# Wood Frame Grammar:
*CAD Scripting a Wood Frame House*

SASS Lawrence
*Department of Architecture, MIT, USA*

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**Abstract:** This paper demonstrates a novel method to generate house designs completely from 3/4” plywood sheets. A shape grammar routine is employed to divide an initial solid shape into constructible components for fabrication by CNC wood routing. The paper demonstrates programmable functions that can be performed using CAD scripting. Future goals for the grammar are to develop CAD programs for digital fabrication using CNC routers. The programs will automate the fabrication process allowing the designer to focus on the visual aspect of design evaluation at any scale with little concern for constructability.

## 1 INTRODUCTION

As designers begin using rapid prototyping to build and evaluate high quality physical artefacts (models), new computer programs are needed to make the constructive aspects of process efficient and affordable. New software development used for fabrication will aid the relationship of CAD modeling with rapid prototyping devices by translating 3D geometries to a specific material and geometry for manufacturing. Currently, software used to translate CAD models to tool paths for rapid prototyping machines, known as CAM software, breaks computer models into thin layered plot files for 3D printing or 3D milling. CAM software for CNC devices breaks 3D models into very specific tool paths also in a layered fashion. Here fabrication software refers to a method to break 3D shapes into flat geometries for two dimensional cutting with assembly logic embedded in each component. The novelty of the project is the use of a shape grammar routine that visually describes the process of reduction. The grammar relates to both to materials property and machine processing. To describe the visual aspects of the functions needed to transform an initial shape into functions for CNC cutting a shape grammar is used. This shape grammar is used to generate wood frame housing with studs and internal and external sheet walls. All materials for the walls, wall studs, roofing and flooring are cut from plywood sheets the example at the end of this paper uses 132-4’ x 8’ x 3/4” sheets of plywood to create a 10’ x 15’ x 16’ room. The functional grammar here is referred to as a *wood frame grammar.*

### Wood Frame Grammar

The motivation for the *wood frame grammar* is to create housing exclusively of one sheet material. Typical wood frame construction is built with walls of various size construction components such as 2” x 4” studs, ¾” plywood sheets and metal fasteners at corners. Current construction techniques result in inefficient material manufacturing, weak and low quality connections between walls, floor and the roofs structure (Figure 1a). Structurally weak points in current wood frame housing at the corners and connections between panels are caused by manual measurements and manually driven construction tools.

A modern approach is used here to fabricate all parts of a wood framed room by creating friction fit connections from sheet material cut with a highly precise CNC table router. The *wood frame grammar* defines assembly methods and tool cuts for notched studs that connect to friction fit walls and studs. Additional connections are granted with the help of structural dog bones used to attach panels to panels and studs to studs. The grammar yields corners of one precise piece with an angle that can be connected to a flat section or infill single panels (Figure 1b). In contrast to conventional construction the strength is in the corners, this method does not need special fasteners at connections between panels.

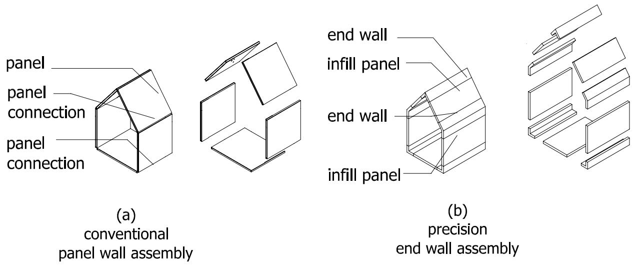


**Figure 1 Typical wall panel system (a), panels cut using CNC technology (b)**

## 2 GRAMMAR FUNCTIONS AND CAD SCRIPTING

The argument to use shape grammars is a need to visually explore the construction process leading to the automation of CAD. Ultimately a shape grammar interpreter could read the drawings in this paper then translate them to CNC code for the manufacture of each sheet of plywood. With or without an interpreter the process to create connections, wood cuts and assemblies needs a visual context. Shape grammars are best for visual descriptions of shape transformations and operations.

This *wood frame grammar* is a rule based presentation of early stage research results within a longer term goal to write VBA scripts for a solid modeling program. These scripts are functions that will translate an initial shape to plywood parts. The process is divided into two phases; the shape grammar in this paper generates geometries for Phase 1.

Phase 1 is composed of 5 sets of scripts (translated from shape grammar rule sets) that transform a single 3D CAD model to a 3D construction model with specific parts and pieces based on 3/4” plywood sheathing and studs (Figure 2). The first script subdivides the initial shape in the form of a CAD model with 1/2” walls into corners and end walls. The second, third, and fourth scripts build new geometry based on ¾” plywood sheets. Each of the four wall types is a double sided stud wall with notches for friction fit connections between the studs and the sheathing. Results of the first phase of five script sets will generate a CAD model of walls and studs.

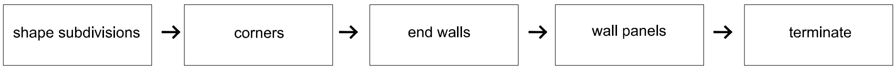


**Figure 2 Phase 1 - Rule sets**

Phase 2 is composed of script sets for fabrication at 1/12 the scale of reality. The first script translates 3D geometries to a flatten position then cuts that geometry into parts that fit within a 4” x 8” boundary sheet. These boundary sheets are a simulation of a 4’ x 8’ sheet of plywood. The boundary sheet also has a thickness that is 1/16” scalable to ¾” plywood. For walls larger than a boundary sheet the grammar cuts the part and places a dog-bone between the sheet for a solid connection in construction between inner and outer sheathing (Figure 4). The same process occurs for studs longer than 8”; they are divided and a mini dog bone connection is set at the joining edges. The fourth script checks for a proper tolerance connection between each part assuring a solid friction fit connection. Then the program terminates. The technique used to friction fit wood panels follows past techniques on self assembled building components (Sass 2004).

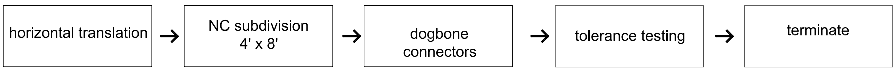


**Figure 3 Phase 2 - Rule sets**

## 3 BACKGROUND

There are three past papers on generative fabrication processes using shape grammars or generative computing and CNC manufacturing. The first paper presents a program that generates design artefacts in CAD with models printed in 3D from a shape grammar routine (Wang and Duarte 2002). The program known as *3D shaper* generates shapes with rules based on the relationship of rectangular shapes grouped and organized by the grammar. A shortcoming of this process was that models did not contain a fabrication methodology resulting in physically small shapes for formal evaluation only. Larger models were needed for internal space exploration. The second paper was a shape grammar based computer program used to generate sheet metal panels for the manufacture of lightweight parts (Soman et al. 2002).

Rules for the grammar are based on the material and assembly properties of sheet metal and CAD CAM operations. The grammar is built of rules for notching, bending and punching sheet to fabricate stereo encasings. Last and most recent is a paper (Kilian 2003) presenting a computer program that generates a puzzle connection between two flat or curved CAD surfaces. The program calculates the relationship between surfaces then generates new geometry built of semi circular extensions and subtractions. Each extension fits into the subtraction of the opposing sheet. The program generates zipper joints of varying scales based on the level of curvature between the two surfaces. The three papers are novel generative methods to bridge the relationship between computation, materials and computer controlled machinery. This paper follows the logic of the three by organizing the rules for the design and fabrication of buildings.

**Figure 4 Left, photo of dog bones, studs, and wall panels with notches for dog bone connections cut of 1/16" cardboard stock simulating 3/4" plywood sheets Right, photo of panels, studs and dog bones in one packaged container**

## 4 WOOD FRAME SHAPE GRAMMAR

This *wood frame shape grammar* transforms an initial shape to cut sheets for laser cutting later. Later the same cut sheet can be used for CNC wood router cutting. Shape grammars are typically used to generate shapes based on shape rules (Stiny 1980). Here shape rules transform an initial shape a $\rightarrow$ b to flat geometries of various formations that reflect a specific material property (3/4" plywood).

Starting with an initial shape in Figure 5, rules 1 – 4 subdivides an initial shape into corners, end walls and panels. The rule assume an initial shape were $t$ = 1/2", the thickness of the wall panel at a scale of 1" = 1'-0". Symbols are used to identify the insertion point of each panel type, $*$ is used for corners, $\bullet$ for end walls and ■ for flat panels. There are two corner types depending on base angle$\theta$, if greater than 90° rule 2 is applied. Rules 5 … 10 break typical corners into components and variables. Rule 9 defines variables for notched connections between the panels and studs. The notch in the stud and panel gives the double plywood wall its strength. Rule 11 … 16 are for special shaped corners that join end walls on three sides.

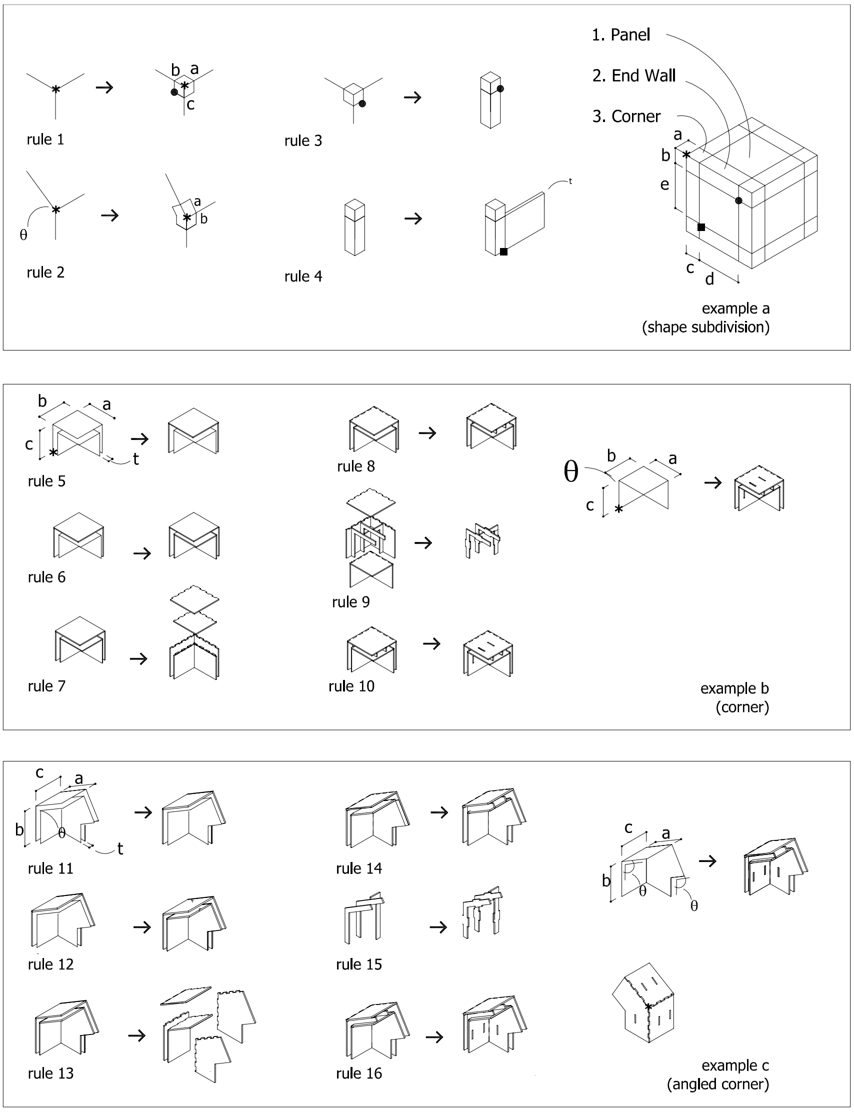


**Figure 5 Rules used to subdivide the initial shape and build corners**

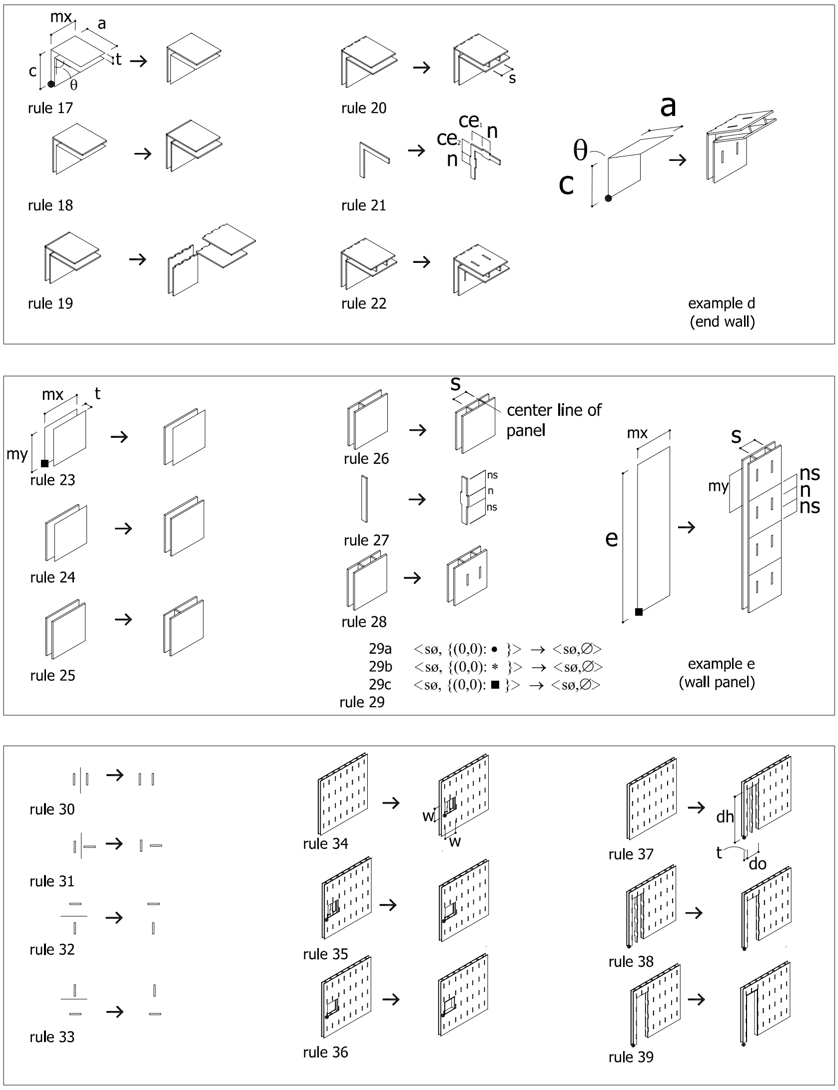


**Figure 6 Rules used to define end walls, wall panels, windows and doors**

Rules 17-22 define end walls with notched connections between flat panels as well as connections between studs and panels. Notched edges for panels are created using rules 7, 13 and 19. Rules 23-28 define straight walls with notched studs, example e in Figure 6 describes the addition of wall units to create a full infill wall of many studs and panels. Rules 29a-29c erases insertion symbols. Rules 30-33 are used to join panel and studs, for example rule 30 is used to fuse an end wall to a straight wall panel. Rules 34-39 describe the subtraction of wall panels for windows and doors. Variable "t" is the thickness of the wall panel for a smooth connection between doors and walls.

## 5 GENERATING A ROOM

The *wood frame shape grammar* can be used to create a valid room/house. Figure 7 is a demonstration of a process of operations for a shape grammar routine. If this were a computer program or script the user would be prompted with variables. The first prompt would request the user create an initial 3D shape. For this example the initial shape is a room with a pitched roof. Rules are run on a model scaled to 1" = 1'-0". Rule 1 is applied to the initial shape of 10" x 15" room with a 16" high ceiling, walls "t" are 1/2" thick. This rule is used to generate corners at the bottom and ridgeline of the roof. Rule 2 generates corners for the roof angle while rule 3 and 4 divide the model into end walls and panels. Rules 5-10 transform 1/2" thick walls into 1/16" thick panels with internal studs notched into inner and outer panels. Rules 11-16 divide the corners at the spring of the roof. Rule 17-22 creates end walls with notched corners followed by rules 23-28 that create a straight wall panel of notched studs. This phase of the grammar is terminated by apply 29a-29c to erase symbols used to insert panels. Windows measuring 2" x 2" are applied by placing a • symbol to the left of the window at the bottom of an adjacent notch. Door insertions also use a • to mark the insertion in this case at the bottom of the floor below, 1/2" from the edge "t". Phase 1 of the grammar is terminated with the application of 29a used to remove the window and door symbols.

Phase 2 of the process translates all objects in the 3D model to a horizontal position. Each panel and stud is translated to a flattened position then numbered based on the parts location in the 3D model. Walls are broken into regions north, south, east and west followed by a set of numbers for all parts within each region. After the geometry is flattened and numbered, each part is positioned within a 4" x 8" panel to be cut from 1/16" thick cardboard. In this derivation of a room there are 132 - 4" x 8" panels or (4' x 8' x 3/4") sheets of plywood (Figure 8). Next, wall panels for each side of the room are cut to fit within smaller sheets of plywood then circular subtractions are made for dog bone connectors. Smaller dog bones are used for joining studs. Phase 2 is terminated after test for tolerance connections between parts.

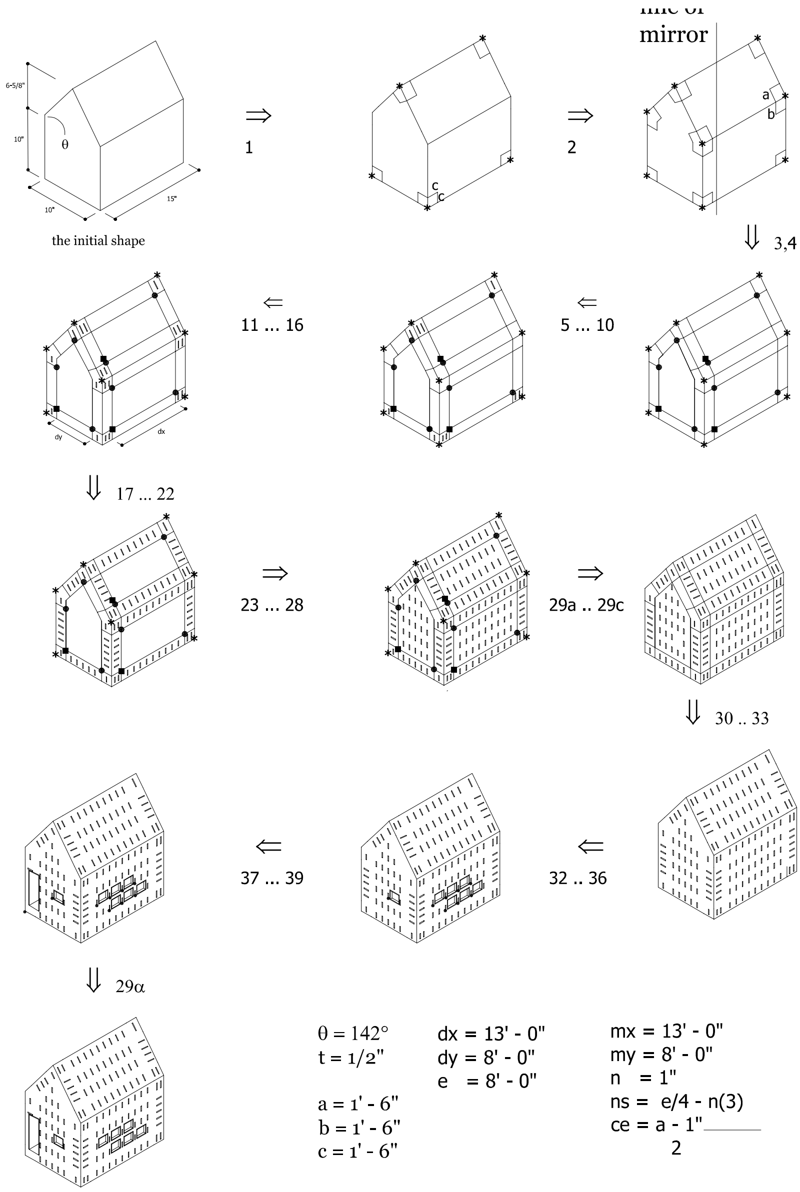


**Figure 7 Grammar derivation**

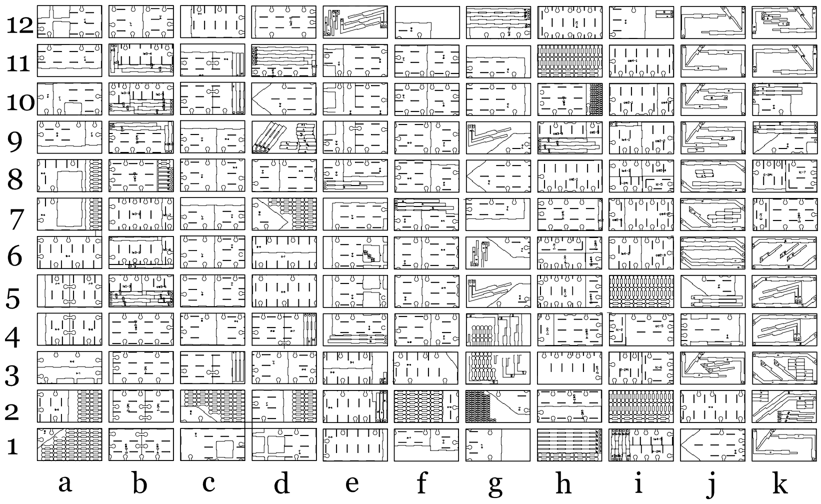


**Figure 8 132 cut sheets for 4" x 8" panels of 1/16" sheet material used to build the model in Figure 7**

## 6 CONCLUSION

The *wood frame grammar* demonstrates an effective way to generate designs and construct housing of friction fit wood connections using a shape grammar routine. The grammar also demonstrates that working with 1/16" cardboard and laser cutting is scalable to 3/4" plywood (Figure 9). The full process starts with a 3D CAD model, followed by files of parts generate from rules cut on a laser cutter. Next parts are assembled to creating a physical representation of the initial CAD model with embedded assembly logic (Figure 9a).


**Figure 9 (a) 3D print and a model of cardboard sheets measuring 10" x 15" x 16", (b) student assembling a friction fit full scale plywood section at the roof**

Having a shape grammar that handles complex building methods will lead to dynamic design shapes for rooms and buildings. The novelty of this process is the precise notching of studs to panels and panels to panels with very solid corners. A shape for a space is presented in figure 10. This shape is far more complex that that of the model in figure 9a. Future research results will demonstrate CAD scripts as functions for each rule set where initial shapes generated in 3D CAD are translated by scripts for subdivisions, corner builders, end wall scripts and wall panel functions. Ultimate goals will lead to a design program for generating wood frame houses from shape models.

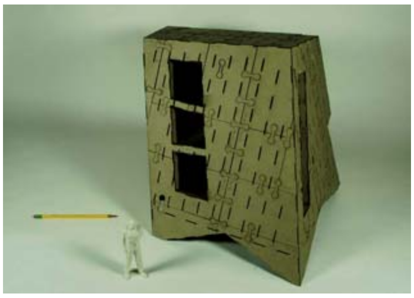

**Figure 10 Alternative design of many complex sides**

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