allows it an alternate structural state and accommodates organic geometry more closely than the approaches of the past. The two most obvious drawbacks are assembly and the systems anisotropy, and for me, this will remain an open case.

In hindsight, there are things that certainly might be treated or done differently, and in a certain sense, exploration precedes selection in this work, so this is where the chase

must end, for now. Because historically type has been constrained by the limited capacities of traditional production methodology, it does follow that a relative increase in these capacities now serves its liberation.
<table>
<thead>
<tr>
<th>Structure Typologies - Prouve</th>
<th>Alphabet des structures</th>
<th>Alphabet der Systeme</th>
<th>Alphabet of Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type portiques axiaux</td>
<td>Type portiques axiaux</td>
<td>Type Mittelstütze</td>
<td>Type of jointed frames</td>
</tr>
<tr>
<td>Typ Schale</td>
<td>Typ Schale</td>
<td>Shell type</td>
<td>Shed type</td>
</tr>
<tr>
<td>Type coque</td>
<td>Type coque</td>
<td>Type shed</td>
<td>Shed type</td>
</tr>
<tr>
<td>Typ Krücke</td>
<td>Typ Krücke</td>
<td>Propped type</td>
<td></td>
</tr>
<tr>
<td>Type à béquilles</td>
<td>Type voûtes</td>
<td>Vaulted type</td>
<td></td>
</tr>
<tr>
<td>Typ H-Stütze</td>
<td>Type à portique axial en H</td>
<td>Type of H-shaped axial frame</td>
<td></td>
</tr>
<tr>
<td>Typ mit tragendem Kern</td>
<td>Type à noyau central</td>
<td>Centre core type</td>
<td></td>
</tr>
<tr>
<td>Typ xTabourets</td>
<td>Type tabouret</td>
<td>Stool type</td>
<td></td>
</tr>
<tr>
<td>Type réticulaire à surface</td>
<td>Type plastique</td>
<td>Variable area grid type</td>
<td></td>
</tr>
<tr>
<td>Typ für freien Grundriß</td>
<td></td>
<td>Plastic type</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix B | May 26, 2007 Presentation - Aeck

**THESIS DIAGRAMS**

**3 HOUSES**

**FRAMING TYPOLOGY**

**PROGRAM "SCHEMA"**

**LOGIC, TECTONICS, GEOM.**

**PRODUCTION METHOD**

**ECONOMY / AVAILABILITY**

**MATERIAL CONSTRAINTS**

**PROGRAM QUANTITY**

**LOCATION / SITE / LOT SIZE**

**USER NEEDS**

**PROGRAM "SCHEMA"**

**SUM of "structure shown basically**

**MBC House vs. "Cube Box"**

**"Pure" - Project of the future**

**"All" - Aspects of the residence**

**"DRY" 2 BATH**

**eg. Stippled Home's Masterrooms**

**"Not" - 3 layer, metal walls**

**consistent logic of relationship**

---

**WHY? MACRO**

1. DESIREABLE PRE-MAUFACTURED HOUSES INTENDED FOR ACTUAL INDIVIDUALS

2. OPERATION UPON TYPE: VARIATION "OF" TYPE vs. VARIATION "ON" TYPE

3. REWORKING & DERIVING TYPE STARTING WITH THE STUDY OF WHAT PEOPLE ALREADY WANT

4. RECOGNITION OF THE ADVANTAGE OF CONTINUOUS VS. DISCRETE SYSTEMS

5. RELEVANCE OF BOTH "BLINDING" & "INCREMENTAL CHANGE" TO DIGITAL & PARAMETRIC DESIGN STRATEGIES

6. BRANDS AS A SUITABLE TOTAL OF MANUFACTURING PROCESS, TECTONICS, FORM, MATERIALS & TACTILITY.

---

**DIGITALLY MANUFACTURED**

"HYBRID" FRAMING SYSTEM

- BLENDED TYPE
- VARIATION "OF" TYPE

- VARIATIONS "ON" EXISTING TYPE
DETACHED HOUSE TYPOLOGY

3 TYPES

- SHOTGUN
- SPLIT-LEVEL
- DUPLEX

FRAMING SYSTEMS

MATERIALS & METHODS

STRUCTURE CLASS
FRAMING SYSTEMS & TYPE

QUONSET FRAMING

BRANDED

SURFACE STRUCTURE

STAMPED METAL STRIPS

TECTORICS: LAPI JOINTS, STRAIGHT MOLD, BEAMS

SINGLE CURVATURE

PLATFORM FRAMING

ORTHOGONAL

SHEATHED FRAME

WOOD

TECTORICS: SPLAY & LAP JOINTS, FRAMING NAILS

QUONSET FRAMING: ATTEMPTING 3 TYPES

SHOTGUN

SPLIT-LEVEL

DUPLEX

PLATFORM FRAMING: 3 TYPES

SHOTGUN

SPLIT LEVEL

DUPLEX

CAPACITIES & CONSTRAINTS

26’ ORIGINAL QUONSET

20’ SINGLE RADIUS

14’ TYPICAL

14’ SPACE DIVISION

GOOD SPAN DISTANCE. POOR AT DIRECTION CHANGE & INSULATION

POOR SPAN DISTANCE & FORM. GOOD AT DIRECTION CHANGE

MANUFACTURING LIMITATIONS
CANNOLI FRAMING SYSTEM (CFS)

PEOPLE WANT WOOD HOUSES!

LESS MATERIAL OVERALL - COMPOUND CURVATURE
LESS METAL FASTENERS - OFF-SITE - NO CONTRACTOR

MILLED SHINGLE

SHEATHED FRAME

METHOD CHANGE

LIGHTWEIGHT PERMANENT FORMWORK

RIGID URETHANE FOAM
TYPE ATTRACTS TRANSITION

PERPENDICULAR
transitions perpendicular to circulation
(single-shotgun)

PARALLEL
transitions along circulation
(single-shotgun)

BARBEK
transitions along bend & to cap ends
(same-shot)

STEPPING
transitions to step 2 when stepping
(side-to-side)

LOCALIZED
transitions @ roof & in exceptional spots
(raised-ranch)

INSIDE-OUT
transitions from inside-out
(mirror-plan)

OUTSIDE-IN
transitions from outside-in
(hetero-plan)

STRUCTURAL TRANSITION
CANNOLI *S.I.P.*
DIGSTUDWALL
CIRCULATION
PARTITION / NON-STRUCT
**BG**
NORTH BI-SHOT

transitions over 2 main rooms

**DH**
CAMEL SIDE-SPLIT

transition allows jump from 2 floors to 1

**CFLN**
BI-HETERO LINK-DETACHED

flip for solar orientation
6 PRELIM / MACHINING CONSIDERATIONS

1. MAXIMIZE THE USAGE OF THIN MATERIALS
2. MINIMIZE THE USAGE OF METAL FASTENERS & NAILS
3. NO EXHAUSTING SURFACING
4. ORTHOGONAL & CURVILINEAR GEOMETRY CAPABLE
5. LONG-SPANNING WHEN DESIRED / REQUIRED
6. CONSIDER THE INTERGRATION WITH EXISTING SYSTEMS

5-AXIS CUTTING?

INITIAL SPECULATION

CFS PRELIM

1" = 1'
5.6 Modularity Types

The PDM Group (Tihonen et al., paper, 1995) used five categories of components, in a scale close to the salesperson's perspective: dependencies between components are kept as simple and standardized as possible:

1. **standard components** (one size, one design)

2. **modularly standard components** (the component itself can easily be reconfigured to fit a customer, typically in software and electronics)

3. **parameterized components** (size and design parameters stated per order, before delivery)

4. **components designed per category of customers** (typical for physical interfaces to a product's environment)

5. **premise-ware components** – not yet designed, requiring new specification and design work (in the case of software or high-tech components and of businesses with an "Engineer-to-order" tradition).

In an optimal component strategy, we stress the desirability of PDMG's categories 1, 2, 3 above, trying at the same time to keep 4 at a reasonable level and to minimize 5.

In software, Barry McGibbon[1] uses 3 major categories, in a scale close to the potential component re-user's perspective – that is, typically the software architect's or the developer's:

1. **pluggable, customizable, and configurable components**

2. **Customizable components** support the "black box" concept. What the component does is well known, but not how it does it. It has "hard" edges and fittings specified once and for all as well-defined software interfaces; it can be likened to a Lego brick.

3. **Configurable components** are pluggable components that can have their behavior or data changed through well-defined mechanisms. These still remain a "black box" as the configurator does not know how the internals of the component have been changed, it only knows the expected effect of the change.[2]

4. **bus** – a common standard basis, easily connected to any other component types supporting its standard interfaces (today typical of PCs or of automotive electronics or of large configurable software environments, for instance IBM @Websphere's Eclipse engine)

5. **section modularity**, like Lego-bricks – an architecture interconnecting any component with any others, in an ever-growing number of combinations. This requires hand-homework in design (and most often an industry standard) but it pays off in terms of maximum robustness, i.e., resilience to heterogeneous or volatile requirements. Here, the trick is the versatile standardized interface between components, which fits in, whatever the component's shape, functionality or inside – like in Lego, or railway carriages in most of Europe, or the TCP/IP communication protocol (figuratively, the standard "plumbing software" under the Internet).

6. **mix modularity**, easily combined with the other five points (for example in paint/finish/coating, raw material blends, additives).

With a consistent cross-product or cross-brand co-modularization, there is of course a risk of some market segments perceiving products from very different price-categories as too similar. In B2B, this is seldom a big issue; obviously, the costs and long-term benefits of a truck (i.e., lorry) are analyzed much more thoroughly by customers than its looks: this customer attitude is more common in B2B.

With consumers however (B2C), similarity is a real issue in many industries: why buy an Audi instead of two Skodas[3], or why go to an expensive high-profile bank, instead of a website providing exactly the same service package at a fraction of the price (and sometimes, even co-owned by the very same bank), or why pay an SAS airline ticket instead of three Snowflakes (the same owner, and same planes, but two brands until recently)? Parametrized or modifiable components, or those designed specifically for a product category, are often superficial and are placed on the surface in order to distinguish the look-and-feel between brands.

Carmakers Ford and Jaguar are a good example of how components can be shared successfully "under the bonnet", yet still dramatically differentiating the mid-market Ford Mondeo from the executive-saloon Jaguar "X".

Ubrich & Tung once defined a scale of five component-architecture categories, or kinds of modularity, closer to a production or manufacturing perspective. A sixth category was added by B. J. Pine and called mix modularity (Pine, 1993). Some of their categories overlap since the classification was based on the components' way of complementing each other (figure 5-3).

1. **Component**

2. **Common kernel**

3. **Variable component dimension**

4. **Bus**

5. **Section modularity**

6. **Mix modularity**

---

*Figure 5-3: Modularity categories inspired by Ubrich & Tung[1]*

1. a **common component** – the same component type employed in several products (now typical of automotive & manufacturing, electronics & computers, and many other industries)

2. a **common kernel** – a basic component shared with various components in various products (like the fore-mentioned VW-platform A2 in Skoda Octavia, Audi A3 and Golf/Rabbit/Bora 4)

3. a **variable component dimension** in various products (similar to PDMG's parametrized components above)

B. J. Pine’s, complemented version (Pine, 1993).
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