Framing Lumber from Building Removal: How Do We Best Utilize This Untapped Structural Resource?

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ABSTRACT

Compared with other construction materials, wood products are environmentally attractive because they sequester carbon, are renewable, and are low in embodied energy. Lumber salvaged from building removal possesses these same qualities but with additional environmental attributes. In spite of the environmental attractiveness of reclaimed lumber, its widespread acceptance is hampered because it is not formally recognized in our grading or engineering design standards. This causes confusion for consumers, builders, and building officials, both in the marketplace as well as at the jobsite. In this article, possible alternatives for recognizing and accommodating reclaimed lumber in lumber grading and wood engineering design standards are provided.

INTRODUCTION

The past decade has seen tremendous growth in green building practices, and the building design and construction industries are paying more attention to reducing a building's energy and water usage, reducing a building's waste and carbon footprint, and specifying building materials that are not only sustainable, but that have the lowest environmental impact.

To this end, the green building community has stressed the use of newly manufactured recycled content building materials or exotic "green" materials (e.g., bamboo flooring, wheatstraw doors, hempcrete) in building construction projects. Until recently, relatively little attention has been given to reusing the millions of tons of building materials we already have; that is, the components and materials salvageable from building removal that would otherwise end up in the landfill. This is surprising because, as the three "R's" of wise material use (Reduce, Reuse, Recycle) state, reusing material is higher up the hierarchical ladder than recycling material (or using a material with recycled content). Whereas reusing some building materials and components is impractical because they are difficult to take apart and reinstall (such as a concrete beam in a cast-in-place concrete building), other materials, such as framing lumber, in most cases can be easily salvaged and reused.

Wood possesses many positive environmental attributes, including renewability, low embodied energy, and the ability to sequester carbon (Falk 2009). Life-cycle analyses, especially those related to the efforts of the Consortium for Research on Renewable Industrial Materials (CORRIM 2010), have shown the advantage wood building materials have over other common building materials (e.g., steel, concrete) from an embodied energy and carbon footprint standpoint (Lippke et al. 2004, Perez-Garcia et al. 2005).

Recent research points to the added environmental benefits of reusing lumber and its positive impact on reducing carbon footprint (Napier et al. 2007, Bergman et al. 2010). Reusing wood materials, and avoiding the upstream energy to reproduce the product new, makes reclaimed lumber a leading contender for the greenest of green building materials.

In this article, we will discuss the potential for reusing lumber in construction, some of the current barriers to wide-scale reuse, the state of engineering research to quantify its residual properties, and some suggestions on how to move forward to broaden acceptance of reclaimed lumber in the marketplace.

STATE OF LUMBER REUSE TODAY

The salvage and reuse of lumber and timber is in many ways nothing new, and as long as wood buildings have been built, some amount of salvage has occurred. Some believe that more building materials were salvaged before World War II, and that the associated development of large construction machinery during and after the war allowed rapid mechanical removal of buildings (M. Taubert, Duluth Timber Company, personal communication, 2000). Also, the development of safety regulations that distanced a worker from the materials in a building and a trend of compressing the time allowed to remove a building and prepare a site for redevelopment, have resulted in a disincentive to salvage building materials.

As early as the 1970s, the timber framing industry recognized the value of salvaged wood and has used larger timbers reclaimed from industrial structures for the exposed framing of high-end new construction. Framers value not only the dry and stable nature of these larger members, but also their unique character, especially the aged patina and old-growth qualities (see, for example, www.tfguild.org).

More recently, interest in salvaging and reusing smaller dimension (2-by) framing lumber found in most single-family house construction has been growing. Reused building material businesses have grown rapidly over the last 20 years, and many of these businesses sell lumber reclaimed from the deconstruction (or dismantlement) of wood-framed buildings. Habitat for Humanity (HfH) ReStores, which sell donated and salvaged building materials, now number over 700 in the United States and Canada. The first ReStore opened about 20 years ago, in 1992. Several hundred non-HfH reused building material businesses have also opened in the same time period (Building Materials Reuse Association, personal communication, 2012).

RESOURCE POTENTIAL

A significant amount of lumber is potentially available for future reuse. Since the turn of the 20th century, more than 3 trillion (3×10^{12}) board feet (7×10^{9} m^3) of lumber and timber have been sawn in the United States, much of it still residing in existing structures (Steer 1948, Howard 2001). As the building infrastructure in North America ages, there will be increasing opportunities to reclaim materials from building removal. Of the roughly 100 million (100×10^{6}) housing units in the United States, most (55%) are 29 to 69 years old. About 15 percent of the housing stock is 70 years old or older.

The US Environmental Protection Agency (US EPA) estimates that there are more than 270,000 housing units demolished each year in the United States (US EPA 2009). Assuming these houses average about 1,000 ft^2 in size, it is estimated that these demolished houses contain about 1.7 billion (1.7×10^{9}) board feet (4.0×10^{6} m^3) of framing lumber. The wood sheathing, trim, and finish wood materials in these houses add to this total.

Many older (1800 to 1960s) industrial structures, including warehouses, sawmills, and industrial buildings, were also built from solid timber. Although no private sector estimates exist for the larger timbers in industrial buildings, in the 1990s, the US Army Corps of Engineers estimated that more than 250 million (250×10^{6}) board feet (590,000 m^3) of structural lumber existed in their buildings slated for demolition at that time (P. Dolan, US Army Corps of Engineers, Construction Engineering Research Laboratory, unpublished calculations, 1995).

CURRENT BARRIERS TO REUSE

In talking about barriers to wood reuse, it is important to differentiate between the two types of reclaimed wood members available and how they are marketed. For discussion purposes, we will loosely define these two groups as "larger timbers" and "2-by lumber." Although grading rules technically define "timbers" as anything 5 inches and larger in least dimension, for purposes of this discussion we will define "larger timbers" as anything larger than a 2 by 12, the largest solid sawn wood member typically used in single-family house construction.

Larger timbers are typically salvaged from larger industrial buildings and usually end up in one of two markets, depending on size and species—the timber framing market or the remanufactured wood flooring market. The timber framing industry has relied on job-specific grading and engineering approval of the timbers used to meet local building codes. Flooring is appearance graded and is a nonissue from a structural standpoint.

Two-by lumber is more ubiquitous and is typically salvaged from single-family house deconstruction or from the lighter framing of industrial buildings. Unlike the larger timbers that are destined toward a specific market and uses that are individually engineered, 2-by lumber salvaged for reuse in most cases is sold into the broader house construction and remodeling market, typically without the benefit of grading agency quality control.

Because larger reclaimed timbers go to markets where a quality control system is already in place, the following discussion and recommendations are focused on 2-by lumber.

Currently, reclaimed lumber is not *expressly* acknowledged in existing lumber grading rules, engineering design standards for wood, or national building codes. This omission is understandable because the development of these lumber rules and standards historically focused on newly sawn lumber, and over the course of their development there was not much call for guidance on reusing lumber. Existing grading rules have been (and in some cases, still are) used to grade reclaimed lumber. However, because reuse is not specifically addressed, the degree to which existing rules, standards, and codes should apply to this material is currently undefined.

This lack of definition can result in uncertainty, especially at the building site, where approval for reuse of lumber is inconsistently granted. On one hand, a building inspector may judge that a piece of reclaimed lumber is acceptable for reuse, justifying approval on the fact that it functioned well in its previous structural application. Another inspector, however, may disallow reuse altogether because there is no guidance available that specifically allows reuse. Unfortunately, neither scenario is ideal, because the first relies to a certain extent on blind faith with no quality control to assure product performance, and the second rejects out of hand the use of a viable resource because no guidance is available.

Also, lumber grading agencies in the United States and Canada are inconsistent on reuse options for reclaimed lumber. The American Lumber Standards Committee (ALSC) recognizes seven lumber grading rules that have been accredited as conforming to the American Softwood Lumber Standard (National Institute of Standards and Technology 2010; Table 1).

Table 1. Certified softwood lumber grading rules.

Rule	Agency
Standard grading rules for Northeastern lumber	Northeast Lumber Manufacturers Association (NeLMA), Cumberland Center, ME; info@nelma.org
Standard grading rules	Northern Softwood Lumber Bureau (NSLB), Cumberland Center, ME; info@nelma.org
Standard specifications for grades of California redwood lumber	Redwood Inspection Service (RIS), Pleasant Hill, CA; info@calredwood.org
Standard grading rules for Southern Pine	Southern Pine Inspection Bureau (SPIB), Pensacola, FL; spib@spib.org
Standard grading rules for West Coast lumber	West Coast Lumber Inspection Bureau (WCLIB), Portland, OR; info@wclib.org
Western lumber grading rules	Western Wood Products Association (WWPA), Portland, OR; info@wwpa.org
Standard grading rules for Canadian lumber	National Lumber Grades Authority (NLGA), New Westminster, BC; info@nlga.org

An informal phone survey of these seven agencies indicates that two currently grade and stamp salvaged lumber for structural usage (using existing grading rules), and five do (or will) not. Several of the agencies that do not currently allow reuse expressed that if definitive standards and guidance were available, they would consider allowing reuse.

WILL RECLAIMED 2-BY LUMBER PERFORM STRUCTURALLY?

A logical question to ask before considering the recognition of reclaimed lumber for reuse in construction is "Will the reclaimed lumber perform adequately when reused in a structural application?"

The authors (with others) attempted to answer this question by initiating a testing program to evaluate the residual engineering properties of 2-by lumber salvaged from different buildings in different geographic locations (Falk et al. 2008). In that study, several thousand pieces of full size 2 by 6, 2 by 8, and 2 by 10 Douglas-fir lumber salvaged from World War II military buildings were graded on-site, and those meeting No. 2 and Select Structural grades (about 1,100 pieces) were selected for testing. These two grades were chosen to conform to ASTM D1990 (ASTM International 2012) sampling protocols. The collected lumber was tested to determine residual bending stiffness and strength. Wood characteristics (e.g., knots, slope-of-grain, checks) and existing damage (e.g., nail holes, bolt holes, splitting) were quantified for each piece. Small clear bending specimens were cut (where possible) from the failed lumber and tested. All tests performed and data adjustments made were in accordance with ASTM standards. More details and a complete analysis can be found in Falk et al. (2008).

COMPARISON WITH OTHER DATA

A logical step in determining whether reclaimed lumber is adequate from a structural standpoint is to compare reclaimed lumber test results with other established data sets, design values, or other standardized reference data.

As a first comparison, the data described above (Falk et al. 2008) were compared with raw strength data from the In-Grade lumber testing program (Green and Evans 1988). The test data from the In-Grade testing program are the basis for current allowable engineering design values for wood found in the *National Design Specification (NDS) for Wood Construction* (American Forest & Paper Association [AF&PA] 2012), the primary guidance document used by engineers and architects to design wood structures. The In-Grade testing program was performed in the 1980s and involved strength and stiffness testing of thousands of pieces of 2-by lumber sampled from lumber mills. While objectives, sampling methods, and lumber sources were different for the In-Grade program than for the above-described study that tested reclaimed lumber, it does offer some degree of comparison for specific lumber sizes and grades. As detailed in table 18 of Falk et al. (2008), the 5th percentile bending strength (modulus of rupture [MOR]) of the reclaimed Douglas-fir lumber was found to be between 16 and 28 percent lower (depending on size and grade) than the In-Grade bending strength, whereas bending stiffness (modulus of elasticity [MOE]) was about 10 percent higher. Testing of small clear specimens cut from full-size reclaimed lumber also exhibited higher bending stiffness but had average bending strength and specific gravities comparable with historical values. These small clear testing results seemed to indicate that the material properties of the wood had not degraded as a result of its prior service life and that reduction in engineering strength properties is likely due to the macrocharacteristics in the lumber, including damage and knots.

Although comparing reclaimed lumber data with In-Grade data is informative, conclusions drawn from it are somewhat limited because not all sizes and grades could be compared (i.e., Douglas-fir 2 by 6s were not tested in the In-Grade program). A more general comparison can be made by looking at the ASTM D1990 (2012) derived MOE and MOR characteristic values used by the wood industry to establish lumber design values. According to Section 3.2.2 of ASTM D1990 (2012), a characteristic value is defined as,

> The population mean, median, or tolerance limit value estimated from the test data after it has been adjusted to standardized conditions of temperature, moisture content and characteristic size. The characteristic value is an intermediate value in the development of allowable stress and modulus of elasticity values. Typically for structural visual grades, standardized conditions are 73 °F (23 °C), and 15 percent moisture content. A nonparametric estimate of the characteristic value is the preferred estimate. If a distributional form is used to characterize the data at the standardized conditions, its appropriateness shall be demonstrated.

By adjusting all the reclaimed data to a single size and moisture content, a single estimate of strength and stiffness can be computed for each grade. Tables 2 and 3 show established wood industry characteristic values for mill-produced Douglas-fir, as well as characteristic values calculated for the reclaimed lumber tested in Falk et al. (2008).

As indicated in Table 2, the characteristic bending strength of the reclaimed Douglas-fir is lower than the characteristic value for mill-produced Douglas-fir by 17 percent for No. 2 grade and 23 percent for the SS grade. As shown in Table 3, bending stiffness values for No. 2 and SS grades are higher than the mill-produced lumber by 13 and 8 percent, respectively.

Table 2. Characteristic modulus of rupture values for mill-produced Douglas-fir (DF) and reclaimed DF lumber.[a]

Grade	Mill-produced DF[b]	Reclaimed DF[c]	Difference (%)[d]
No. 2	2,246	1,866	17
SS[e]	3,748	2,855	23

[a] Values are in pounds per square inch. To convert to pascals (Pa), multiply by 6.8948×10^3.
[b] Mill-produced data used with permission.
[c] Does not include potential Grade Quality Index reduction nor test cell data checks per ASTM D1990 (ASTM 2012).
[d] Percent difference = (mill-produced DF − reclaimed DF)/(mill-produced DF).
[e] Select Structural grade.

SO, WHERE DO WE GO FROM HERE?

First and foremost, it is clear based on experience from this research that reclaimed lumber destined for reuse in a load-bearing application (e.g., joist, rafter, stud, truss members) needs to be regraded by qualified lumber graders to assure a predetermined level of quality control. We believe that

Table 3. Characteristic modulus of elasticity values for mill-produced Douglas-fir (DF) and reclaimed lumber.[a]

Grade	Mill-produced DF[b]	Reclaimed	Difference (%)[c]
No. 2	1.55	1.748	−13
SS[d]	1.83	1.972	−8

[a] Values are $\times 10^6$ lb/in^2. To convert to pascals (Pa), multiply by 6.8948×10^3.
[b] Mill-produced data used with permission.
[c] Percent difference = (mill-produced DF − reclaimed)/(mill-produced DF).
[d] Select Structural grade.

amendment to existing grading rules to formally recognize reclaimed lumber as well as clear guidance on how to grade this material is necessary to increasing its acceptance. This could include suggestions on how to deal with characteristics found in reclaimed wood not found in newly milled lumber (e.g., nail holes, in-service damage, deconstruction damage).

Also, from an engineering standpoint, it is important to establish appropriate design values for reclaimed lumber that assure that the reused lumber will perform as expected in service. Because the study reviewed above indicates that the reclaimed lumber exhibits strengths lower than its new lumber counterpart, some adjustment needs to be included in lumber use provisions and design codes to account for this reduction. Several options have been suggested for visual grading. These include the following:

1. Develop a distinct reclaimed lumber species group, "Reclaimed." This option would essentially treat reclaimed lumber as a unique species group within the *NDS for Wood Construction* (AF&PA 2012) and would require the same review and approval process via the ALSC as any new lumber species submission. Published design values would reflect the reduction in strength indicated above.
2. Apply reduction factor to current lumber design values. This option would use the current NDS species grouping and apply a reduction factor to bending strength design values based on the percent reduction in strength found in Table 2.
3. Take a one grade reduction in properties. At least one grading agency, when asked for guidance by engineers and designers, suggests one visual grade reduction in properties (e.g., from Select Structural to No. 1) for reclaimed lumber. Interestingly, this recommendation corresponds to the results of reclaimed lumber grade reduction studies performed by Falk et al. (1999).
4. Include reclaimed lumber in a lower strength NDS species grouping. As indicated in Table 2, the bending strength of Douglas-fir reclaimed lumber doesn't meet the characteristic strength of mill-produced lumber. However, as shown in Table 4, it would meet the bending strength requirements of the species grouping of Western Woods.

Table 4. Characteristic modulus of rupture values for mill-produced Western Woods and reclaimed Douglas-fir (DF) lumber.[a]

Grade	Mill-produced Western Woods[b]	Reclaimed DF[c]	Difference (%)[d]
No. 2	1,636	1,866	−14
SS[e]	2,242	2,855	−27

[a] Values are in pounds per square inch. To convert to pascals (Pa), multiply by 6.8948×10^3.
[b] Mill-produced data used with permission.
[c] Does not include potential Grade Quality Index reduction nor test cell data checks per ASTM D1990 (ASTM 2012).
[d] Percent difference = (Western Woods − reclaimed DF)/(Western Woods).
[e] Select Structural grade.

Table 5. Characteristic modulus of elasticity values for mill-produced Western Woods and reclaimed Douglas-fir (DF) lumber.[a]

Grade	Mill-produced Western Woods[b]	Reclaimed DF	Difference (%)[c]
No. 2	1.02	1.748	71
SS[d]	1.15	1.972	71

[a] Values are $\times 10^6$ lb/in^2. To convert to pascals (Pa), multiply by 6.8948×10^3.
[b] Mill-produced data used with permission.
[c] Percent difference = (Western Woods − reclaimed DF)/(Western Woods).
[d] Select Structural grade.

As indicated in Table 4, the characteristic bending strength of the reclaimed Douglas-fir is greater than the characteristic value for mill-produced Western Woods by 14 percent for No. 2 grade and about 27 percent for the SS grade. The bending stiffness values for both grades of reclaimed Douglas-fir are significantly higher (71%) than the Western Woods grouping (Table 5).

CONCLUSIONS

Compared with other construction materials, wood products are environmentally attractive because they are renewable, are low in embodied energy, and can sequester carbon. Lumber salvaged from building removal possesses these same qualities, but with additional environmental benefits: less energy to produce than new lumber and a reduction of material destined for the landfill. In spite of these environmental qualities, the widespread acceptance of reclaimed lumber is hampered because it is not formally recognized in our lumber grading or wood engineering design standards. This causes confusion both in the marketplace as well as on the jobsite.

The engineering testing of reclaimed lumber has shown that there is significant residual capacity in salvaged lumber. Based on these findings, we have provided some possible approaches to more formally recognize and accommodate reclaimed lumber in our grading and design standards. More important than the option chosen, we need to take the effort to better use this untapped resource and make it more available to the building community.

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