# The Instant House: A production system for construction with digital fabrication

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## Abstract

*A system that guides the physical production of building construction with one digital fabrication device is presented. It is a rule based system for wood frame construction that generates construction information for the production of design artifacts; as design models or full scale buildings. The goal of the research was preparation for an automated system that supports generative design production. Examples of the system are presented in the form of models and as a full scale building.*


## Introduction

Many countries in non-western, developing worlds are in desperate need of housing for population growth and housing upgrades (Figure 1a). One country in need of rapid deployment of housing is South Africa where a mandate has been pasted stating that the country must provide over 350,000 homes per annum or 1000 homes per day [1]. Two research questions follow this mandate; how should the houses be designed and delivered? Also how can design variation be considered as a variable in manufacturing? One prototypical house will not meet the needs of millions of individuals, large and small families or villages. House design will need to vary by town, by family or purpose. Needed is an automated system for rapid design generation and house manufacture. The system must allow for flexibility in design and manufacturing such that houses can vary in function and shape for the same relative the same cost per square foot of construction.

*Figure 1 Typical house (a) and a Fab Lab (b) both within the town ship of Soshanguva, South Africa, students designing and constructing with a laser cutter [2]*

This research project illustrates a suitable means to link design modeling with digital fabrication devices across scales. As part of this research a full scale house was constructed to illustrate our method and results when using digital fabrication. Novel findings from this exploration uncovered new forms of building component joinery and component function. This project is part a larger research enterprise focused on worldwide installation of digital fabrication laboratories (Fab Labs) in rural villages (Figure 1b). The goal of the labs is to open the possibilities for personal fabrication everywhere, for anyone at anytime [3]. There are machines throughout each lab that supports fabrication at a variety of scales from circuit board manufacture to house and furniture manufacture the goal of this project is to illustrate the possibilities with housing.

Research in this paper takes advantage of the relationship between CAD modeling for construction and digital fabrication by demonstration of a design delivery system [4]. Within this system each component is fabricated and attached to adjoining components with matting parts enabling joinery from friction by control of component precision; nails, screws or adhesives are not used to join components. Benefits in working this way are speed by way of paperless production from computer models. Second is the reused of design information for construction, new house designs will reuse the same construction system where the geometric system is reused or programmed to generate new geometry from the same rules for construction.

## Design Systems for Personalized Variation

It is our belief that digital fabrication can support personalized generative design fields such as shape grammars [5] and evolutionary design [6]. These fields have identified the need for design generation with computation and design variation driven by effective rule structures. Generative ways of thinking support concepts for personalized designs based on individual needs [7]. However, these two fields do not identify methods to materialize generated design solutions. For this research a range of design possibilities were prepared for our house production system. Each example illustrates design variation within the limits of the sheet material. The research in this paper presents rule based production of on of the houses in the corpus (Figure 2).

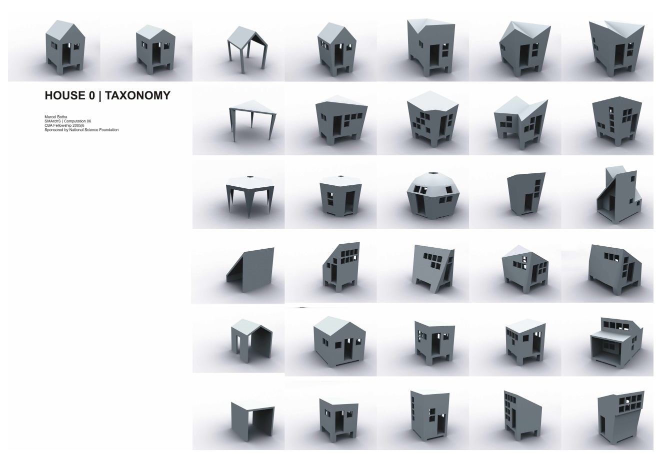


*Figure 2 Range of house types set for digital fabrication production*

## Legacy Construction Descriptions

Common construction used to erect wood framing (prior to water proofing and finishes) is composed of studs framing with a variety of materials for inner and outer sheathing (Figure 3a). This system allows for errors in construction assembly and low tolerances between components. We refer to this process as a legacy constructions system. For typical wood frame construction this pattern of stud and sheath construction is used to build walls, roofing and flooring of a range of sizes for structural members. With this system buildings are manufactured from calculated drawings or a CAD model on paper, translated by hand to the construction site with handheld measuring and cutting tools. Unfortunately, highly precise computer models hand driven construction does not take advantage of the precise links computer modeling could have with digital fabrication. Most digital fabrication devices used for the production of very large products (boats, houses, cars) require that components be manufactured from flat material stock opposed to legacy production that uses an array of stock materials. The argument of this work is based on a need for effective digital fabrication as a mathematical link between machines, materials and modeling (for design or construction). A uniform link between the three (materials, machines and modeling) is defined as a *computable construction description* inclusive of logical structures for design, fabrication and assembly (Figure 3b).

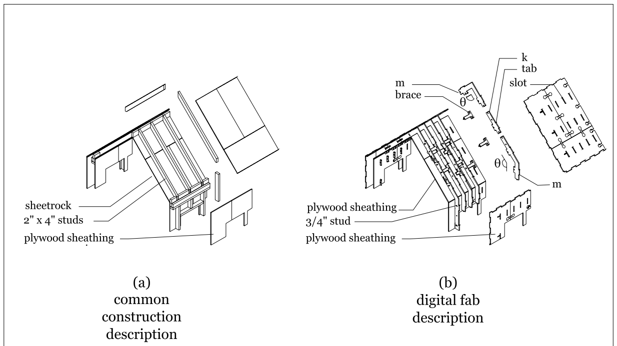


*Figure 3 Legacy assembly of wood frame construction (a) in contrast with CNC construction methods that use one material type with integral attachments (b)*

## Legacy Descriptions for Digital Fabrication

Current digital fabrication for architecture is a two part process. First, rapid prototyping is used by a wide array of designers for field testing prior to mass production [8]. Physical models are built by lateral slicing of a starting shape (Figure 4a) into paper-thin sections (Figure 4b). Workflow for rapid prototyping starts with a solid 3D file (stl) as meshed information. Models are produced in steps with intervals defined by the machine software [9]. For an overview of the most recent rapid prototyping methods, see Chua et al. [10]. Second CAD/CAM production has focused on industrial applications for mass-manufactured products such as airplane and automobile parts. Today CAD/CAM or CNC machinery is also used to manufacture many items for short manufacturing runs of specialty products. Particular to this study, CNC manufacturing has seen extensive use in processing wood products such as kitchen cabinets, staircases, and furniture from virtual models and drawings. For an overview of CNC milling and alternative machine application see Kunwoo [11]. An effective representation with rapid prototyping (laser cutting) or CNC routing is bilateral slicing of the starting shape (Figure 4b) into fewer components placed strategically throughout the artefact (Figure 4c). This representation is composed of outer layers with a mesh of internal structural support.

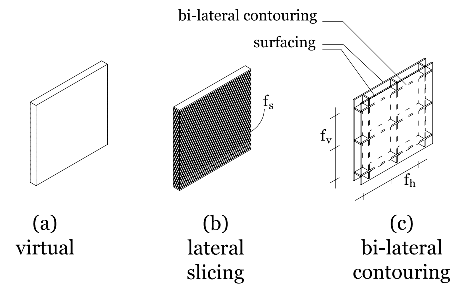


*Figure 4 Virtual solid in CAD (a) to rapid prototyping (b) to bilaterally contoured structure between two surfaces (c).*

## A Computable Construction Description

Designers create descriptions in CAD as drawings and or 3D models of legacy construction systems as building information models (BIM). As mentioned earlier geometric complication found in legacy construction descriptions are difficult to compute. Also legacy rapid prototyping methods used to build models are computable but inefficient in large product material representation and assembly. An efficient computable construction description requires that geometric descriptions be organized by two factors: rules that compose elements, and rules that describe the elements' functions (purpose, use, type, etc.) [12]. It is believed that an effective description for digital fabrication as a design or for construction is needed for a fully integrated and eventually generative design system (figure 3b). The first of two novel concepts that generate computable designs subdivides a starting shape into components as flat shapes for manufacture with a digital fabrication device. Second, a new concept for component attachment is explored. The reasons for a new form of attachment is that assemblies between smaller components make nailing, screwing or adhesives difficult without some form of alignment between mating components. Here component jointing is by tab and slot included within the manufacture of each component. Permanente joining is sustained by friction between components. Lower levels of strength by friction are for components alignment only. Researchers in the field of plastics have an array of similar ways to build and connect plastic parts by alignment and part-interlocking only. Referred to as an integral attachment the plastics industry has explored methods to build mechanical attachment features by way of mating parts manufactured with each component [13].

## Design Production

Design production refers to the translation of a design model to a physical building starting with a modeled shape (Figure 1). This production process takes in specific materials and machine constraints as part of the design input then translates the shape to specific components based on rules. Results are a model built exclusively of thin components at a real scale, e.g. ¾" in thickness built for construction (Figure 5). Starting with a building model as a solid shape, the inner and outer surfaces are remodeled as sheets with thickness (stage 1). A construction grammar of rules based on a new system for plywood construction is employed to further subdivided sheets into smaller components with limits based on the extent of the CNC router [14]. Between sheathing layers studs (of the same sheet material) are generated at intervals in horizontal and vertical directions. After, studs are also subdivided into smaller components based on a maximum length and width of the machine bed, guided by rules from the construction grammar. At this stage the model is a collection of precisely modeled components (stage 2). Next, joineries are built based on the relationship between component geometry. Each joint is provided a mating attachment from the list of attachment types discovered in early assembly testing. Last, (stage 3) components generated in 3D are translated to 2D positions and sorted for fitting within sheet boundaries. Component order and organization on each sheet is based on assembly order and not optimized for waste limitations in cutting.

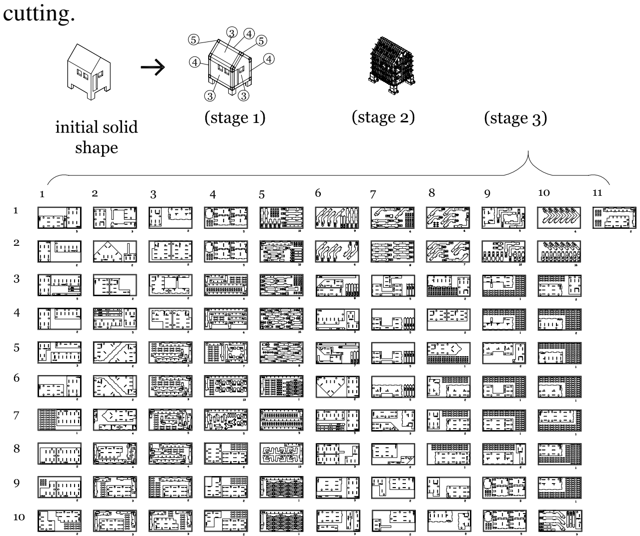


*Figure 5 Production stages starting with a solid model concluding with cut sheets*

## Materializing Design

Materialization in this study is a relationship between computer controlled routing, plywood and geometric primitives built from the construction grammar. Translation from a house shape to machine tools is based on a transformation from shape to tool paths or cut-sheets. Two artifacts were built from the same cut sheets at two physical scales. The first is a desktop model built of 1/8" plywood at a scale of (2" = 1'0") (Figure 6a). This model was constructed of total of 984 parts cut with a 50 watt laser cutter.

The purpose of the desktop model was to compare the physical behavior, assembly design and structural functions of a scale model against the full-scale construction. This model was laser-cut from (18" x 32" x 1/8") sheets of plywood and assembled with small amounts of glue in 3 working days. The second artifact was constructed of ¾" plywood built at full scale over the course of 1 month (Figure 6b). The same CAD data used to manufacture the desktop model was also used to build a full scale building with a Techno Isle CNC 4' x 8' table router (1/2" drill bit), EZ CAM software, and 101 sheets of plywood. Although this full scale construct prototype was built for demonstration each component was painted with waterproofing followed by 2 days of outdoor drying. On average, plywood sheets were cut in 20 minutes after 10 minutes of file translation from AutoCAD format to EZCam (i.e., 30 min. per sheet). Five to seven sheets of plywood components were cut per day. Total cutting time on the mill for the 101 sheets was 55.4 hours, not including file translations to CAM software and plywood setup. True assembly time was 35 hours (estimated time) with a rubber mallet and crow bar for alignment.

*Figure 6 Laser cut model at 1" = 1'-0" (a), the same information used to build the final house (b) constructed exclusively of ¾" plywood with studs and furniture.*

## Results

The resulting artifacts from the system were a desktop model and full scale building assembled with a rubber mallet and crow bar only (Figure 7). Joint friction proved to offer sound solid connections between components to sustain assembly. A key function in the method was that internal studs were manufactured of many parts from standard sheets of plywood all were less than 6' square, held together by friction only. Longer term research goals with houses to follow are improve assembly efficiency, reduce the number of components and assure waterproofing as part of the system generation. This project illustrates the possibility of manufacturing one room in approximately 6 days from conceptual modeling to full scale delivery. The resulting structure was tested for weathering for two calendar months with few signs of warping or disassembly. However, the structure will require a weatherproof skin.

*Figure 7 Full scale artifact under construction (a) and finished (b).*

 

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## Author Biography

*Larry Sass is an architect whose research explores the relationship between design, computing and digital fabrication. Current research projects explore a range of interests in digital fabrication, specifically by study of physical models and buildings. He was trained in design at Pratt Institute (BArch) and computing at MIT where he received his SMARCH and PhD.*