A Bootstrap Language:

Grassroots CNC and the Urban Housing Crisis

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I Introduction

This paper presents CNC shelter architecture as a pattern-language response to the contemporary urban housing crisis. The houseless comprise a hugely diverse population, united by occupying spaces outside the norm (Henry, et. al.). This is where pattern language has the most to offer: it is an approach for solving unfamiliar problems by analyzing the known context, identifying commonalities, and looking to collective knowledge for guidance (Alexander, 1977).

Among a range of innovative architectural responses to houselessness, CNC kits-of-parts offer ease of construction along with durability and aesthetic appeal. Front-loading the work in this way saves time and energy on site – particularly useful in cases of emergency, or in the often-challenging environments that typify shelter villages. There is a shared pattern of construction among these projects, but also considerable variety in its application (fig. 1). Examining several projects in context will illustrate the range, possibilities and constraints for addressing diverse problems in houselessness.

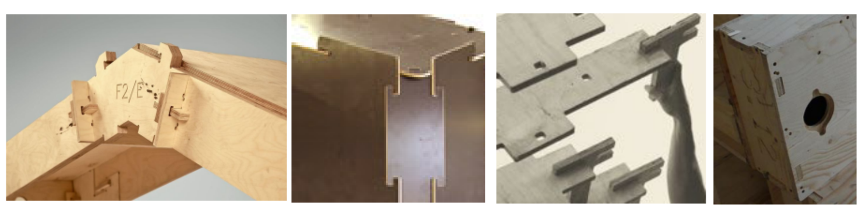

Figure 1: Diverse project details using friction-fit plywood

The discussion will trace CNC shelter architecture from general, social phenomena to specific details. It will first review general considerations in design for the houseless. It will then catalogue CNC strategies through the lens of shared grammar, syntax and design vocabulary. Finally, it will present a case study project in Portland, Oregon generated through an integrative, user-informed process. Collectively, these examples demonstrate the inextricable relationship between the CNC pattern language and its context, and between component parts and the larger structures they comprise.

II The State of Houselessness

The social and health effects of houselessness are substantial. Houselessness is strongly associated with premature mortality, particularly through injury, overdose and weather exposure. It is strongly associated with chronic pain, skin problems, dental problems, infectious disease, mental illness and economic vulnerability (Bagett, et. al.). And yet the provision of housing is rarely treated as high a priority as the provision of other services such as food, water, healthcare and education (Busch-Geertsema et. al.). One challenge is uncertainty as to whether houselessness is a symptom or cause of its comorbidities (Fazel, et. al.). Likely it is both, and should not be treated as a condition unto itself but as one node in an interrelated network of health challenges. The downside here is that a shelter is not a cure; the upside is that it is much more than just a place to sleep.

What, then, are the spatial needs of the houseless? It is a hugely diverse population, and the very definition of the term 'homeless' is a point of disagreement among researches. According to Busch-Geertsema's et. al.'s framework, 'homeless' may refer to lack of accommodation (those sleeping open public spaces, public buildings, etc.), it may refer to temporary or crisis accommodation (nightly shelters, refugee camps, etc.) or it might mean inadequate/insecure accommodation (living with relatives, living under threat of violence, squatting, etc.). The authors further propose three central characteristics of housing: 1) a "security domain" that consists of tenants' rights to maintain occupancy for an extended period of time, and includes cost considerations, 2) a "physical domain" that refers to the adequacy of a dwelling in terms of protection from the elements and provision of basic amenities and 3) a "social domain" that refers to the ability to cultivate interpersonal relationships and maintain a sense of privacy and security. Other studies similarly cite the need for security, autonomy and access to support services (Crawley et. al.).

With these issues in mind, architects can begin to ask how design can improve the living conditions of the houseless. One universal priority is lowering costs. A number of other considerations unique to shelter design include:

-social context (turnover rate, neighborhood acceptance)

-user well-being (security, IEQ, storage, hygiene, accessibility)

-ease of construction (fabrication, assembly and transportation)

-cost of materials (duration and unique environmental challenges)

-physical context (site challenges, aggregation, relocation)

As will be discussed in the next section, CNC design and fabrication technology offers advantages in some of these areas. Even within this specific and newly introduced subcategory of shelter design, architects have already developed a range of innovative approaches.

III Trends in CNC Shelter Housing

As skilled construction labor becomes scarcer and costlier, kit-of-parts plywood housing offers an increasingly viable alternative to conventional construction (Sass). The basic process is simple: design software enables architects to model each piece in a kit of parts, which automated and precise machines then fabricate. These are made with slots and tabs such that they can be assembled by low-skilled workers with few tools. The sheet material can also be flat-packed and shipped to challenging sites more easily, or mass produced and stored in preparation for future needs. The benefits of this process are therefore especially pronounced for relief and shelter housing, where there are so many unknowns and resources are limited.

Instant House

Shelter 2.0

WikiHouse

Blokaloks

Terrapeg Home

Facit Homes

D1 Disaster Shelter

PlyPAD

Figure 3: Diverse strategies in CNC plywood housing and shelters. At top, cross-braced framing; lower left, interlocking panels, lower right, self-supported modules.

The combination of router and plywood sheets creates an identifiable construction logic to CNC architecture (fig. 2). Finger and slot joints are common, as are dog-bones, shim joints and routed bolt-holes. However, there is wide variety in how different projects employ this shared vocabulary to solve specific challenges (fig. 3). The diverse structural approaches present a series of sub-patterns for designers to draw from. Since this is an emerging field in which designers are still exploring the most appropriate systems for different contexts, the following discussion will review both shelter-specific and related projects.

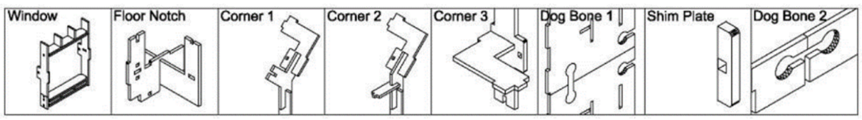

Figure 2: Joint Taxonomy (from Sass and Botha)

<u>Customizable Shelters</u>

Some of the earliest CNC shelters remain the most technologically forward thinking. Lawrence Sass' groundbreaking *Instant House* anticipated many of the possibilities inherent in CNC design and manufacture. With this system, a script subdivides a surface-based design into interlocking parts, scaled to fit available sheet materials and laid out for cutting. In other words, the entire process of translating a conceptual mass into a kit-of-parts is automated. This offers the dual benefits of variety and convenience, and the project's aim is to "provide mass customized, designed housing to emergency and poverty-stricken locations" (Sass and Botha, 2006). Several versions of the *Instant House* have been built as proof-of-concept, and its premise and many details have laid the groundwork for much of the research that has followed.

Alastair Parvin and Nick Ierodiaconou's *Wikihouse* is the most comprehensive realization of the *Instant House* concept to date. This open script offers adjustable parameters including basic dimensions, roof slope, column locations, etc. (fig. 4) and labels and lays out parts for cutting. The structure is a series of plywood box-beam ribs, with external and internal wall panels. Though versions of the *Wikihouse* have been built throughout the world, as with the *Instant House,* wider implementation for shelter housing remains largely aspirational.

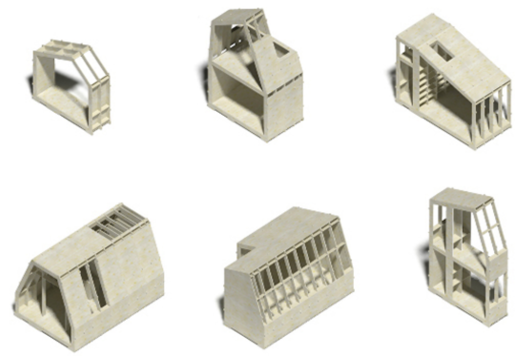

Figure 4: Permutations of the Wikihouse (from Parvin)

Recent manifestations of the custom CNC house have turned towards the residential housing market. England's Facit Homes and its partner Eentileen in the Netherlands have developed a proprietary system for creating hollow box modules, with precut holes and channels to integrate MEP. It is designed for construction by two people, and the companies are experimenting with a mobile CNC shop in a converted shipping container for on-site construction. While the design and manufacture of these projects is perhaps more advanced than necessary for shelter housing, their general success supports the viability of CNC homes as an alternative to conventional construction.

Standardized Shelters

Instead of customizable systems, another group of projects offers pre-designed, standardized kits-of-parts. These employ CNC tools less for parametric flexibility than for the ability to cut parts with ease and industrial precision - in other words, less for design than for fabrication. These projects focus on a particular context or problem, and several have taken aim at shelter and disaster relief housing.

The Shelter 2.0 is designed specifically for disaster relief, with fifty or more constructed across the world. The structure is a series of arched ribs held together by cross bracing and clad with corrugated metal panel. Due to the half-cylinder profile, there is no division between roof and walls, minimizing the need for flashing and unique waterproofing details. The repetitive nature of the ribs also helps simplify assembly. The design packs neatly into a custom wood box for shipping, though the project's long-term aim is to help establish fabrication facilities in areas of need so that shelter construction can feed into the local economy (Shelter 2.0).

Gregg Fleishman's DH1 disaster house takes flat pack to an extreme. Its large, interlocking plywood panels minimize the number of required parts. In Fleishman's words, it is 'flexible but strong' and sits on 'four pier points for use in difficult environments' (Fleishman). The project began as an attempted solution to houselessness in Los Angeles but developed towards disaster relief housing Fleishman points out that waterproofing, finishes and insulation would depend on the local environment, and may vary from spray foam to a simple membrane cover. Terrapeg's *Home for Haiti* also offers a pure CNC wooden structure held together with shim joints and presented in a fairly conventional domestic form.

<u>Modular Shelters</u>

Some modular projects sit between these extremes of custom and fully standardized. These "site-customizable" designs offer a limited degree of variability by providing standard pieces that can be reconfigured to fit users' preferences. Rather than during the design process, customization here happens after manufacture.

The Oregon based Blokaloks project offers modular blocks that snap together. Each is a simple sandwich of plywood and insulation – in other words, a small SIPs panel—and they come in four basic types (the T-BLOK, U-BLOK, L-BLOCK H-BLOK) for dealing with edges and openings such as windows and doors. The project highlights ease and speed of construction, for both indoor and outdoor use and the company has constructed a tiny house for the homeless in Seattle as proof-of-concept. Another semi-customizable design to be discussed in depth in Section 3 is the PlyPad. This is made of larger 'programmatic modules' that are prefabricated independently and can be snapped together on site. In this case, the sectional profile is standard, but it can be rearranged or expanded to accommodate different site and user needs.

Summary Comparisons

The projects discussed above illustrate that even within a fairly niche construction system – CNC plywood sheets—there is a wide variety of systems for addressing different problems in disaster and relief housing. A few trends can be observed: one major distinction between projects is the overall structural approach. Projects tend to consist either of cross-braced framing, interlocking panels, or self-supporting modules (or a combination thereof). Another difference is the degree of on-site fabrication, ranging from on-site CNC work to flat-pack shipping for on-site assembly, to fully prefabricated homes. Further, figure 5, below, also shows the range in customizability (from parametric to standardized) and its relationship to module size.

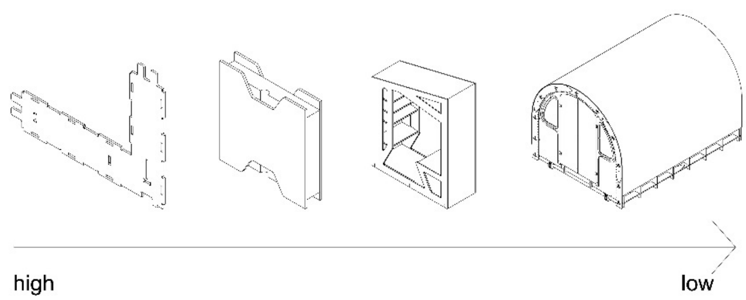

Figure 5: Module size and customizability of different approahces From left, each component part of projects such as the WikiHouse and Facit Homes is parametrically flexible. With Blokaloks, the module is a given, but its aggregation is variable; whereas the PlyPAD has a much larger "programmatic module." Finally, Shelter 2.0 and the D1 house offer single, standard designs.

Another key difference between CNC houses is their integration of additional systems beyond the plywood structure (fig. 6). This may include cladding, waterproofing, insulation, or full MEP. At one end of the spectrum, the D1 shelter is a basic plywood shell. At the other, the Facit chassis is specifically designed to integrate a variety of support systems. The choice of approach will depend on various contextual factors such as location, access to additional facilities, expected duration of use, etc.

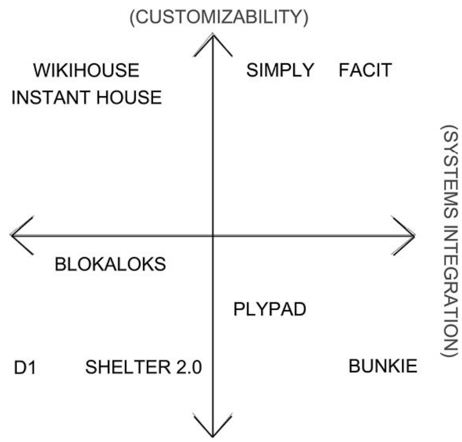

Figure 6: Customizability and systems integration for select projects

Some of the projects are aspirational – that is, a proof of concept—while others are developed for implementation. This is still a new construction process, so both the experimentation and the application are of value. And of course, it is also worth noting that in architecture, the 'fitness' of a design is as complex as its context. Variation, aesthetic appeal and a captivating concept can play as large a role in obtaining the funding and community approval to build a project as purely performative criteria.

IV A Case Study in Context

An in-depth discussion of a case study will help to illustrate the complexity of the context for building shelter housing, and the unexpected ways this context can influence a design. The PlyPAD was designed for Kenton Women's Village, a community of 14 female residents in transitional housing in North Portland. The residents participate in shared-governance, with assistance from local support organizations. They sleep in individual shelters and have access to shared sanitation and cooking facilities on site. It is a unique village, having been approved directly by neighborhood governance, but is in many ways representative of the challenges facing homeless villages throughout the country: an underdeveloped site, limited access to utilities, potential security issues, neighborhood approval concerns and an uncertain future.

In 2016 a Portland startup, Maslow CNC, was successfully funded on Kickstarter to produce low cost CNC machines. The company's aim – as reflected in its name – was to help society advance along Maslow's hierarchy of needs by creating more shelter housing. If architecture is a pattern language, engineering is no less so: Maslow CNC's design draws upon a lineage of related devices, adapting them to the specific goal of affordably cutting a 4' x 8' sheet of plywood. It consists of a mobile scaffold made of a router and brick weights, which travel along bike chains fixed to the corners of the plywood. The entire assembly (minus the bricks) fits in a small box for shipping, and costs only $499, compared to the typically tens of thousands for a traditional CNC machine.

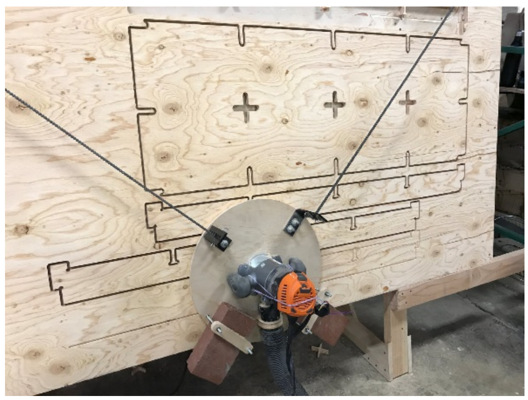

Figure 7: The Maslow CNC cutting parts for the PlyPAD

Maslow teamed with the Portland Art Museum to sponsor a public build of their first tiny home in association with the museum's launch of a new exhibit, *John Yeon: A Quest for Beauty*. Since Yeon was an innovator in Plywood construction and the Maslow machine was designed to specifically cut plywood parts, there was significant overlap between the two initiatives. The conditions thus added several unique constraints to the already complex challenges in shelter design. First, the project would have to be made of plywood and cut with Maslow's prototype CNC. Second, it would have to be distinct enough to capture interest at a museum display and third, it would have to accommodate multiple moves - from the ADX makerspace to the museum, and from there to the Kenton Women's' Village. The PlyPAD, selected through an open competition among Portland architecture firms, was a collaboration between SERA architects and the Building Wellness Lab attempting to resolve these diverse constraints.

The project began with an analysis and scale reconstruction of the WikiHouse, from which several observations were made. The box-beam and panel structure was impressively rigid. However, the number of cuts presented a challenge for Maslow's machine, and the initial 'basic box' design was deemed too conventional to attract jury and public interest. Further, the interdependent structural system meant that once assembled, the house would either need to be moved as a whole or fully disassembled for transport.

To solve these problems, the PlyPAD drew further inspiration from Facit Homes and Shelter 2.0. Rather than box beam ribs with paneling, the PlyPAD expanded the box beam structure to form wholly self-supporting modules, like oversized versions of the Facit Home modules. These were prefabricated, insulated and weatherproofed at the makerspace. This system provided flexibility in the Museum display, allowing Maslow to showcase finished units as well as progress pieces, while giving a live demonstration of their machine. After the display, it was then transported to the site and bolted together, with rubber gaskets sandwiched between every pair of adjacent units to prevent water infiltration (fig. 8). Drawing from the simplicity of the Shelter 2.0, it was clad in a simple skin of corrugated metal.

To celebrate the structure – and the potential of the CNC machine – the profiles of each unit extend into the space to form in-built furniture. A bed, a desk, and a series of shelves were each designed into the structure, transforming the modules into distinct programmatic units. In theory these can be re-ordered or added upon adapt to users' preferences.

Figure 8: Programmatic units of the PlyPAD, in transport and assembled

Several significant discoveries were made over the course of the design. On the positive side, the initial specifications called for ¾" Plywood but it was found that this was only necessary for bottom surfaces (floor panels and shelf/bed supports). The box beams proved strong enough that ½" material was otherwise sufficient. The parts fit together with relative ease and were assembled on site and clad over the course of a day by three team members. Further, the project was monitored through several weather events and found to be fully waterproof. In terms of lessons-learned, several of the 'design features' proved to be more trouble than they were worth. The sawtooth roof was difficult to flash and finish in a clean and aesthetically pleasing manner, and the custom clerestory windows likely present a thermal weak point. The built-in furniture, while attractive and sturdy, created inefficiency in the cutting sheets.

Neither a template for replication nor a purely abstract exercise, the PlyPAD is a test of the fit of CNC shelter language to the complex context of Portland's housing crisis. The project falls somewhere between the extremes discussed in Section II. It offers variability, but only in particular aspects; it includes insulation and plans for cladding but does not go so far as to accommodate MEP; it's made for easy transport but is neither fully prefabricated nor site-built (this is probably its most valuable contribution to future work, as proof-of-concept for large box-beam modules). It drew lessons from a variety of past projects and is also full of lessons learned. Most importantly, it is an aspirational project, but is also currently occupied by a formerly houseless resident.

V Conclusion

Shelter architecture is a bootstrap type of problem. There is an immediate need, with limited resources, disagreeing attitudes and many unknowns. CNC shelters have emerged as one potential tool in alleviating this need. This research has attempted to illustrate that the emerging pattern of CNC construction offers unique advantages in customizability, structural approach, transport and ease of construction. These benefits have been adapted in a variety of ways and, indeed, this adaptability may be the system's primary strength in addressing the diverse needs of houseless and displaced individuals. However, it is also a system still very much under development. When, how and why we use it are questions to repeatedly ask, and that will hopefully have clearer answers as we learn to improve social support for the underserved houseless population.

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