Author's Note: I wrote this paper and presented it at the first Greenbuild Conference in Austin, Texas in 2002. It remains relevant today.

The Use of Salvaged Structural Materials in New Construction

Mark D. Webster, P.E.[1]

[1] Senior Staff Engineer, Simpson Gumpertz & Heger Inc., Phone: +1 781 907-9369. Fax: +1 781 907-9009. E-mail: mdwebster@sgh.com

1. INTRODUCTION

Most "green" building guidelines encourage the use of salvaged materials in new construction, and for good reason. Using salvaged materials diverts potential waste from landfill, reduces the consumption of new materials, and often contributes to the aesthetics of the new construction. Unfortunately, structural materials are seldom salvaged. The intent of this paper is to encourage the salvage of structural materials. The author reviews (1) techniques for evaluating the properties of salvaged brick, wood, and steel; (2) obstacles to their use such as code restrictions and contamination; (3) approaches to overcoming these obstacles; and (4) reuse options. Example projects illustrate the successful use of each salvaged material.

A distinction must be made between "salvaging" and "recycling." For the purposes of this paper, salvaging is taken as the reuse of an item (brick, piece of lumber, steel column) with minimal processing. Processing is limited to actions such as trimming, drilling holes for connections, and so on. Recycling is taken as the destruction of a used or waste item so that it can be manufactured into a new product. Examples of recycling include melting down scrap steel to process it into new steel and grinding up waste wood for use in pressed particle board.

One way to obtain salvaged materials is to "deconstruct" an existing building. Deconstruction is a demolition method whereby a structure is carefully disassembled with an eye towards salvaging as many components as possible. It is much slower and usually more costly, even accounting for the value of the salvaged material, than traditional, more destructive, demolition methods.

When using salvaged materials, it is helpful to know where the materials came from. Knowing the era and location of the building can provide clues as to the structural properties of the material. In the best of cases, original construction documents might be available which explicitly state the required design properties.

Three structural materials in particular offer excellent salvage potential: brick, steel, and wood. Brick and wood timbers are already frequently salvaged for specialty applications. Steel framing and dimension lumber are rarely salvaged.

2. BRICK

Brick is the most commonly salvaged structural material. When brick is salvaged, it is most often for aesthetic reasons. Brick is often left exposed in construction. Its appearance varies widely, depending on the color of its constituent ingredients, its size, how it was formed and fired, how it has weathered, and so on. Therefore, when repairs or patching of an existing brick wall requires the introduction of additional units, brick is often salvaged from the building under repair to achieve a close match. Salvaged brick may be used on a project even when brick matching is not an issue, for many people prefer the warmth and color of aged, molded bricks compared to the appearance of modern bricks.

2.1 Engineering Considerations

Our interest here is with bricks salvaged for structural use. When salvaged bricks are used for applications such as patio pavers—a popular choice—they are not subject to the stress levels encountered in a wall, nor are there serious consequences associated with leakage and deterioration. When using salvaged brick in a wall, whether a multi-wythe bearing wall or a single-wythe veneer wall tied to a back-up, it is critical to address issues such as strength, durability, and leakage potential.

2.1.1 Strength

Walls constructed of salvaged brick are generally weaker than walls constructed of new brick. The bricks themselves are weaker, the mortar is weaker, and the bond between the brick and mortar is weaker.

Bricks salvaged from buildings constructed in the early 1900s and before are often not as well fired as modern bricks. These bricks were stacked and fired in wood- or coal-burning kilns. The “hard-burned” bricks located in the high-temperature zones of the kiln were better fired than the “salmons”—so called because of their color—in the low-temperature zones. The hard-burned bricks are stronger and more durable than the salmons, and were typically used in the outer wythes of multi-wythe exterior walls. When brick walls are demolished, the durable exterior bricks become mixed with the softer interior bricks, unless a concerted effort is made to keep them separate. When they are salvaged, it is difficult to distinguish the salmons and the hard-burned bricks. The two types of brick often look similar even when clean and undamaged; distinguishing them becomes even more difficult when the bricks are weathered and discolored by old mortar.

The mortars used for salvaged brick walls also tend to be weaker than the mortars commonly used for modern walls. Most authorities recommend using a weaker mortar to help prevent damage to the weaker bricks. A lime and sand mortar, for instance, offers three advantages: it imposes lower stresses on the brick due to shrinkage and temperature changes, it bonds well with porous bricks, and it is generally low in salts, reducing the potential for efflorescence (Ritchie, 1971).

Mortar residue and dirt on salvaged brick can reduce the strength of the bond between the bricks and the new mortar. This material clogs the brick’s pores, reducing mechanical adhesion to the mortar (BIA, 1988). Studies show that the bond strength for salvaged brick typically approaches 80% of the bond strength for new brick (Biggs, 2001). Initial rate of absorption (IRA) testing, described in ASTM C 67, may be used to evaluate the likely bond strength.

Standard tests may be used to better understand the strength properties of the wall assembly. Bond-wrench tests (ASTM C 1072) measure the bond between brick and mortar. Tests prisms may be constructed and tested (ASTM C 1314). The brick units themselves may be tested for strength (ASTM C 216).

2.1.2 Durability

The durability of exterior walls constructed using salvaged bricks in cold climates is of utmost concern. Salmons in particular are easily damaged by freeze-thaw action due to their porosity and weakness. Even hard-fired bricks from older (pre-1920) buildings will likely be less durable than new bricks, due to the weathering they have already experienced and the higher quality standards used to manufacture modern bricks.

To avoid durability problems, never use salmon bricks in exterior applications in cold climates. It is advisable (and required by common building codes) to test the salvaged brick for absorption and freeze-thaw weathering using ASTM (American Society for Testing and Materials) C 216 procedures.

In addition to reducing the wall's strength, poor bond between mortar and brick can increase the penetration of moisture into the wall, further reducing durability. Water intrusion can also lead to efflorescence problems.

2.2 Code Issues

The 2000 edition of the International Building Code (IBC) permits reuse of salvaged units that "conform to the requirements of new units. The units shall be of whole, sound materials and be free from cracks and other defects that will interfere with proper laying or use. Old mortar shall be cleaned from the unit before reuse" (2103.6).

The relevant test standards are ASTM C 216 for "facing brick" and ASTM C 62 for "building brick." Both of these standards specify minimum requirements for compressive strength and durability, as measured by water absorption or freeze-thaw testing. C 216 has tighter standards on size, distortion, and surface defects, as facing brick is intended for exterior (visible) use. Durability requirements in both standards are waived in "negligible weathering" zones, which in the continental United States include southern Florida, parts of Texas, Arizona, and California.

The test methods, including sampling requirements and minimum number of specimens, are spelled out in ASTM C 67. This standard calls for a minimum of 10 specimens for lots of 1,000,000 bricks, and an additional 5 specimens for each additional 500,000 bricks or fraction thereof. For salvaged brick, it may be advisable to perform more tests, due to the greater variability of the material. The compression test and the water absorption and saturation test cost around $500 each. The 50-cycle freeze-thaw test, which takes up to 10 weeks to complete, costs around $1500.

2.3 Contamination

The primary contamination concerns are lead paint, where brick has been painted, and tarry or oily deposits on former chimney brick. In both cases, it is usually not practical to salvage the brick because of the difficulty of removing the material and the possibility of damaging the brick while doing so.

2.4 Reuse Options

Durability is the most critical concern when using salvaged bricks. Thus applications where durability is less of a concern, such as the interiors of heated spaces and in warm climates, are ideal for salvaged brick.

When salvaged brick will be exposed to freeze-thaw cycles, care must be taken to select hard-burned brick. Samples should be chosen from each source of brick and tested for durability using ASTM procedures as quality assurance.

Salvaged bricks are commonly used in repair operations. In these projects, the bricks are often removed from a building, cleaned, and either replaced or used elsewhere in the same building. Thus the source of brick is known, allaying quality concerns, and the brick will blend in well with the brick left in place.

2.5 Economics and Availability

The biggest cost associated with salvaging brick is the clean-up cost. Removing old mortar is time-consuming, labor-intensive, piece work. Lime mortars, used mostly pre-1930, are readily removed with hand-tools, such as hammers and chisels; even "scrubbing with a fiber bristle brush" is often enough (Biggs, 2001). Portland cement mortars are extremely difficult to remove; cleaning usually requires power tools such as saws. Thus most salvaged brick available on the market is from pre-1930 buildings (Ritchie, 1971). An internet search turns up multiple sources. Retail prices for salvaged brick typically range from 35 to 50 cents per brick (Costello, 2002), which is comparable to the 45 to 65 cent price range for new brick quoted by a Boston-area brick supplier for building quantities (10,000+ bricks).

2.6 Example Project

The example project is one of the rare cases where aesthetics demanded salvage of brick set in portland cement mortar. A condominium association hired Simpson Gumpertz & Heger Inc. (SGH) to address leakage problems at a 20 year old brick-clad building with steel stud backup. The repairs required removal and replacement of shelf angles and flashing. Three courses of brick had to be removed for access. SGH could not find a source of new brick to match the existing brick, and opted to salvage the brick and replace it. The contractor used chisels and saws to remove the cement mortar, which was very strong and well-adhered to the brick. There was no need to test the brick, as it was used in its original application. The salvage cost, about $2.00 to $3.00 per brick, was high due to the difficulty of removing the mortar.

3. WOOD

The salvage rate of wood members is roughly proportional to the member size. Timbers (6x and bigger) are frequently salvaged, while dimension lumber (4x and smaller) is rarely salvaged. Timbers can be much more easily removed from a building without damage. One timber can be cut into many boards for use in flooring or furniture. Dimension lumber is often full of nails and nail holes, particular near the ends of the members, and tends to be shorter in length, reducing salvage options.

There are no technical obstacles to the reuse of both dimension lumber and timbers in structural applications. Structural reuse is preferable to downgrading the material by burning it, mulching it, or cutting it up for non-structural use, because it maintains the integrity of the wood, maximizes its potential, and leaves the option open for reuse again and again in future buildings. A beautiful old-growth 12x12 timber post removed from an old mill building can continue to amaze viewers if it is reused as a post in a new building, but if it is cut up and spread across a floor it loses much of its grandeur, and will less likely be salvaged for future use at the end of the building's life.

3.1 Engineering Considerations

The engineer, when confronted with a piece of salvaged lumber, must determine its design properties (primarily strength and stiffness) to use it most effectively. The key steps are to identify the species and grade the member.

3.1.1 Identification

A small sample of the wood is usually needed to identify it. A wood expert can usually identify the species by examining a thin slice of the sample through a microscope. It is helpful to know whether the allotment of salvaged members all came from the same building, and what approximate age that building was. The chances are good that if all the wood came from the same building it is all the same species. Samples should be taken from several members of different size and location in the demolished building (if known) for verification. Knowledge of the demolished building's age is helpful, since the availability of certain species has varied over time. If the demolished building was of fairly recent construction, it may be possible to find grade stamps on the lumber.

3.1.2 Grading

It is possible to hire a professional grader, certified by one of the several U.S. or Canadian grading agencies, to grade salvaged lumber prior to use. If the grader works for the Northeastern Lumber Manufacturers Associate (NELMA), the cost will be about $300 per day, and the grader will be able to grade 500 to 2000 pieces per day, depending upon the grading set-up and quality of the lumber. The grader will use the same grading rules he or she would apply to new lumber. The result will be that much of the lumber will be "down-graded" by about one grade relative to its actual strength. The reason is that standard grading rules are based in part on the appearance of the wood. Salvaged wood is often marred during its use or during removal from the original structure, and could get penalized a grade as a result. NELMA graders are permitted to certify salvaged wood for grade, but will not certify the strength.

The United States Forest Products Laboratory (FPL), based in Madison, Wisconsin, is in the midst of a large-scale testing program to develop specialized grading rules for salvaged lumber. To date, the lab has tested thousands of salvaged timbers and pieces of dimension lumber (e.g. Horne-Brine et al. 1999, Falk et al. 1999). They expect to publish recommendations within the next year.

While we wait for the FPL to finish its work, we may use ASTM D 245, Standard Practice for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber.

This procedure grades for strength alone; there are no deductions for visual characteristics that do not influence strength. The grader examines all four faces and ends of the piece of lumber, noting the size and location of defects, such as knots, slope of grain, etc. The allowable stress for the piece is taken as a percentage of the allowable stress of a defect-free member. The reduction is based on the number, severity, and location of visible defects in the piece. This procedure may be applied to salvaged lumber by treating bolt holes and other similar damage as knots. SGH has successfully used this procedure to grade members in place with only three sides exposed.

Another option for grading which warrants consideration, particularly when a large number of boards must be graded, is mechanical stress rating (MSR). There is a known correlation between member stiffness and strength. MSR machines measure a board's flexural stiffness in the weak direction and assign a strength based on the result. The degree of automation and speed of the process varies tremendously with the price of the machine. MSR should be used in combination with visual grading criteria.

3.1.3 Properties

The properties of salvaged lumber vary widely. Compared to new lumber, it is more likely to have come from old-growth forests, where large, slow-growing trees provide dense lumber with few knots, resulting in greater strength. On the other hand, the lumber may be damaged from use or from salvage operations. It may be notched, contain bolt or nail holes, or have suffered decay. These properties can be evaluated by grading. The sizes are likely to differ from modern finished sizes, so marrying them into existing construction may be difficult. Salvaged lumber is usually dry, so less shrinkage can be expected compared to new lumber.

3.2 Code Issues

Codes are generally quite strict regarding who may grade and approve the use of wood for structural purposes. For example, the 2000 IBC states:

> "Lumber used for load-supporting purposes...shall be identified by the grade mark of a lumber grading or inspection agency that has been approved by an accreditation body that complies with DOC PS 20 or equivalent. Grading practices and identification shall comply with rules published by an agency approved in accordance with procedures of DOC PS 20 or equivalent procedures. In lieu of [a] grade mark on the material, a certificate of inspection as to species and grade issued by a lumber grading or inspection agency meeting the requirements of this section may be accepted for precut, remanufactured, or rough-sawn lumber, and for sizes larger than 3 inches nominal thickness" (2303.1.1).

DOC PS 20 refers to the U.S. Department of Commerce NIST American Softwood Lumber Standard. These requirements prevent unapproved agencies from grading lumber for structural use. Local building officials may agree to allow an unapproved agency, such as a wood technologist or structural engineer, to grade the wood in some cases. Most common building codes also include provisions for "alternative" materials, which may be interpreted to include salvaged materials. See for example IBC section 104.11.

3.3 Contamination

The most common contaminant on salvaged wood is lead-based paint. Paint may be sand-blasted or planed off, but the cost of this effort is likely justifiable only with large timbers. The faces of salvaged timbers are often routinely sawn down to remove dirt and surface damage. If the wood is salvaged from an industrial facility, it may be deeply contaminated with oils, solvents, or other toxins. In these cases, it is usually not feasible to salvage it. Asbestos dust and creosote contamination are other potential problems.

Another “contaminant” is nails. Nails are usually removed by hand, which can be expensive. The wood should be scanned with a metal detector to ensure that all the nails have been removed prior to reuse.

3.4 Reuse Options

The most common structural application of salvaged wood today is framing for post-and-beam houses and other small buildings. The timbers are commonly obtained from the demolition of old mill buildings.

There is a vast potential supply of dimensional lumber from demolished housing which is waiting to be exploited. In today’s market, using existing techniques, economics do not favor deconstructing houses to salvage their lumber. Methodologies must be developed to make deconstruction more economical. One approach could be to cut the roofs, floors, and walls of a building into panels and remove them from the structure. These panels could then be deconstructed by specialized teams off-site or on-site if space permits. This approach would permit the rapid removal of the structure demanded by most construction schedules. It would also allow most of the deconstruction to occur on the ground where is can be performed more safely and systematically.

Even if a large supply of dimension lumber could be economically extracted from a building, its use in a new structure might be limited. Most salvaged lumber ends up slightly shorter than it was in its original use, as the ends are often damaged and must be cut off. So the eight-foot studs used to frame a wall in the former building may now be seven-foot-six. New technologies and construction methods must be developed to effectively utilize this wood.

Two technologies which could make ready use of these shorter members are metal-plate-connected wood trusses and finger-jointed lumber. These are excellent potential markets once grading rules for salvaged wood are established and promulgated. Certainly an increase in the price of virgin lumber would help this market grow as well.

3.5 Economics

In a 1996 study of the deconstruction of two military buildings in Minnesota, Falk (1996) cites the following resale value for dismantled wood (price received by dismantler): $0.40 to $0.60/board foot for “smaller” dimensions, and $2.00 to $3.00/board foot for “larger” dimensions. A Massachusetts demolition contractor estimates that salvaged wood sells for $0.50 to $2.50/board foot (Costello, 2002).

According to the National Association of Home Builders (NAHB) website (www.nahb.com), the average cost nationwide of new framing lumber was about $0.32/board foot late in 2001. A couple of lumber retailers in the Boston area were selling 2x10s and 2x12s for about $0.60/board foot during this same period.

New large timbers are still available from a number of mills. All but the very largest sizes (roughly 12 by 24 inches and larger) are less expensive to purchase new. The new timbers are usually not dry, however, and will shrink and crack more than salvaged timbers.

3.6 Example Project

Benson Woodworking, Inc. of Walpole, New Hampshire constructed a 17,000 sf retail vegetable store in Lexington, Massachusetts using salvaged timber. The rough-sawn Douglas-Fir timbers, which are as large as about 12 by 30 inches, were salvaged from a number of sources, including the former Long-Bell Lumber Mill in Oregon. There were no serious contamination issues to contend with, and the building official allowed the use of the timbers without requiring certified grading or testing. The square-foot cost of constructing this building exceeded the cost of typical retail construction, but the owner received a dramatic and beautiful space that draws crowds of shoppers.

4. STEEL

While structural steel from buildings is nearly always recycled, it is very seldom salvaged in today's construction environment. The steel industry proudly touts its recycling rate, and rightly so; structural rolled shapes such as wide-flange members sold in the United States have nearly 100% recycled content. However, producing steel, even from recycled material, is highly energy intensive and generates a considerable quantity of greenhouse gases. Why use this material when you can salvage? The environmental impact of salvaged steel is limited to its transportation and refabrication, and therefore much reduced when compared to even recycled steel.

4.1 Engineering Considerations

The engineering properties of salvaged steel are easier to identify than either salvaged brick or wood, because the manufacture of steel is much more controlled than the manufacture of the other materials, resulting in a more uniform product.

4.1.1 Identification

A number of iron-based materials have been used in buildings over the past two centuries. According to Newman (2001), cast iron arrived first, coming into use around 1800 to the early 1900s. Malleable iron arrived next, chiefly used from around 1840 to the early 1900s. Wrought-iron was introduced into buildings in around 1850 and was largely discontinued by the early 1900s. Steel, arriving in about 1885, supplanted all three materials.

Knowing the age of the building from which the material was salvaged is therefore helpful in identification. Appearance can also serve as a guide (Beckmann, 1995). For instance, cast iron typically has a pitted surface due to the sand molds used for casting. The shape of the member may also offer clues. Cast iron beams, for example, often have larger bottom flanges, and flanges may be wider near mid-span. Wrought iron and steel, though, are difficult to distinguish visually.

Metallurgical tests are the most certain way to identify the material, and also provide other useful information, as described below.

4.1.2 Weldability

It is helpful to know whether the salvaged material is weldable, for the member's weldability will determine how it will be used and how it will be connected to other members. Many older iron-based materials, especially cast and wrought iron, are difficult or impossible to weld. Even some early steels had too much iron, phosphorous, and/or sulfur to weld. As a rule-of-thumb, all steel produced before 1923 should be checked for weldability (Newman, 2001). Metallurgical tests may be used to determine weldability.

4.1.3 Strength

If the age of the material is known, standards dating from the time of manufacture may be used to estimate the material strength. "Coupon" testing provides the most reliable measure of strength. Coupons are small samples of material which are tested for strength in testing machines. The material can be used more efficiently if the strength can be determined, so testing may pay for itself in saved material.

4.2 Code Issues

The IBC does not specifically address the use of salvaged steel. The IBC requires conformance with the American Institute of Steel Construction (AISC) steel specification for the design, fabrication, and erection of structural steel buildings. The AISC specification requires that structural steel meet certain ASTM material standards. For example, structural steel meeting ASTM A 36 may be used. ASTM A 36 places limits on (1) the chemical composition of the steel, depending on the type of shape and the shape's thickness; and (2) the tensile strength of the steel. As discussed above, these properties can be determined using laboratory testing. If tests show that the salvaged material does not conform to modern material standards, it may be still be possible to obtain approval from the local building official for its use, particularly if the structural engineer stands behind it.

4.3 Contamination

The biggest potential contamination issue is lead paint. Even if the steel member does not have a finish coat on it, it may have a lead-based shop coat. It is a good idea to remove lead paint even if local regulations do not require it. Sand-blasting or hand-stripping are two options.

4.4 Reuse Options

With the limited supply of salvaged steel currently available in the used material markets, it's helpful to know where the steel is coming from when starting design of a new structure. For instance, if there is a building on the site or nearby with a supply of salvageable steel, it may be possible to survey the available material before laying out the new structure and to tailor the new building to match that material, say by establishing bay sizes and floor-to-floor heights that permit reuse with the minimum amount of refabrication. Creative engineering can make the most of existing material. For instance, cantilever beam construction could be considered where there is a mix of long heavy beams and short light beams.

Bridge girders are the most frequently salvaged structural steel members today, driven by the high cost and long lead time of new girders.

Ultimately, steel should be routinely salvaged from demolished buildings and stored for resale, perhaps near a steel fabricator. With a good supply of material, the fabricator could select the beams required for a given design, splice and refabricate it to meet the project requirements, and perhaps ship it out at a lower cost than if the steel were new.

4.5 Example Project

The Minneapolis office of LHB, an architecture and engineering firm based in Duluth, Minnesota, designed the new 60,000 square foot Phillips Eco-Enterprise Center (PEEC) in Minneapolis. This building had numerous “green” features, but of primary interest here is the incorporation of salvaged steel joists. In a serendipitous stroke of good fortune, one of the designers stumbled upon a field full of salvaged open-web steel joists from a demolished warehouse that matched the 40-foot bay spacing of the proposed building. LHB load-tested a limited percentage of the joists to failure to verify their load-carrying capacity. The contractor later found that a number of welds were weakened due to the joists’ exposure to the weather, so they thoroughly inspected all the welds and made repairs where needed before moving the joists to their new home. If the welding had not been needed, there would have been a small cost savings and a substantial time savings using the salvaged joists in the place of new joists. Even with the repairs there was only a small additional cost compared to new joists. The local building official offered no resistance to the reuse of the salvaged joists, given the engineer’s thorough review of the material and willingness to stand behind it.

5. SOURCES OF SALVAGED STRUCTURAL MATERIALS

One obvious source of salvaged material is an existing building on a proposed construction site that must be demolished. The designer should survey the building and see if any of the structural materials can be incorporated into the new building. The designer should also look for other buildings in the region which are slated for demolition and inquire into the nature of the material and whether the demolition schedule would permit deconstruction.

Other sources to consider are salvaged material web sites and material dealers. Web sites such as build.recycle.net are a bit hit-or-miss, but with luck might have the sought-after material. New material dealers may also offer salvaged materials. Brokers also sell salvaged materials. Brokers act as intermediaries between the dismantling company and the new building contractor. As the demand for salvaged materials increases (LEED should help drive that demand), we can expect to see an increasing and more diverse supply of these materials enter the marketplace, particularly if the cost of virgin material increases.

6. LEED

LEED 2.0 includes two points for the use of salvaged materials. Materials & Resources Credit 3 offers one point for specifying salvaged or refurbished materials for five percent of all building materials and an additional point for specifying an additional five percent. The percentage is based on the cost of the materials. If the cost of the salvaged material is less than the cost of new material, the cost of new material may be used in the calculation.

7. CONCLUSIONS

- Brick, wood, and steel are good candidates for salvage and reuse in structural applications in new construction.
- Salvaged structural materials can safely be used in new construction if their engineering properties are evaluated with tests or conservatively estimated prior to use.
- Codes such as the IBC do not usually address the use of salvaged material, and in fact may discourage it by specifying standards which are difficult or impossible to meet with salvaged material. Standards must be developed and codes revised to facilitate the use of salvaged materials.
- Many building officials will permit the use of salvaged materials in new construction if endorsed by the structural engineer.
- Improved markets and handling of salvaged materials are needed to increase efficiency and reduce cost.

8. REFERENCES

ASTM. Various standards. American Society for Testing and Materials. West Conshohocken, Pennsylvania

Beckmann, Poul. 1995. *Structural Aspects of Building Conservation*. McGraw Hill, London.

BIA. 1988. *Technical Notes on Brick Construction, 15 Revised, Salvaged Brick*. Brick Industry Association. Reston, VA.

Biggs, David T. 2001. Reusing Existing Brick. *TMS Responds*. Vol. 1, No. 4, pp. 1-2. The Masonry Society. Boulder, CO.

BOCA96. 1996. *The BOCA National Building Code/1996*. Building Officials & Code Administrators International, Inc. Country Club Hills, IL.

Costello, Daniel T. 2002. Telephone conversation with the author.

Falk, Robert H. 1996. Feasibility of Recycling Timber from Military Industrial Buildings. *Proceedings, The Use of Recycled Wood and Paper in Building Applications*. pp. 41-48. Proceedings No. 7286. Forest Products Society.

Falk, Robert H., Green, David, and Lantz, Scott C. 1999. Evaluation of Lumber Recycled from an Industrial Military Building. *Forest Products Journal*. Vol. 49, No. 5, pp. 49-55.

Horne-Brine, Preston and Falk, Robert. 1999. Knock on Wood: Real Recycling Opportunities Are Opening Up. *Resource Recycling*, August 1999.

IBC2000. 2000. *The International Building Code*. International Code Council. Falls Church, VA.

Newman, Alexander. 2001. *Structural Renovation of Buildings*. McGraw-Hill. New York.

Ritchie, T. 1971. CBD-138: On Using Old Bricks in New Buildings. *Canadian Building Digest*. http://www.nrc.ca.