DESIGN FOR DECONSTRUCTION AND MODULARITY IN A SUSTAINABLE BUILT ENVIRONMENT

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ABSTRACT

Construction, renovation, and demolition are significant consumers of energy and natural resources. Design for deconstruction (DfD) and modular construction are two design methods with the capacity to reverse this trend by streamlining construction processes and conserving building materials for reuse at various levels of pre-assembly. This paper seeks to highlight the challenges and advantages of each system in the current industry and then propose a hybrid system that will integrate DfD and modularity, eliminating many of the drawbacks of each design technique.

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INTRODUCTION

Environmental issues have gathered increasing attention from the construction industry in America and abroad over the last couple of decades. While green building certification bodies are already requiring basic measures to slow resource depletion, design for deconstruction (DfD) and modular construction are two innovations that further refocus the construction industry to become more sustainable.

Chini and Bruening (2003) define DfD as "the disassembly of structures for the purpose of reusing components and building materials. The primary intent is to divert the maximum amount of building materials from the waste stream." DfD is the act of designing a building with all of the possible future uses and end-of-life redistributions in mind. It is in this way that some of the prohibitive barriers to deconstruction are avoided, ensuring a reduction in construction waste and resource depletion.

Modular construction takes the sustainability commitment of DfD one step further by eliminating the high economic and energy cost of completely dismantling a structure before it can be reused elsewhere. It performs the same function on the macro scale – that is, with modules. A module is a pre-manufactured cell that usually comprises an entire room. Or, in more advanced design, a room might be site-built using two or more modules. On-site construction activity is thereby reduced considerably, lessening site impact, labor mistakes, weather delays, and many other construction problems.

It is important that the construction industry be targeted for an environmental overhaul because it accounts for a dominating share of waste in America.

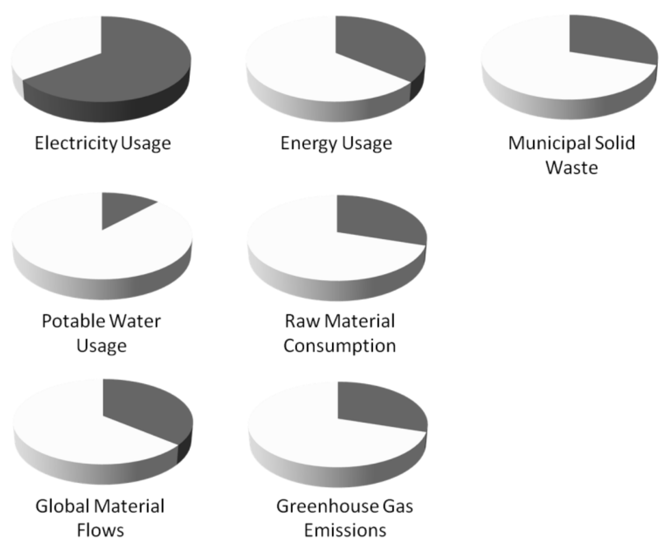

Figure 1 – Levels of consumption attributed to the construction industry and built environment

Many different numbers have been offered forth by various sources, but Kim (2008) suggests that 65% of the electricity, 36% of the total energy use, 12% of the potable water, and 30% of the raw material consumption are the direct result of the built environment in the United States considering both construction and day-to-day activities (see Figure 1). Perhaps more alarming considering the present atmospheric concerns is the building sector's contribution of 30% of both the nation's municipal waste and greenhouse gas emissions. Roodman and Lenssen (1995) add that new construction, maintenance, and renovation account for 40% of the world's material flows. Further investigation gives mildly different values from different sources, but these are largely representative. While these statistics include daily activities of buildings already constructed, it will be shown that modular construction not only scales back effects to the environment and the site during construction, but also in operation due to the higher quality of workmanship that is possible only in a factory setting. This lowers consumption of electricity, energy, and greenhouse gases. DfD contributes to the solution by checking energy use for manufacturing new materials, raw material consumption through reuse, municipal waste, and greenhouse gases.

The urgency of construction industry reform is slowly catching up to the automotive industry; this lag is perhaps due to consumer awareness (gas mileage is easier to track than overhead energy costs and resource waste) or the conservative nature of the construction industry. However, there are still formidable hurdles to be overcome before the construction industry embraces sustainable building concepts such as DfD or modular/factory built housing. Hassell et al. (2003) outlined five difficulties the residential building sector faces: competition, violent economic swings, low research and development budgets at small companies, industry fragmentation, and what the authors call the construction industry's open nature, which makes it difficult to maintain competitive advantages.

This paper will survey the current industry landscape of sustainable building practices by focusing on DfD as well as modular construction. The economic, environmental, and practical issues facing both will be examined to better understand what must be done to foster the growth of sustainability in the building sector. This paper will answer to the following objectives:

1. Analyze the current status of DfD in housing.
2. Review modular construction techniques in construction.
3. Examine the issues posed by building materials in connections for implementing DfD strategies.
4. Envision a new paradigm for design, engineering, and construction using elements of DfD and modularity.

DfD

An Introduction to DfD

Chini and Bruening (2003) offer the five end-of-life outcomes for a material. In descending order of environmental preference, they are: up-cycling, reusing, recycling, down-cycling, and land filling. Up-cycling happens when a material's subsequent uses are of higher value than the use before it. Reuse differs from recycling in that recycling requires an energy input; only then can the resource be reused. An example of reuse is refilling a water bottle, whereas an example of recycling would be to chemically clean and break down a water bottle to manufacture a new one, which requires energy but preserves the resource. Down-cycling refers to the degradation of a material before reuse. It will be reused, but at a lower value and with a shortened lifespan. Cutting off the top of an old water bottle to catch cooking grease illustrates this concept because it is no longer fit for the original use. Sending used materials to a landfill is the final and least attractive option.

The concept of DfD addresses the industry's desire to shift the accepted end-of-life destination for building materials. Instead of the current trend of sending the majority of demolished building materials to landfills, DfD facilitates outcomes in the reuse, recycle, and down-cycle range (see Figure 2). Crowther (2002) uses his own concept of what he calls the "recycling hierarchy" (reuse, remanufacture, recycle, maintenance) to further clarify that DfD is more effective if the materials are reused rather than recycled, which requires extra energy input. DfD affects other positive changes as well. The sustainability movement adopts what is known as the "Triple Bottom Line," which is a form of accounting that introduces social and environmental effects to traditional financial accounting. DfD can be assessed within this framework rather effectively and favorably.

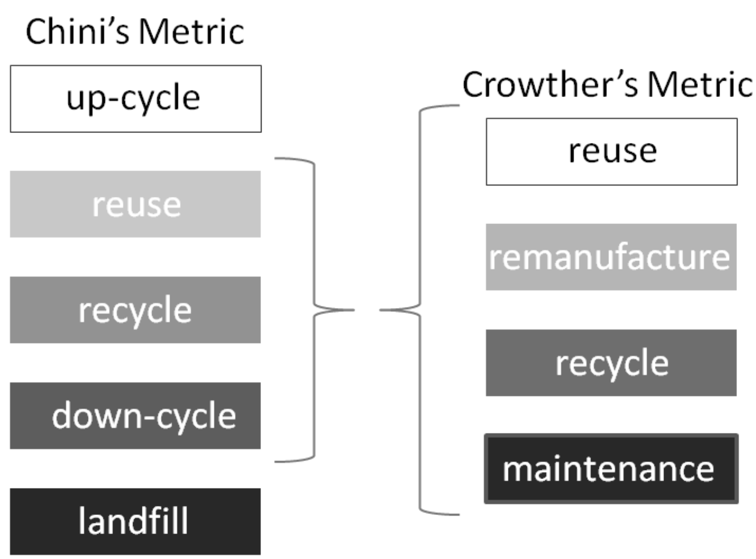

Figure 2 – End-of-Life Metrics

For the remainder of this paper, the definitions given at the Building Research Establishment conference by Hobbs and Hurley will be assumed. "'Disassembly' is the taking apart of components without damaging, but not necessarily to reuse them elsewhere. 'Demolition' is a term for both the name of the industry and a process of intentional destruction. 'Deconstruction' is similar to disassembly but with thought given toward reusing the components."

An Overview of the Impact of DfD on the Triple Bottom Line

The first and most closely related effect of DfD on the environment is the alleviation of pressure on current landfill sites. An increase in the reuse and recycling of building materials means a decrease in landfill waste. Franklin Associates (1998) report the EPA estimate that 90% of the 115 million tons of construction and demolition waste in 2000 that was sent to municipal solid waste landfills was due to renovation and demolition. Remembering that 30% of municipal waste is credited to the building sector, this means that over a quarter of the volume of land-filled materials in the United States is due to renovation and demolition. Also, because DfD requires invasive inspection and sorting of deconstructed building elements, the work site environment sees less contamination from hazardous materials such as asbestos, lead, and dust (Macozoma 2002).

Reducing demand for new material has a number of secondary environmental effects that are felt all the way back to the extraction process. The focus on land management is allowed to shift from the economics of logging to the health of the forests; resource depletion is slowed when iron ore and alloy elements are left in the ground; and, greenhouse gas emissions dwindle as work activity slows to meet demand. Manufacturing and transportation energy consumption drops as new materials are not forged and the construction industry becomes more localized according to material availability (salvage yards).

The second "Bottom Line" participant is society. Deconstruction is a delicate task when compared to demolition. It requires special skills and methods, as well as many more labor hours to complete. At present, these are important reasons that deconstruction has yet to firmly take hold as a popular practice. To combat these issues will require a newly trained workforce and advanced planning strategies in both the design phase and during the building's operational life. Chini and Bruening (2003) argue that the market niche, which they call "resource recovery," created by the acceptance of DfD will create ten jobs for every landfill and demolition job. This creates a chain reaction including small business growth. A move toward resource recovery and away from solid waste disposal would also make high quality yet inexpensive building materials available to low-income areas, providing an assumed opportunity for community revitalization. Further government subsidies would spur this used material flow as a means for sweeping environmental, economic, and social improvement.

The final "Bottom Line" is the economy. Multiple case studies for deconstruction have shown that deconstruction is cheaper than demolition. Take note that the buildings these studies evaluate are generally chosen because they are particularly amenable for deconstruction. The deconstruction feasibility will be addressed later in this paper, but in short, they are structurally sound, contain valuable materials, and exist in regions with a demand for used building materials. Also be aware that deconstruction only becomes cheaper after the salvaged materials are sold on the reuse market. The initial cost or capital expenditure is categorically higher due to the labor hours required for disassembly versus demolition – materials are carefully removed, sorted on site, and then either sold on site or transported to a salvage market. Chini and Bruening (2001) estimate that this process takes between two and ten times as long as demolition. Landfill tipping fees are avoided at this point, but these are heavily outweighed by the labor required. These studies additionally only consider the economic feasibility from the previous owner's perspective. If, because of the labor hours required, salvaged building materials become more expensive than cheaper new materials, the salvage market would fail as an institution. However, all economic studies contributing to this paper were performed on buildings that were not designed to be deconstructed (Kibert et al. 2000). The concept of designing for deconstruction is to make deconstruction more attractive than demolition, and this translates directly to the speed of deconstruction, because in the field, decisions are based on finances first, with the environment and society taking a distant back seat.

Current Design Strategies in DfD

A successful DfD industry depends on extensive planning for a future that holds unknown societal trends toward the built environment. As such, architects and engineers will be required to produce designs that can accommodate needs which are currently unknown.

The concept of building layers has been used by multiple deconstruction experts to attempt to redefine how buildings are perceived. Instead of seeing it as a monolithic mass, the architect or engineer should be careful to discriminate between discrete building layers that are time sensitive. Using this mode of thought, buildings can be designed and built so that elements requiring more frequent replacement or maintenance are not entangled with elements with significantly longer maintenance-free lives.

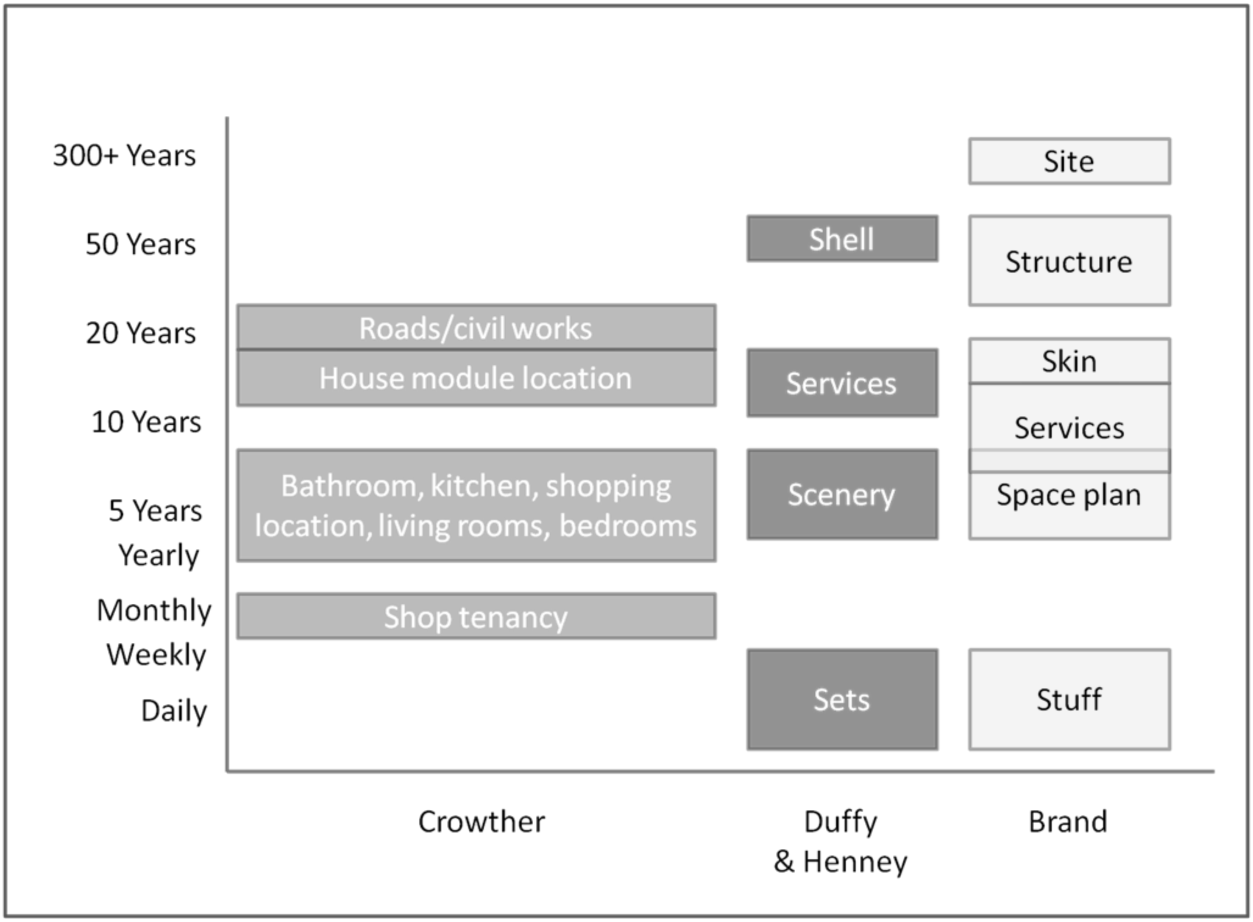

Figure 3 – Building layers

In Figure 3, Crowther (2002) identifies his seven-layer system which relates more to modular construction, which will be addressed later, but provides a good point of reference for comparison. The first layer is "roads/civil works," to which he assigns a 20-year lifespan. Next is the "house module location," which is estimated to last 15 years. Then, in descending order from approximately 8 to 3 years are living rooms & bedrooms, workplaces & offices, shopping location, and bathrooms & kitchens. Finally, "shop tenancy" lasts for 6 months. Crowther then cites two more perspectives on layers which center more on concepts relating to DfD. Duffy and Henney (1989) give four layers: shell, services, scenery, and sets. The "shell" has a 50-year lifespan and includes the foundations and structure. The "services" represent the electrical, hydraulic, HVAC, lifts, and data systems, and are assigned a lifespan of 15 years. "Scenery" is intended to be adjusted every 5 to 7 years, including partition walls and furniture. The "sets" are "arrangements of movable items" which have daily to weekly layouts. Brand (1994) expands Duffy's model to six categories. "Site" is eternal and represents the ground on which the building sits. "Structure" replaces Duffy's "Shell" but the lifespan is a range between 30 and 300 years. "Skin" is the roofing and cladding. Brand issues skin a lifespan of 20 years because of maintenance issues as well as changing fashion and technology. "Services" has the same definition, but with a slightly altered lifespan. "Space plan" is the same as Duffy's "scenery" and "stuff" is equal to Duffy's "sets."

The most critical design consideration when aiming for deconstruction over demolition is the connections. Contrary to seismic design principles, deconstruction is most easily accommodated by few connecting elements rather than many smaller elements. In this example, the assumed structural system is timber connected with steel bolts; changing the design philosophy to favor deconstruction results in decreased ductility because large bolts are less likely to fail while the timber is more likely to crush. The connection should also be easy to locate and access with power tools for ease of disassembly. Adhesives should be avoided, especially when used between heterogeneous materials, as is commonly done in flooring systems to minimize squeaks.

Crowther (2002) makes an important connection between the buildability and deconstructability of a design. He argues that a building that is designed to be built quickly and efficiently will also adhere to many of the principles that support deconstruction over demolition. In this light, he presents seven principles of buildability as given by the Construction Industry Research and Information Association (Crowther 2002). Their findings are to: carry out thorough investigation and design, plan for essential site production requirements, plan for practical sequence of building operations and early enclosure, plan for simplicity of assembly and logical trade sequences, detail for maximum repetition and standardization, detail for achievable tolerances, and specify robust and suitable materials. Adams (1989) gives three guidelines – adhere to the tenets of simplicity, standardization, and clear communication. The Construction Industry Institute adds the necessity for construction-driven planning and programming, design simplification, standardization and repetition of design elements, specification development for construction efficiency, development of modular and pre-assembly design to facilitate prefabricated installation, accessibility of labor, materials, and plant, and for designs that facilitate construction under adverse weather conditions.

Current Deconstruction Strategies in DfD

Deconstruction need not wait until the buildings that are beginning to be designed for it are ready to be torn down. The first step in deconstructing a building is to determine if it is worth deconstructing by performing an inspection. Then, a deconstruction permit is required to begin work. This step varies with jurisdiction, but is typically different from a demolition permit. Deconstruction permits carry more stringent rules regarding hazardous materials such as lead, asbestos, and dust. Finally, deconstruction work can begin.

Taking an accurate building inventory is the key to making an informed decision as to the method of razing the structure. Salvage experts, while few and far between, are preferred agents in this step. Architects, engineers, builders, and materials inspectors are also satisfactory candidates. Things to look for include the condition of structural members with respect to holes resulting from field-fit HVAC, plumbing, or electrical conduit or structural fasteners, rot, rust, or the presence of hazardous materials. Special attention to the connection scheme can pay dividends, as some are prohibitively time consuming to deconstruct while preserving the value of the connected element. Chini and Bruening (2003) list some favorable characteristics: heavy timbers of unique woods, specialty items such as expensive hardwoods, doors, or fixtures, brick combined with low-strength mortar for easy cleaning, and undamaged, structurally sound elements. Moulton-Patterson et al. (2001) published a Building Materials Inventory Checklist that has been reproduced in the Appendix of this report.

At this point, the feasibility assessment can begin. Chini and Bruening (2003) give three assessment methods that range in accuracy and commitment. The first is an informal site visit by a deconstruction agent, preferably a salvage expert, in which there is no invasive survey. This method, while expedient, leaves much room for error in the economic analysis due to a high degree of uncertainty as far as labor hours, hazardous material disposal costs, and resale quality. The second method is the building materials inventory described above. In simple terms, Macozoma (2002) writes that the building materials inventory reveals "how and of what the building is made." Guy (2001) has designed a computer program to assist the deconstruction agent. The program includes tools to facilitate pre-sales, which affords more accuracy to the economic analysis, and also guides the agent with questions targeted at "revealing the potential profitability."

Deconstruction proceeds in roughly reverse order of construction – trims, casings, and moldings go first, then appliances, finish plumbing, cabinets, windows, and doors, then floor coverings, wall coverings, insulation, wiring, and rough plumbing, and finally the framing (roof, walls, and floors) (Moulton-Patterson et al. 2001). The term "soft-stripping" was coined by the National Association of Home Builders Research Center (2000) (NAHBRC) and refers to removing the finish elements such as appliances, fixtures, cabinets, etc. At the completion of soft-stripping, structural elements are then brought down in reverse order of construction. It is for this reason that enlisting a builder to help plan a deconstruction project is advantageous to the deconstruction team.

Economic Case Studies of DfD

A successful deconstruction effort requires economic feasibility on the regional and site levels. For example, a building might be built according to the tenets of deconstruction, but if it is built in an area with an inadequate market atmosphere, material salvage prices will not make up for the extra labor expenditure or salvage may not be possible at all. Factors that affect the regional economic viability of deconstruction include the level of new construction activity and old development, the reuse market, and public sector involvement. The site-level economic outlook has more to do with the building and where it is located.

The single most important factor affecting the decision to deconstruct or to build with deconstructed materials is the availability of those materials or markets. Without a market, reused materials will not be salvaged or designed and built with, so the deconstruction industry suffers. Macozoma (2002) points out that a healthy deconstruction industry depends on a large number of buildings being available and suitable for deconstruction or salvage. Achieving these conditions relies on a heavily developed region with an active new construction industry. Tables 1 and 2 indicate the growth potential regarding the amount of salvaged materials that actually end up being sold and at what price. Just as important is the presence of a reuse market. This includes used lumber yards, re-grading protocols, involvement of the governing codes, and consumer perception and acceptance. One way to promote these changes is to involve the public sector. This could include government subsidies or tax breaks on land used for storing inventory, favoring deconstruction over demolition or adjustments to the permit process that would influence owners, builders, and designers to consider designing for deconstruction. In other words, local demand plus government benefits must compensate for land use.

Table 1 – Example of Market Reaction - Results of Riverdale Site Sale (Chini 2001)

Salvaged Material	% of Total Amount of Item Sold	Sale Price As a % of Estimated Retail
Framing - 2x4 higher quality	75%	45-50%
Framing - 2x4 lower quality	15%	~25%
Framing - 2x8 higher quality	50%	45-50%
Framing - 2x8 lower quality	40%	~25%

Table 2 – Results of Whole House Recycling Project in Portland, OR (1993)

Salvaged Material	Sale Price As a % of Estimated Retail
Framing lumber	40%
T&G siding	50%
Doors	30%
Brick	35%

Table 3: Comparison between demolition and deconstruction costs for Presidio Building #901

Item	Deconstruction Cost	Demolition Cost
Labor	$ (33,000)	
Equipment/Disposal	$ (12,000)	
Administration	$ (8,000)	
Total Expenses	$ (53,000)	$ (16,800)
Material Salvage Value	$ 43,660	
Net Cost	$ (9,340)	$ (16,800)
Savings	**$ 7,460**	

The sample study in Table 3 from the EPA (2003) shows some of the differences in cost between demolition and deconstruction. Notice that it is virtually impossible to deconstruct cheaper than to demolish; however, material salvage value and other important factors make deconstruction the favored route in most cases. Further study in the field of economics is warranted to predict supply and demand curves for deconstructed or salvaged building materials in various regions.

Challenges in DfD

Kibert et al. (2000) address nine challenges that DfD faces: "existing buildings are not designed for dismantling, building components are not designed for deconstruction, deconstruction tools most times do not exist, demolition disposal costs are low, deconstruction takes substantially more time, building codes do not address component reuse, costs are unknown in deconstruction, lack of broad standardized industry practices, and the hazardous material, economic, and environmental benefits are not well known and understood." Market acceptance is possibly the most important challenge to overcome. With public interest and involvement will come pressure to solve some of the more technical issues facing DfD.

Consumer taste not only refers to the owner but also to architects, engineers, and builders (Recycled Construction Product Market 2003). However, consumer perception does begin with the owner – human nature tends to gravitate toward new and flashy rather than used. Architects have their tendencies as well. Typically a planner is comfortable with certain brand names, manufacturers, or products. Specifying reclaimed materials can be unnerving when one's reputation is at stake. That said, architects are the most likely of the three groups to accept and design with salvaged materials. Builders are the slowest to accept used or recycled materials. The Recycled Construction Product Market suggests that this is due to the nature of the construction industry – contractors are reluctant to change what is already a proven method. These barriers are best confronted with knowledge, which would alleviate the perception of risk that is associated with using salvaged materials in new construction. For this to occur, standards for recertification and code acceptance will be required.

At present, visual grading rules for dimension lumber are intended for new stock (Chini 2001). Nail holes, utility punch-outs, slight damage, and various other imperfections resulting from the deconstruction process are not addressed by grading agencies (Falk 2002). In addition, re-grading (when legal – which is not the case in Florida, according to the Southern Pine Inspection Bureau) is only done in large batches for economic reasons, and these large batches are given a blanket rating which lowers the value of the higher-strength members. Mechanical testing at the Forest Products Laboratory is ongoing to study the effects of bolt and nail holes, warp, knots, and other damage-related defects (Grothe and Neun 2002). This information should open the door for efficiently and effectively visually grading salvage lumber.

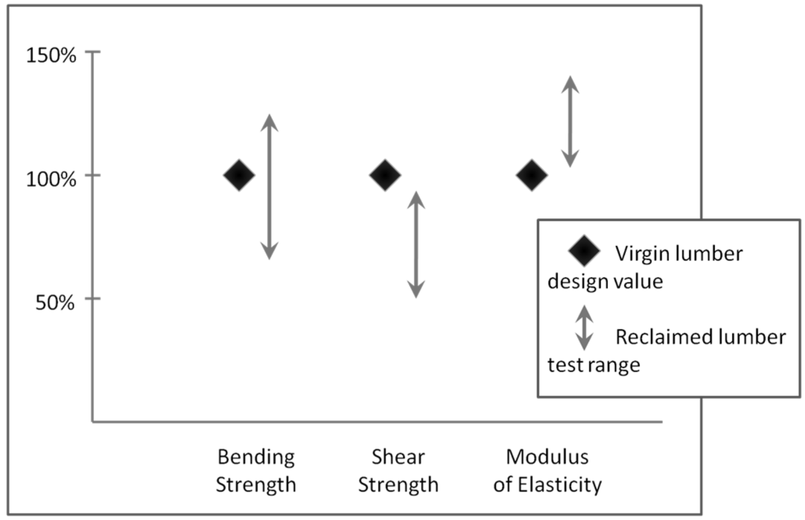

Figure 4 – Virgin lumber design strength versus reclaimed test results

Results from mechanical grading tests are provided by Chini (2001) to compare strength values of virgin lumber to salvaged lumber. Bending, shear, and deflection checks reveal surprising results: reclaimed lumber scored between 71 and 125% of the bending strength of virgin wood, shear values were between 50 and 95%, and the bending modulus of elasticity was between 109 and 137%. These numbers are explained quite simply. First, virgin lumber is graded quite conservatively to account for the high variability of an organic material. This process uses the 5% exclusion method, so that nearly all pieces of dimension lumber would score higher in all three categories than their rated strength. This explains why reclaimed lumber can exceed virgin lumber values. Second, reclaimed lumber was virgin lumber at least 20 years ago – although it is more likely 50 years ago. There was not the shortage of old-growth timber that there is now, and as a result dimension lumber of yesterday was denser and therefore stronger. This explains the higher modulus of elasticity. Finally, shear values tanked due to bolt and hail holes near the supports. Trimming these pieces would increase their strength values, but with careful attention paid to the usability of a board that is trimmed too short. Designing a non-destructive connection and applying a simple safety factor to reclaimed lumber would negate these discrepancies and usher in a host of new possibilities in the deconstruction industry. Technical and theoretical knowledge regarding re-grading protocol should provide comfort to grading agencies and code authors and as a result, the consumers, architects, and builders who will use this resource.

Other necessary advances are assessment tools, small business development, and involvement of the public sector. Guy (2001) has written a computer program to assist the deconstruction agent with spreadsheets as well as prompting the right questions to ask. Tools such as this are a vital part of the puzzle. Development of physical tools, both automated and hand-operated to help decrease the excessive labor-hours required, would be an obvious boon. Finally, small businesses with local roots are needed to provide used lumber yards as a place to sell these deconstructed materials to. This step will require some government intervention in the form of grants, tax breaks, or other incentives because the size of the deconstruction industry is prohibitively small for companies to risk devoting land to this uncertain market sector.

MODULAR CONSTRUCTION

An Introduction to Modular Construction

Modular construction can be thought of as DfD on a larger scale. Instead of dismantling to the individual element, modularity entails preserving whole modules in deconstruction. Doing so represents a paradigm shift in favor of economy and simplicity. While the concept of mass customization does apply to modular design, there is an incremental loss in design freedom. Merging the two design methodologies will be shown to negate this loss, however.

A modular home is not the same as a manufactured, mobile, or HUD home. Whereas these homes are intended for low-income consumers and are of lower quality than a conventional site-built home, modular homes are customized homes substantially built in a factory, then shipped to the site in modules or units which are tailored to fit on semi trailers (Gurney 1999). The increased worker comfort, supervision, and inherent checks as a module moves down the assembly line actually cause factory-built homes to be of higher quality than a conventionally built home. Kim (2008) reports that conventional housing creates 2.5 times as much construction waste than a modular home due to the nature of a modular factory. There is, however, a 9% decrease in materials use in conventional construction because each module must be freestanding, so interior walls between modules are doubly thick. A tradeoff is seen in a modular home's global warming potential on the order of 5% lower than conventional because the workmanship tends to be higher quality. Thus, the modular home is 80% more airtight (Kim 2008).

Current Modular Construction Process

Modules are built on a factory floor, and as a result, many of the principles of "mass customization" used in the production of airplanes, automobiles, computers, and other products can and should be borrowed. Mass customization was coined by the computer company Dell as a way to efficiently deliver a product that is both mass produced (sameness promotes economies of scale and efficiency) and customizable (Kieran and Timberlake 2004). Henry Ford figured this out in the early 20th century with his invention of the assembly line, which brought the work to the worker. This also allows the workforce to specialize and become extremely efficient at a single task, such as assembling the dashboard. Or in the case of home construction, a specialty might be compared to a subcontractor in conventional construction, with the exception that a single factory would employ all subcontractors simultaneously to complete multiple modules per day at a more steady work rate. Redman Homes has used this concept to reduce its schedule from order to on-site installation from 4 months to 8 weeks (Kim 2008).

Much like the assembly-line Ford automobiles, Boeing aircraft, or Dell computers, modular homes are constructed on an assembly line (Kieran and Timberlake 2004). Depending on the needs of each order, the line configuration can be manipulated to consolidate the use of specialized or heavy tools. Certain lightweight tasks are not tied to a physical spot on the factory floor. For example, a workstation designated for painting might need to be stationary because moving the paint sprayer down the line slows progress more than installing finish electrical or plumbing fixtures would. Mullens (2004) reports that a module moves through the factory in one to four hours. During this time, labor is divided into workgroups that are very similar to subcontractors. Some groups that perform lighter tasks are free to move up and down the line if they are working faster or slower than the movement of the module through the factory. These spatially-flexible groups are immune to stoppages due to bottlenecks.

The Economics of Modular Construction

The economic benefits of modular construction lie in the concept of mass customization. Cameron and Di Carlo (2007) cite that modular construction financially outperforms similar conventional construction sites typically between 5% and 15% due to less loan interest (shorter construction time), less soft costs, more immediate revenue, less market risk (change orders and market swings), less labor, and by the concept of scale economies. There are additionally fewer mistakes because the upfront design and detail work is much more exhaustive. The higher end of the savings spectrum can be attained in regions with a strong modular market that promotes the economy of scale, sound design with many early modular-specific value-engineering decisions, and low-cost, high-quality labor. The economic risks assumed by the developer are caused by the fast production time of a modular building (Cameron and Di Carlo 2007). Unless the owner phases development of a modular community or has significant presales to protect him- or herself financially, there is likely to be too little time from beginning production to react to changes in demand. In a conventional development, construction is slowed or halted upon realization of declining sales, whereas in modular construction, the entire development may already be out of the factory. Gurney (1999) adds that the transportation cost is often the most prohibitive obstacle to overcome.

Challenges in Modular Construction

In 1996, the modular housing industry owned 2% of the national housing market (Bady 1996). By 2002, Traynor (2002) reported that this number rose to 3% after enjoying a 12% increase in 2001. A 2008 survey by the Census Bureau found that 7% of homes were produced by the modular construction industry, thanks to a rise from 32,000 to 37,000 units that year (Kim 2008).

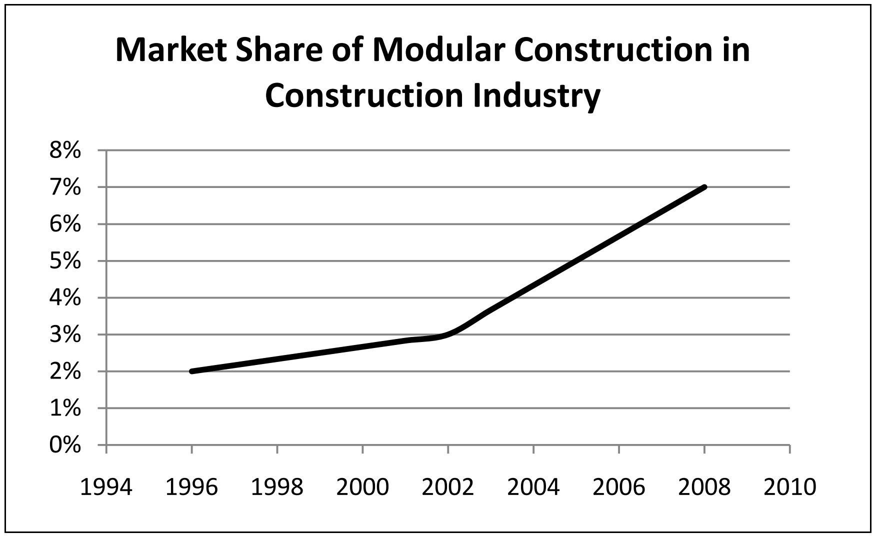

Figure 5 – Modular Construction Market Growth

More importantly, however, they found that while conventional construction rose by 8%, the modular industry jumped by 11%. This increasing market share shows that the consumer is becoming more aware and interested in the modular market. Of note is the concentration of these market share gains – Cameron and Di Carlo (2007) report that between 2001 and 2007, the northeastern United States saw a 57% growth in modular construction. This is arguably due to a push to move construction indoors during the inclement winter months and hot, humid summer months.

However, the modular industry still has a long way to go before it is a main player in the construction industry. Mullens (2004) identifies four roadblocks to this end: public perception, design, production, and construction. Confusion and lack of knowledge or awareness is the culprit for the public perception problem, because “modular” and “factory-built” sound too similar to “mobile” and “manufactured.” However, the similarities between a factory-built home and a HUD or mobile home end at the name. Many of the same opportunities to customize a home exist in the modular industry as in the conventional construction industry. The quality of a modular home tends to outperform a conventional home too, because of the close control that exists in a factory environment. Carlson (1991) expands on the design problem by saying that “modular can’t keep pace with the site-built competition with a wide enough range of form, finish, detail, and technology options.” Mullens (2004) affirms that this statement holds some truth, but these issues can be overcome with more research and innovation. Production is a roadblock because the construction method is fundamentally the same as site-built. As Mullens says, “modular manufacturers still build the same way as stick-built, just under a roof.” Mullens argues that manufacturers should investigate more truly modular construction techniques. Finally, connecting the modules onsite still employs the same construction techniques used in conventional construction.

The nature of modularity that makes it an advantageous construction method also presents some drawbacks. Because the structure is built in sections, certain transportation limits apply, as well as some issues pertaining to the joining process onsite. Since travel permits become expensive with increased widths, the dimensions of modules and subsequently the rooms in a home are limited to discrete increments. Gurney (1999) mentions the related issue of the necessity to over-design modules to withstand the stresses felt during transportation and especially during the final lift and set process. She describes some tricks to protect the areas likely to be damaged in this process: OSB wrap, metal bracing at the corners of headers, temporary walls (for joining multiple modules to make one open room), rounding off recessed corners in drywall, and using trailers designed to reduce the forces transferred to the modules in transit. Travel distance is also a concern. Redman Homes is reported to have a maximum travel radius of almost 1800 miles (Kim 2008). Hopefully, with the proliferation of the modular industry, this radius (seen in Figure 6) will shrink considerably for the average modular company. More innovative solutions are being sought to improve the shoring design for modules in transit, especially open-sided modules destined to become half or part of a single room.

The final step in modular construction is module interfacing, or joining sections to complete the home. While this design is responsible for many positive effects such as better insulation and soundproofing due to double-wythe walls, less mold as a result of better quality assurance and tighter waterproofing, and better structural integrity due to the repetitiveness required by the transportation (Cameron and Di Carlo 2007), there are still some difficulties – mainly the awkward lifting challenge and getting the field fits down to an acceptable tolerance. Thankfully, in low-rise multi-family and smaller residences, the awkward lifting required by expansive room sizes don't occur (Cameron and Di Carlo 2007). The tolerance requirement is also eased because the factory environment allows builders to store lumber inside and by acquiring inventory, to avoid using green lumber (Kim 2008).

Figure 6 – Redman Homes module transportation radius

The design and engineering of a modular building goes a long way toward making it a more preferable choice over conventional construction. Probably the most discouraging design issues are mechanical, electrical, and plumbing conduit. Utilities are the main reason that buildings cannot be designed as flexibly as many designers would like. For instance, moving a wall to accommodate a new floor plan entails remodeling the utility connections. Tackling this issue at the outset of a design would open up many new possibilities in panelized construction as opposed to modular construction. Methods to achieve this end include standardizing utility fixture locations providing conduit that is ready for use but not necessarily employed (see Figure 11).

The versatility of modular construction is profoundly affected by the materials used. Gurney (1999) argues for the use of engineered lumber products to enable advanced architectural framing schemes. Typical problem areas that would require specialized materials or engineered components include marriage headers between modules, ordinary headers, and wall, floor, and roof framing. Gurney reports that “steel does not appear to have a significant future in the modular housing industry,” citing the monumental effort required to get a modular steel operation in full swing. It is worth pointing out a successful foray into steel as a modular material in Mullens’ steel chassis design, which is a type of grade beam foundation design using hollow rectangular steel sections for the grade beam and running steel sections vertically as the backbone, on which modules and structural members can be attached (Mullens et al. 2005).

MATERIALS AND CONNECTIONS NEEDS

Hobbs and Hurley (2001) briefly discuss the current direction that the DfD industry is taking with respect to the four main construction materials: steel, timber, masonry, and concrete. Steel presents a challenge unique to the material in that it cannot be used if it has entered the inelastic range. This results in a preference for reinforcement steel to be reclaimed for recycling rather than reuse. Currently, there are heavy duty magnets that collect reinforcement steel as reinforced concrete is crushed for use as aggregate. Bolts are an additional source of steel that ideally would be reused, but this would require a specialized tool to be developed that could non-destructively remove bolts. The Scandinavian countries have begun to specify a “connector-free zone” in timber construction which eliminates the necessity of removing nails and screws, but the reclaimed timber is salvaged at a shorter length. Masonry is difficult to deconstruct because it violates one of the main tenets of deconstruction-friendly structures, which is to stay away from adhesives. In this case, the mortar acts like an adhesive. The best course of action is to use lime-based mortars over Portland cement, as Portland cement is stronger and thus more difficult to separate. Using high-quality bricks reduces the risk of damage in the deconstruction process. Reusing concrete is much more difficult, and excludes cast-in-place concrete. The authors suggest that the Dutch have seen some success at reusing pre-cast concrete sections, but with difficulty. All of these processes share one thing in common – extensive labor hours. This escalates the probability of accidents and injuries, so worker training and safety assumes even higher urgency. Kibert et al. (2000), Guy (2001), Chini (2001), and the NAHBRC (2000) all recommend plans that are worth further investigation.

Hobbs and Hurley’s discussion raises the concern that innovative construction methods are hindered largely by conventional materials. Steel experiences plastic deformations unseen to the naked eye, wood is viscoelastic and suffers stress relaxation around holes caused by connecting elements – even engineered lumber, with the introduction of plastic, undergoes large strains due to creep, masonry is prohibitively difficult and time consuming to clean, and cast-in-place concrete must be removed destructively. In order to reduce the burden of construction materials in the waste stream, a product must be engineered with adequate strength, toughness, ductility, and resilience to be valuable for deconstruction and reuse.

Probably the most serious issue impeding the proliferation of DfD and modularity is connection design. DfD depends on maximizing connection simplicity and accessibility, and minimizing the types of connections, number of components, and use of chemical fasteners.

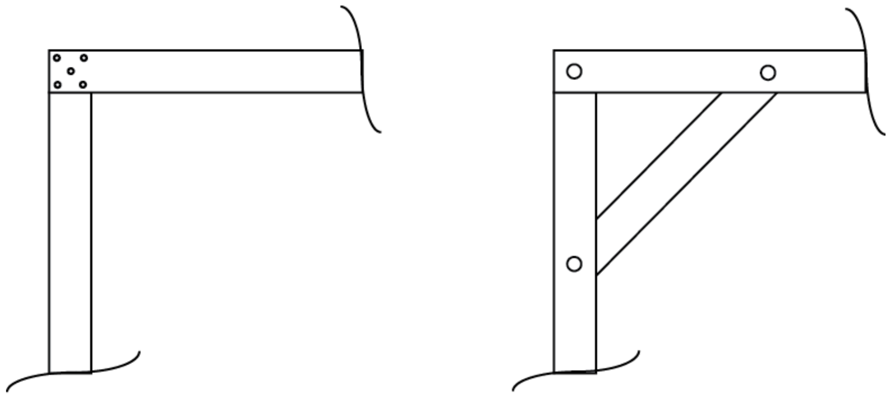

Figure 7 – DfD-friendly knee-brace connection

Simple methods have been devised to sidestep these issues such as siding clips that attach siding boards without damaging the materials being connected. Other strategies include decreasing the number of separate elements used in design to limit the number of joints. Modularity is an exaggeration of this strategy; after the modules are completed in the factory, the building is reduced to a handful of parts. Webster (2005) summarizes intelligent DfD connection design by encouraging transparency, regularity, and simplicity. Easily identified, repeating, and simple connection patterns and materials are quick to deconstruct and cause minimal damage to the connected member. Figure 7 depicts a connection that enforces DfD. The undesirable connection is a moment connection using numerous small, inaccessible bolts; this will mean more labor hours and more damage to the members. The desirable connection achieves the same moment resistance by employing the knee brace, fewer discrete elements, and larger spacing between bolts.

Connections are likewise a concern in modular design, but the problem is connecting modules together rather than individual members. Gurney (1999) proposes that engineered lumber can mitigate many of the difficulties in connecting modules together. Presently, these methods include marriage headers between modules that have an opening and the frequent use of double-wythe walls where modules interface. Connection design in modular construction must be focused on providing the strength and ductility needed in design while being accessible enough to deconstruct.

Further Study

Kim (2008) suggests that additional study is required before a more sustainable construction industry can be realized. While some life cycle analyses have been performed on conventional residential and office buildings, notably by Keoleian et al. (2000), Asif et al. (2007), and Guggemos et al. (2005), the overall sustainability and environmental impact of modular homes has yet to receive adequate attention from consumers and producers. Hassell, et al. (2003) support this charge by calling for help from the federal government in the form of funding research activities, supporting product development, and improving market linkages.

A Proposed Hybridization of DfD and Modularity

Previous work has been done to address the customization capabilities of modular construction. Alchemy Architects offers design options using their standard stackable modules with a product called the Wee House. Kieran and Timberlake built the Loblolly House, which was manufactured and then assembled on site in six weeks. Figure 8 illustrates where these designs fall between entirely conventional and entirely modular. The Loblolly House and the Wee House represent the extreme ends of this hybrid system; Loblolly is a one-off design and is toward the extreme of customization. The Wee House takes advantage of modular construction at the expense of adequate design freedom. The hybrid system that follows is capable of filling in the gap between these two designs, from very custom to very efficient in production.

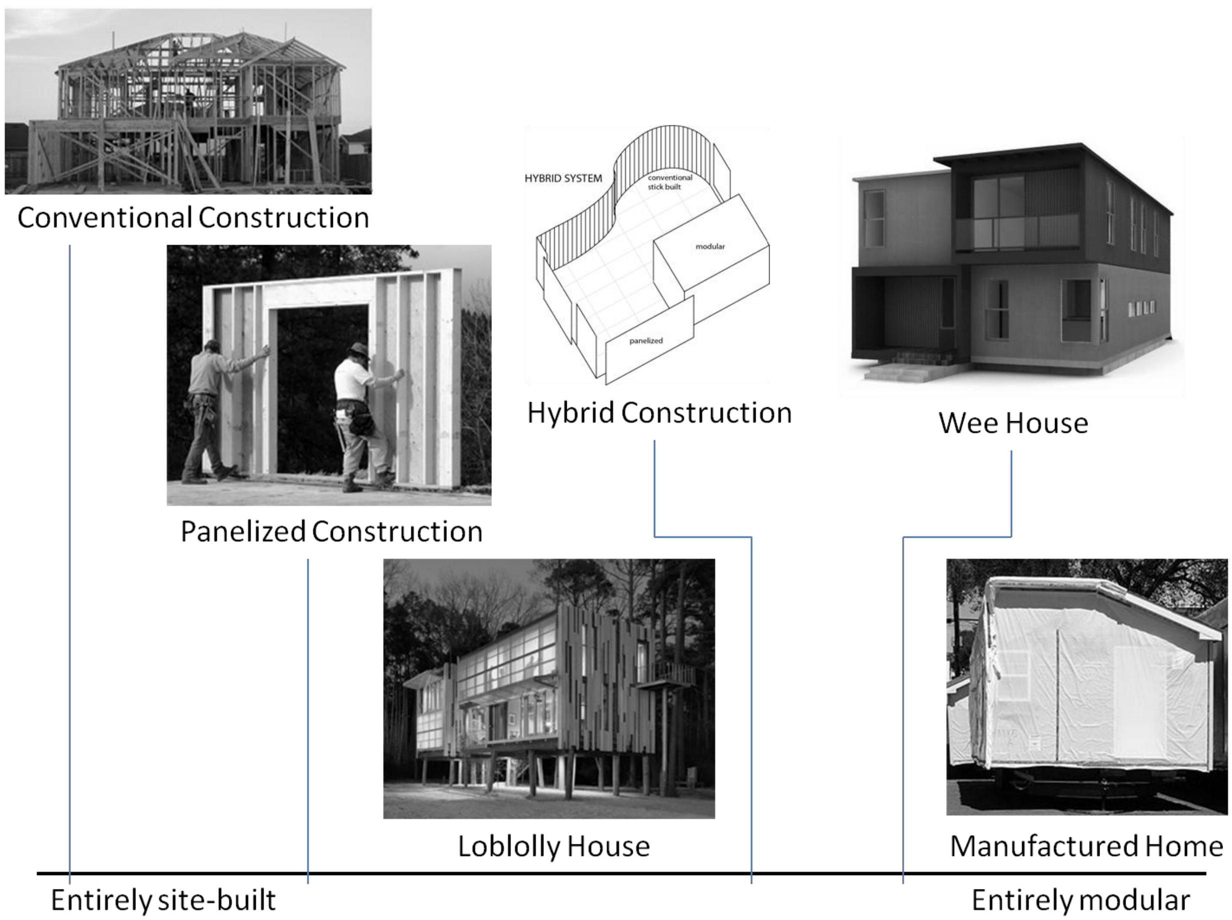

Figure 8 – Location of hybrid system on scale of modularity

Close examination of the advantages and drawbacks of modular construction and DfD reveals that the two complement each other rather effectively. While an entirely modular building may be appropriate for high volume, uniform designs – like those found in subdivisions – adding easily deconstructible filler elements to a modular design gives custom home designers and builders the option of using these sustainable construction techniques without compromising quality or originality. A wide range of architectural possibilities – each with a wide range of structural solutions – can be made possible by combining elements of modularity and conventional construction using deconstructed materials. Modules could be built and used for rooms that fit the requirements of uniformity and conform to factory construction. Rooms, walls, and other components that are not suited to factory construction would be built according to DfD techniques and, if possible, with deconstructed materials.

Take a custom home as an example. The bedrooms, bathrooms, closets, laundry room, and kitchen would likely fit the model for modular construction, and could be delivered to the construction site as previously described, ready for installation. Custom aspects that connect the modules together such as hallways, foyers, atriums, and large living rooms, if not already adjacent, would then be site-built after the modules are placed. Using the principles of DfD where modular construction is inappropriate retains the benefits of both methods discussed previously, while actually minimizing some of the drawbacks. Being careful to dismiss the assumptions of form in the schematics in Figures 9, 10, 11, and 12, the hybrid system incorporates modular and stick-built construction to yield a successful model of mass customization.

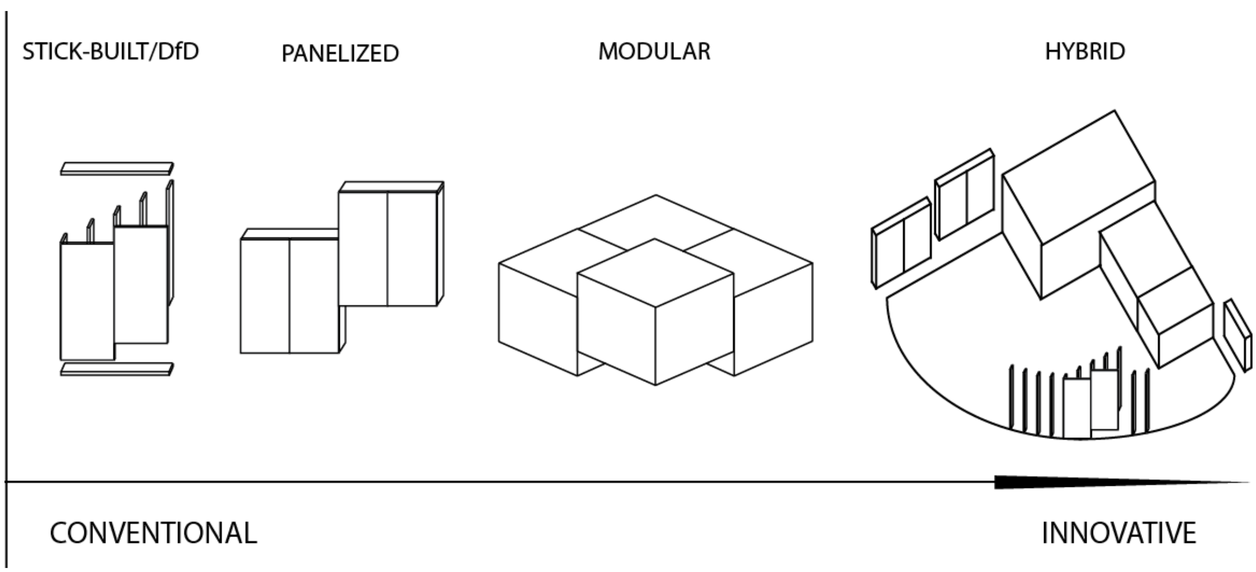

Figure 9 – Sustainable innovation via hybridized DfD and modular construction

The main disadvantage of DfD is the required labor hours. Shifting the focus from constructing entire buildings with deconstructed materials to using it as a supplement to modular construction will reduce the volume of deconstruction work. When the structure is later deconstructed, modules can be simply lifted out after the non-modular sections are deconstructed per DfD guidelines. Similarly, the weakness at the fore of modular construction is the issue of customization and consumer taste. The marriage of DfD and modular construction allows the designers and builders to use modularity where efficiencies are to be gained and DfD concepts where both customization and material and energy efficient design is desired.

The modular/DfD hybridization theory can be expanded to include the production of panels, modules, and finished structures. Conventional construction still employs the vast majority of existing buildings; therefore, including conventional construction in the DfD, modular, and hybrid material flow will increase the supply and demand on used lumber stock and multiply the avenues for accessing the reuse market. Figure 10 depicts this material flow.

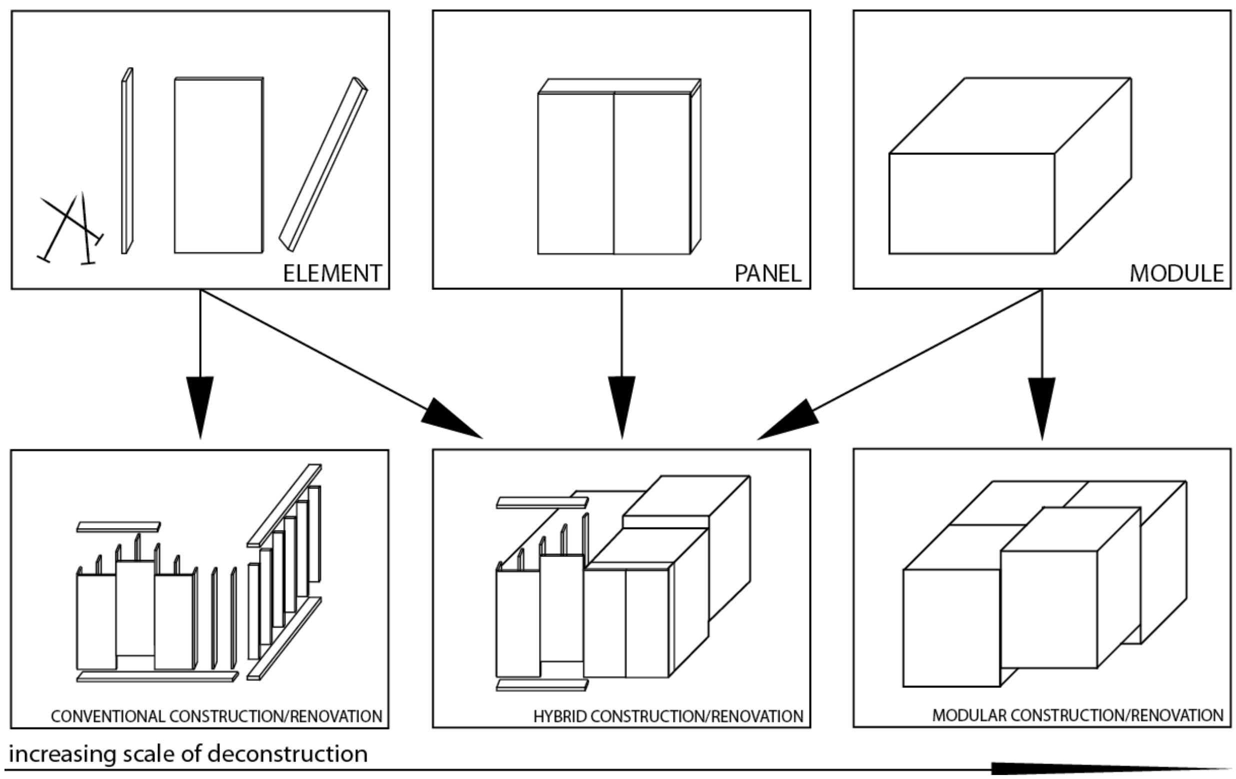

Figure 10 – Material flows

Modules would be built and shipped to modular construction sites just as they are today. When a module is removed – either in renovation, reprogramming, or deconstruction – it is transported back to the factory. At this point, the module can be reused in modular construction as the same module, or it can be broken down into panels if the entire module is unsuitable for reuse. Panels and individual members can similarly be deconstructed or used in the construction of panels or modules. See Figure 10. In this way, DfD permeates modular construction while being used simultaneously to accentuate the advantages of each.

This system relies heavily on transportation, which has been shown to be a restraint on modular design. Hence, mobile factories or industrialized worksites become desirable. The industrialized worksite is not new; builders in Sweden have shown the prudence of laying tracks on which cranes can move materials and construct large developments in short order at low cost (Dolan). The decomposition of modules into panels or panels into elements would ideally take place at the mobile factory to make transportation easier; the reverse process would be performed at the subsequent construction site.

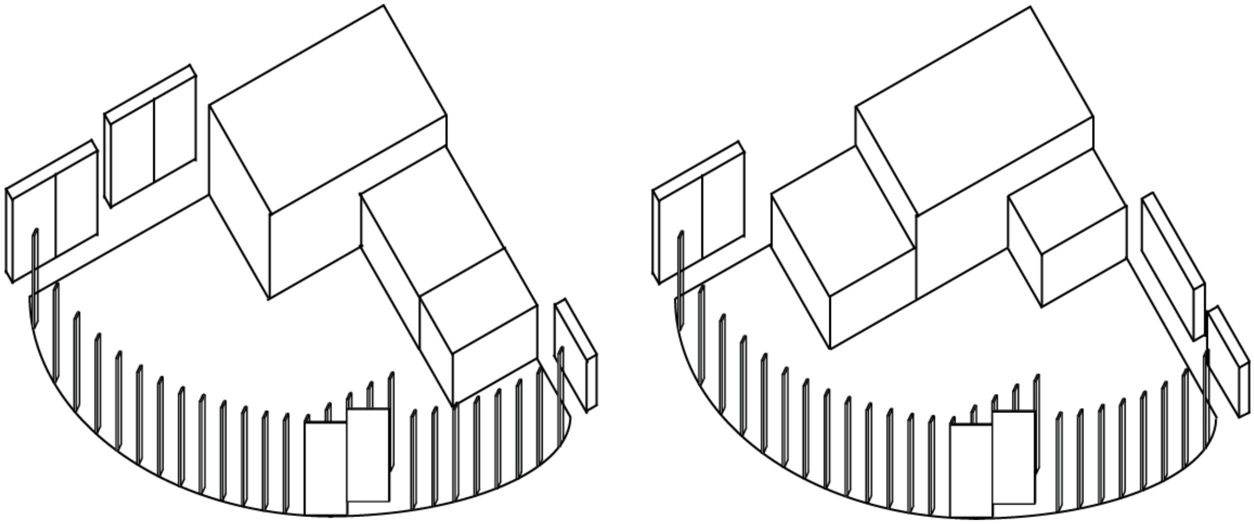

Figure 11 – Scheduled reprogramming

The manufacture, installation, and deconstruction of modules and panels can then become a warranty service from the manufacturer. Using Crowther, Duffy & Henney, or Brand's life spans as the basis for a business model, a manufacturing company could lease modules to a homeowner while providing services such as maintenance, repair, and even reprogramming, which is depicted in Figure 11. The main obstacle remains the size of the market, just as in DfD.

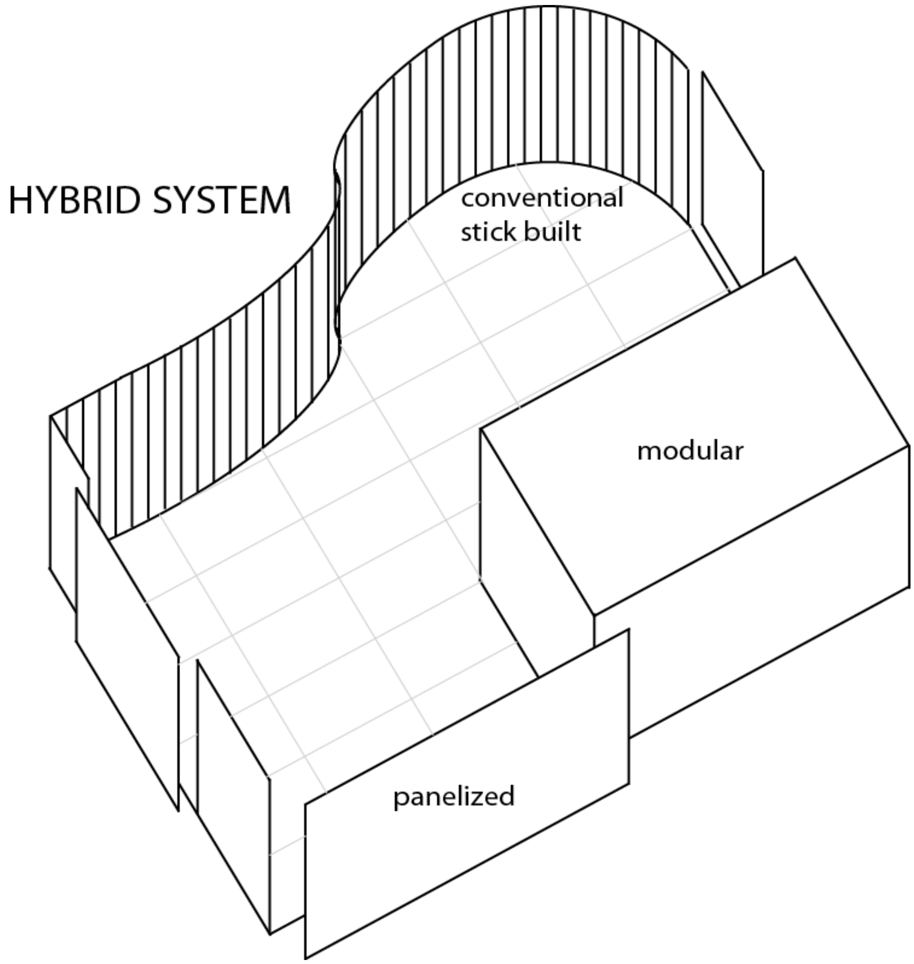

Figure 12 – Arbitrarily custom design with uniform dimension increments

Economic feasibility of this business model depends on the proliferation of the industry. This can be achieved by few large companies maintaining secrecy and competitive advantages over competitors or by standardizing the foundation system and inviting smaller companies to adopt the system standards – analogous to the industry standard 4x8-foot plywood or OSB panels. Mullens' steel chassis foundation design is a great place to start. Any floor plan shape that uses agreed-upon dimensional increments could be built into the foundation, which would be constructed to accept modules from any number of local manufacturers. Figure 12 shows how a steel chassis or any other sufficiently uniform foundation system could facilitate modular design as well as offer a wide range of opportunities for customization using any combination of prefabricated modules, panels, or conventional construction. It also illustrates the case where some aspects of the design would tend toward panelized construction and others may be best suited for conventional framing techniques. Notice that the modules are variably sized; all that must be done is ensure that the increments of dimensions are homogeneous and that the foundation allows for a variety of module placements.

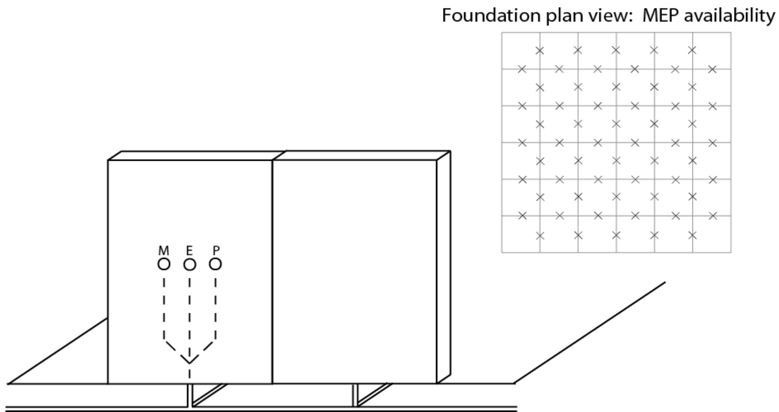

Figure 13 – MEP availability and connection: a panel with and without services

Utilization of a semi-permanent foundation or structural backbone to create a form or dock for modules to be set into allows more architectural freedom without interference from mechanical, electrical, or plumbing utilities or conduit. Similar to an electrical outlet – which is placed permanently but used sporadically – installing permanent conduit at regular intervals allows different modules to hook up to services without requiring extensive planning. Equip each module with aesthetic or hidden punch-outs to access MEP services and a host of opportunities arise with respect to programming and simplicity (Figure 13). This addresses Webster's (2005) call for transparency, regularity, and simplicity. Though he was referring to structural connections, service connections are no less disruptive to designers.

One way to construct a foundation that would cheaply and easily accommodate this system is to use pin foundations with grade beams. Diamond Pier sells pin foundation blocks that handle residential loads quite well at around $100 each. Setting grade beams between these blocks would form the load-bearing grid. This system could be easily expanded or dismantled as the building footprint is changed to facilitate a change in program. Additional costs would be incurred by installing extra fittings for conduit, but these are minimal compared to destructive renovation.

Additional contributions and insights into this gap are provided by Knight and Sass (2010), Kronenburg (2006), Parsley (2009), Richard (2006), and Woudhuysen (2006). In particular, Richard investigates combining what he calls the "site intensive kit of parts" and the "factory-made 3D module" into a hybrid system, and Parsley offers a manifestation of the concept of building layers using a stepped floor and ceiling slab to accommodate MEP services and conduit.

Conclusion

DfD and modularity are two design and construction systems that were created to sustain environmental health without compromising human comfort. The design and construction roadblocks for DfD center on connections and labor, whereas modularity focuses on efficiency at the expense of complete design freedom.

DfD and modular construction are incremental improvements when implemented separately. The advantages of DfD include the responsible use of natural resources, improved economic performance, and the potential for job creation. The benefits of modular construction range from streamlining the construction process for financial success and decreasing emissions resulting from construction activity. When used together in a hybrid system, DfD affords more opportunities for customization while modularity increases efficiency; in this way, the main drawbacks of each system are reduced or avoided. It has therefore been shown that this hybrid system contributes in a substantial way to diverting useful building materials from the waste stream by both saving valuable construction materials in their elemental form and by avoiding unneeded wasteful renovations by instead relying on scheduled reprogramming and repair. It also brings together the financial and practical attractions of both systems to be the optimal construction system in the eyes of the design team.

WORKS CITED

Adams, S. *Practical Buildability*. Butterworths, London, 1989, p. 2.

Asif et al., Life Cycle Assessment: A Case Study of a Dwelling Home in Scotland, Building and Environment, 2007.

Bady, Susan. Editor. 1996. Builders Grow Business the Modular Way. Professional Builder Magazine.

Brand, S. *How Buildings Learn.* Viking, New York, 1994, p. 12.

Cameron, Peter J., and Nadia G. Di Carlo. "Piecing Together Modular: Understanding the Benefits and Limitations of Modular Construction Methods for Multifamily Development." 2007.

Carlson, D. Editor. 1991. *Automated Builder: Dictionary/Encyclopedia of Industrialized Housing.* Automated Builder Magazine, Publications Division, CMN Associates, Inc., Carpinteria, CA.

Chini, Abdol R. "Deconstruction and Materials Reuse: Technology, Economic, and Policy." *CIB Publication 266 Task Group 39.* 2001.

Chini, Abdol R., and Stuart F. Bruening. "Deconstruction and Materials Reuse in the United States." *Future of Sustainable Construction.* 2003.

Crowther, Philip. "Design for Buildability and the Deconstruction Consequences." *CIB Publication 272 Task Group 39.* 2002.

Dolan, Dan. Personal Interview. 14 July 2010.

Duffy, F. and A. Henney. *The Changing City,* Bulstrode Press, London, 1989.

EPA, 2003. *Deconstruction,* Published by the US Environmental Protection Agency, January 25. http://www.epa.gov/epaoswer/non-hw/debris/pubs/decon_br.pdf.

Falk, Bob. "Wood-Framed Building Deconstruction: A Source of Lumber for Construction?" *Forest Products Journal 52.3.* 2002.

Franklin Associates, 1998. *Characterization of Building-Related Construction and Demolition Debris in the US,* A Report to the US EPA Office of Solid Waste and Energy Response, Washington, DC.

Grothe, M., and D. Neun, 2002. *A Report on the Feasibility of Deconstruction: An Integration of Deconstruction Activity in Four Cities*, December 18. http://www.huduser.org/Publications/PDF/deconstruct.pdf.

Guggemos et al. Comparison of Environmental Effects of Steel- and Concrete-Framed Buildings, Journal of Infrastructure Systems, June 2005.

Gurney, Sara J. "Identifying Opportunities for Engineered Lumber Products in the Modular Housing Industry." 1999.

Guy, B. 2001. "Building Deconstruction Assessment Tool," *Deconstruction and Materials Reuse: Technology, Economic, and Policy.* CIB Publication 266. Pp 125-136.

Hassell, Scott, Anny Wong, Ari Houser, Debra Knopman, and Mark Bernstein. "Building Better Homes: Government Strategies for Promoting Innovation in Housing." *Science and Technology Policy Institute*. 2003.

Hobbs, Gilli, and James Hurley. "Deconstruction and the Reuse of Construction Materials." *CIB Publication 266.* 2001. pp. 98-124.

Keoleian, Gregory A., Steven Blanchard, and Peter Reppe. "Life-Cycle Energy, Costs, and Strategies for Improving Single-Family Houses." *Journal of Industrial Ecology,* Vol. 4 No. 2, 2000, pp. 135-156.

Kibert, C.J., A. Chini, and J.L. Languell, 2000. "Implementing Deconstruction in the United States." *Overview of Deconstruction in Selected Countries.* CIB Publication 252, Conseil International du Batiment, pp. 181-239.

Kieran, Stephen, and James Timberlake. *Refabricating Architecture: How Manufacturing Methodologies Are Poised to Transform Building Construction.* McGraw-Hill Professional, 2004. Print.

Kim, Doyoon. "Preliminary Life Cycle Analysis of Modular and Conventional Housing in Benton Harbor, Michigan." 2008.

Knight, Terry and Lawrence Sass. "Artificial Intelligence for Engineering Design, Analysis and Manufacturing." 2010.

Kronenburg, Robert. "Fabric Architecture and Flexible Design." *Architectural Design.* 2006.

Macozoma, DS. "Secondary Construction Materials: An Alternative Resource Pool for Future Construction Needs." 2002.

Moulton-Patterson, Linda, Dan Eaton, Steven R. Jones, and Jose Medina. "Deconstruction Training Manual." *California Environmental Protection Agency Integrated Waste Management Board 2001.*

Mullens, Michael A., Ph.D., PE. "An Industrialized Solution for US Urban Housing." 2006.

Mullens, M., R. Hoekstra, and I. Nahmens, 2005. *An Integrated Interior Infill System for Mass Customized Housing: Final Report.* Report to National Science Foundation, prepared by UCF Housing Constructability Lab, University of Central Florida, Orlando, FL, October.

NAHBRC, (2000), *Deconstruction: Building Disassembly and Material Salvage,* Report for US Department of Housing and Urban Development.

Parsley, Christopher. "Anticipating Change: Integrating Off-Site Fabrication with Adaptable Design Strategies." 2009.

Recycled Construction Products Market, 2003. http://www.depts.washington.edu/cmweb/recycled.htm.

Richard, Roger. "Industrialized, Flexible, and Demountable Building Systems: Quality, Economy and Sustainability." *CRIOCM 2006 International Symposium on Advancement of Construction Management and Real Estate."* 2006.

Roodman, David M., and Nicholas Lenssen. "A Building Revolution: How Ecology and Health Concerns are Transforming Construction." *Worldwatch Institute*. 1995.

Tommelein, Iris D., David R. Riley, and Greg A. Howell. "Parade Game: Impact of Work Flow Variability on Trade Performance." *Journal of Construction Engineering and Management.* 1999, pp. 304-10.

Traynor, T. 2002. Total Housing Even in 2001 at 2.219 Million, *Automated Builder, 39(1).*

Webster, Mark D. "Designing Structural Systems for Deconstruction." *Simpson Gumpertz & Heger, Inc.* 2005.

Woudhuysen, James. "Mass Customization and the Manufactured Module." *Architectural Design.* 2006.

Appendix

<table>
<tr><td colspan="4">Building Materials Inventory Form</td></tr>
<tr><td colspan="4">Building Identification:</td></tr>
<tr><td colspan="4">Date:</td></tr>
<tr><td colspan="4">Inspector:</td></tr>
<tr><td colspan="4">Roof System</td></tr>
<tr><td rowspan="7">Wood Framing</td><td colspan="2">Roof Type (gable, hip, mansard, etc.):</td><td>Pitch:</td></tr>
<tr><td colspan="2">Roofing Material:</td><td>No. of Layers:</td></tr>
<tr><td>Rafter:</td><td>Size:</td><td>Length:</td></tr>
<tr><td>Ridge Beam:</td><td>Size:</td><td>Length:</td></tr>
<tr><td>Framing Spacing:</td><td colspan="2"></td></tr>
<tr><td>Sheathing Type (T&G, butt joint):</td><td>Size:</td><td></td></tr>
<tr><td>Ceiling Joists:</td><td>Size:</td><td>Length:</td></tr>
<tr><td colspan="4">Exterior Wall System</td></tr>
<tr><td rowspan="3">Masonry</td><td>Width:</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Rebar Location:</td></tr>
<tr><td>Steel Lintels:</td></tr>
<tr><td rowspan="5">Wood Framing</td><td>Studs:</td><td>Size:</td><td>Height:</td></tr>
<tr><td>Top Plate:</td><td>Size:</td><td>Length:</td></tr>
<tr><td>Bottom Plate:</td><td>Size:</td><td>Length:</td></tr>
<tr><td>Framing Spacing:</td><td colspan="2"></td></tr>
<tr><td>Sheathing Type:</td><td>Size:</td><td>Length:</td></tr>
</table>

Floor System			
Wood Framing	Joist:	Size:	Length:
	Framing Spacing:		
	Center Carrying Beam for Joists:	Size:	Length:
	Sheathing/Subfloor Type:		
Interior Walls: Wood Framing			
Load-Bearing Walls	Studs:	Size:	Height:
	Top Plate:	Size:	Length:
	Bottom Plate:		
	Framing Spacing:		
	Total Lineal Feet of Wall:		
Partition Walls	Studs:	Size:	Height:
	Top Plate:	Size:	Length:
	Bottom Plate:		
	Framing Spacing:		
	Total Lineal Feet of Wall:		

Masonry Foundation			
	Type (Block, Poured):	Width:	Height:
	Rebar Location:		
	Slab:	Thickness:	Rebar:
	Chimney Type (Solid, Lined):		Size:
	Sump Pump:		
Fascia/Eave			
	Fascia:		
	Rake:		
	Gutters:		
Connections Between Building Elements (Anchor Bolts, Strapping, Hold Downs, etc.)			
	Floor/Wall:		
	Wall/Roof:		
	Window/Wall:		

<table>
<tr><td colspan="4">Finish Materials</td></tr>
<tr><td rowspan="8"></td><td>Plaster/Lath:</td><td colspan="2">Ceiling Height:</td></tr>
<tr><td>Finish Flooring (Type):</td><td colspan="2">Fastening:</td></tr>
<tr><td>Unpainted Wood (Type):</td><td colspan="2">Linear Feet:</td></tr>
<tr><td colspan="3">Cabinets (Type):</td></tr>
<tr><td>Stair Treads (Type):</td><td>Number:</td><td>Width:</td></tr>
<tr><td colspan="3">Shelving (Type):</td></tr>
<tr><td colspan="3">Plumbing Fixtures (Type):</td></tr>
<tr><td colspan="3">Appliances (Type):</td></tr>
<tr><td colspan="4">Heating System</td></tr>
<tr><td rowspan="4"></td><td colspan="3">System (Type):</td></tr>
<tr><td colspan="3">Boiler/Furnace:</td></tr>
<tr><td colspan="3">Hot Water Heater:</td></tr>
<tr><td colspan="3">Radiators:</td></tr>
<tr><td colspan="4">Other</td></tr>
<tr><td rowspan="3"></td><td colspan="2">Doors (Type):</td><td>Size:</td></tr>
<tr><td colspan="2">Windows (Type):</td><td>Size:</td></tr>
<tr><td colspan="3">Metals: Plumbing Piping, Domestic Hot Water, etc.:</td></tr>
</table>

Miscellaneous	
	Extent of Rot:
	Lumber Grading Stamp:
	Overall Building Dimensions:
	Approximate Date of Construction:
	Complicating Site Conditions: Steep Grade, Trees, etc.:
Notes	

Floor Plan Sketch