Materials and Design for Deconstruction

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Introduction

Sustainable building practices often put an emphasis on material choice to reduce CO\textsubscript{2} emissions or embodied energy in a building project. Principles regarding sustainable materials include choosing materials that improve thermal performance, are local, easily or quickly renewed, and that do not require hazardous assembly or treatment. While these considerations are important, the question of what happens to a building’s components at the end of its life cycle also needs to be asked. The reality is that with today’s building industry practices many of these materials may well serve a short life before being sent to the landfill and are subsequently replaced by more new materials.

The life cycle for most buildings is a linear one, made evident by the following facts:

- An estimated 60\% of building construction and demolition materials end up in landfills.\textsuperscript{1}
- Forty percent of the world’s material flows are from construction, maintenance and renovation of buildings.\textsuperscript{2}
- Around 30\% of all solid waste is construction debris.\textsuperscript{3}
- Built space in the U.S. is estimated to grow by 130 billion square feet by the year 2030 and more than a quarter of buildings that existed in the year 2000 will be replaced by then.\textsuperscript{4}

This amounts to a great amount of consumption of new materials and losses of existing resources if current practices continue. The need for closing the loop of building material life cycles is easily apparent and the benefits of reusing or recycling building materials are many, but a vast amount of material simply goes to waste in construction and demolition. A closed loop keeps materials out of landfills...
of the landfill and reintroduces them into the material flow (Figure 19). In order to reclaim these materials and close the loop, the current end of life practice must shift from demolition to deconstruction.

Deconstruction is simply the practice of removing materials from a building so they retain some of their value by being reused or recycled. The Environmental Protection Agency’s Life-cycle Construction Resource Guide describes the two general types of deconstruction illustrated in Figure 20. Non-structural deconstruction, or soft-stripping, is easier and achieves more immediate financial benefits. Structural deconstruction is more time and labor-intensive, but often reclaims higher value materials. Both of these methods yield material goods without energy-intensive processing.

The question, is now why deconstruction and reuse are not common practices?

Reclaiming building materials was common practice around the world until the 19th century and continues today in more industrially undeveloped countries. At present, however, several factors contribute to the lack of reuse and recycling of building materials:
- Economics play a large role, as it is often not seen as profitable to invest the time and labor into dismantling a building and redistributing the materials, especially when landfill fees are low.
- The time it takes to strip a building is often seen as inconvenient or unfeasable for a project’s timeline.
- Hazardous materials can pose a danger to dismantlers, also increasing costs as special care must be taken to safely remove and dispose of them.
- Modern and complex construction methods can result in difficult and time consuming dismantling as well as a lack of usable salvage since the removal process often damages the building materials.

Design for Deconstruction

As mentioned above, the largest roadblocks to dismantling a building are the economics, hazards, and time involved in overcoming its assembly. Most of these can be overcome by designing a project with forethought of the entirety of a building’s life cycle. This practice is referred to as Design for Deconstruction, or DfD, and is an important factor that should be incorporated into building practices in order to maximize the useful life of resources.

Designing for the full life cycle of a building involves three main objectives:
- Design for durability: Durability in a building, especially the structure, ensures a lasting use of the embodied energy in new construction.
- Design for adaptability: Adaptability allows for a longer useful life of the structure when subsytems are allowed to change for changing needs.
- Design for disassembly: Assembling a building in a manner to
facilitate deconstruction will ensure the maximum reuse potential of its components.\(^6\) Certain construction techniques and building characteristics make for a more efficient and profitable disassembly, while others result in fewer valuable materials being claimed from buildings that are difficult to deconstruct. The following lists are of good and bad characteristics dismantlers find when disassembling existing buildings.

**Preferred building qualities for disassembly:**
- **Transparency:** Building systems that are visible and easily identified are easily disassembled.
- **Regularity:** Building systems that are similar and are in regular modules throughout the building make for more efficient stripping and sorting.
- **Simplicity:** Simple connections and a limited number of material types and component sizes are preferred. Complex disassembly can be time consuming and destructive to reclaimed materials.
- **Limited number of components:** It is often easier to dismantle structures built with a smaller number of large members as opposed to structures composed of many smaller members. Smaller members are more prone to damage during disassembly. (However, if hand labor is to be used instead of machinery for deconstruction, smaller members might be more appropriate.)
- **Easily separable materials:** Materials assembled with mechanical fasteners are easier to separate and less damaged in the process than those bound with adhesives. Composite materials can also prove to be too complex for disassembly and have little value unless the entire assembly can be removed and reused.

**Poor building qualities for disassembly:**
- **Complex Buildings:** Building systems that are hidden or complicated are difficult to deconstruct.
- **Non-Standard Components:** Custom components usually have no use in another building and are therefore less valuable.
- **Composite Materials:** Most composite assemblies, such as reinforced, grouted CMU are impossible to deconstruct into their material components.
- **Mixed Material Grades:** Materials that look similar but have different properties are less valuable. Multiple species or grades of wood used to frame a building can be difficult to sort, and are often lumped together with the lowest grade.
- **Mixed Building Systems:** Multiple structural systems can complicate the deconstruction process.
- **Environmental Hazards:** Materials such as asbestos and lead require special handling and require protection for workers, increasing time and labor costs.\(^7\)

**Design Principles of DfD**

Several principles are suggested to achieve a building that will be easily disassembled. Though these are general guidelines, it is important to remember that they must be weighed against other sustainable practices. Whereas many DfD choices complement other sustainable building and material practices, there are at times conflicting ideals. Compromise in the process of deciding what is best for individual projects and future goals is often necessary. It might be necessary to use more steel in a structure now in order to save much greater amounts in the future when that frame is repurposed instead of rebuilt. Some principles may also seem restrictive or less than ideal for signature projects, but for the vast amount of building these principles are highly applicable.

**DfD Architectural Guidelines:**
- Use a simple layout with regular bay sizes throughout.
- Separate or layer building systems as much as possible. Some systems, such as window assemblies, cladding and finishes are replaced more frequently than larger systems such as the structure and should be easy to remove without causing damage to more permanent parts of the building.
- Keep mechanical systems separate from the structure to allow for easier access and maintenance. It also results in more valuable reclaimed materials that are not entangled with wiring, ductwork, or other system components.

**DfD Structural Guidelines:**
- Clarify assembly systems.
- Use standard member shapes and connections that are easily understood, removed and sorted.
- Removable fasteners are preferred over adhesives.
- Composite systems should be
averted if the assembly cannot be removed as a whole.
- Assembly selection should consider current reuse practices, since materials that have high reuse value in current practice will likely have high value in the future.

Other practical considerations made during the design and construction phase can be very to ensure disassembly goals are met future.
- Providing access space for workers to safely maintain and dismantle parts can be very helpful and cost-effective for those involved in the future.
- Labels that indicate date, material grade and strength directly onto members can also simplify the dismantling and redistribution process.
- Drawings with information about maintenance and assembly should be kept on site in a permanent storage location.8

## Structural Materials and DfD

The following is a look at the four most common structural materials, wood, steel, masonry, and concrete, with regard to DfD guidelines.8

### Wood

Salvaged wood has a high reuse value for its character, durability and relative ease of deconstruction. Structural members can be reused for the same purpose, though they are often downgraded and used for finishes. Dimensioned lumber, however, can prove to be less valuable than larger timbers due to damage often incurred during removal.

**DfD suggestions for wood framing:**
- Use screws and bolts instead of nails.
- Moisture management must be effective to prevent decay and insect damage.
- Give preference to timber frame construction over dimensioned lumber.
- Keep services such as electrical, plumbing and HVAC separate from the structure.
- Label members with grades and species.
- Panelized construction at higher levels can allow for removal and deconstruction on the ground.
- Avoid adhesives when fastening sheathing to joists and studs.

<table>
<thead>
<tr>
<th>Deconstruction Type</th>
<th>Description</th>
<th>Characteristics</th>
<th>Types of Salvaged Materials</th>
</tr>
</thead>
</table>
| Non-Structural (soft-stripping) | The removal for reuse of any building contents that do not affect the structural integrity of the building. | • Requires less planning and coordination than structural demolition.  
• Materials can be viewed and removed without much destructive access.  
• Uses few tools and materials are salvaged relatively easily.  
• Does not have a significant effect of project schedule | • Finish flooring  
• Appliances  
• Cabinetry  
• Windows/doors  
• Trim  
• HVAC equipment  
• Fixtures/hardware  
• Fireplace mantels |
| Structural            | The removal, for reuse, of building components that are an integral part of the building, or contribute to the structural integrity of the building. | • Involves a range of tools and mechanization.  
• Heightened safety consideration, and longer time frame.  
• Materials removed are typically large, rough products that are reused as building materials or remanufactured into value added products such as chairs, tables, and surface coverings. | • Framing  
• Sheathing  
• Roof systems  
• Brick/masonry  
• Wood timbers/beams  
• Wood rafters  
• Floor joist systems |

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[Fig. 04: Structural and Non-Structural Deconstruction]
Steel
Due to its durability, steel is a good candidate for reuse. However, with today’s methods of construction and deconstruction, it is more economical to recycle steel. Though this is better than steel going to the landfill, a good deal of energy is required to recycle steel and it would be best to reuse the members. Designing steel structures with disassembly in mind can encourage more reuse.

DfD suggestions for steel structures:
- Use bolted connections.
- Avoid conventional composite floor systems using welded studs and cast-in-place concrete.
- Use precast decks.
- Common shapes and regular spacing simplify the deconstruction process.
- Mark grades and shapes directly on members.
- Find alternatives to spray-on fireproofing, as it can cause problems for steel reuse. It is difficult to remove from members and complicates refabrication.

 Lime mortars are an alternative that generally have adequate strength for veneer and bearing assemblies. Durability, water-resistance, and maintenance issues need to be addressed, however.
- Avoid using grouted reinforcement. One alternative could be unbonded post-tensioned reinforcement.
- Investigate mechanical fasteners to secure bricks instead of mortar.

Concrete
Concrete is the most difficult material to salvage and reuse. Cast in place concrete is essentially only good for recycling wherein it is crushed and used for other purposes such as aggregate. Even in this case the cement, which holds the most value and environmental impact of concrete, cannot be reused. Precast concrete has more potential for reuse if the pieces can be removed and reused efficiently, but secondary construction methods, such as poured floor toppings can inhibit this process.

DfD suggestions for concrete:
- Opt for precast over cast-in-place members.
- Fasten precast members with durable and removable fasteners, allowing for thermal movement at connections to prevent severe cracking.
- Find alternatives to topping slabs, such as plywood on sleepers for flooring.
- Label members with concrete strength and reinforcement.
- Cast work for below grade construction is unlikely to be salvaged. Precast slabs, walls, and footings are alternatives.

DfD Studies
The following information was taken from a comparative analysis of three building projects in California, each of which uses a different structural system. The goal of the investigation was to determine the quantity, embodied energy, and reusability of the materials within each build-
The first step of the analysis quantified the amount of material in each project. Figure 21 shows the material in each building as a percentage of total weight. It also shows the reusability of each material with a gradient of blue to red. In each project concrete clearly dominates the material use by weight and is the least reusable. The next step was to analyze how much CO$_2$ is embodied in each project by material (Figure 22). Figure 23 combines the information to demonstrate by material how much CO$_2$ is created versus how much is potentially saved through reusability.

It is evident that the wood framed Chartwell School building showed great potential for low CO$_2$ emissions and material reuse. The following case study of the school will describe some of the decisions made to design and build the school for deconstruction along with the challenges and resulting benefits that came from the process.

**Case Study:**
**Chartwell School**
**Seaside, California**

Chartwell is a school for K-8 students with language-related learning disabilities. It was designed to achieve
LEED Platinum from the U.S. Green Building Council and in early 2009 became the first educational campus to do so. It holds relatively small classes of 600 square feet but, like many schools, class size and other needs will likely change over time. This is why one of the main design goals for Chartwell was to design for adaptability as well as deconstructability.

To allow for adaptation of classroom size, the interior partitions of the building are non-load bearing and are of a separate system than the overall structure. The shear walls, especially along the corridor, are over-designed to allow for openings to be added later due to possible changes made to class arrangement. For ease of maintenance and replacement of services and utilities, a utility raceway was incorporated in the design that is separate from the building’s structure (Figure 25). It keeps with the idea that if the services are visible then they are easy to access and maintain. Other considerations for larger scale renovations were considered, such as window replacement. Alternate window assemblies were proposed to allow for the removal of windows without disturbing the cladding (Figure 26). To offset the lack of reusability in site cast concrete, the designer decided to use concrete pavers for the site work. The pavers are very durable and have a high reuse value.

For the structural wood frame, the designers followed several of the DfD principles discussed earlier in order to facilitate effective deconstruction. The framing module is 24 inches on center as opposed to the more common 16 inches. This module allowed for fewer but larger members and ended up saving around 30% of framing lumber. To keep things simple and adaptable, the floor plan is laid out on this same module. Simplifying connections turned out to be more of a challenge since the building is under code requirements for construction in a seismic zone. Excessive nailing of plywood shear panels will likely prove to be a hinderance for deconstruction as it increases labor for removal and the chance of damaging the members.

The connection of the roof diaphragm to the wall also required extensive blocking and clips, which are strong but difficult to deconstruct. To simplify this connection and the roof assembly in general, Structural Insulated Panes were chosen. These
composite assemblies could be bolted into place and easily removed and reused. Trusses supporting the roof also must be strapped to wall studs. To reduce the typical size of the 24 inch strap that requires 24 nails into the stud, the designers worked with the manufacturer to develop a strap that uses two through bolts and an 8 inch strap to connect the top plate to the stud.

Wood was reclaimed from wine aging tanks to be used for the building’s exterior siding. In order to minimize milling and planing, a rectangular section was chosen for the members. Fastening the siding turned out to be more challenging, however. The team did not want to use screws because it is possible that the siding could be painted at some point in the future, thus concealing the screws and making them difficult to remove. Screws left in siding that is pryed off would likely be strong enough damage the member. A system of double-bend clips was then proposed (Figure 27). This system proved to be very stable in a mock-up and could be assembled with little impact on the siding members, plus an air gap resulted from the clip assembly that would be ideal for siding as it would allow the members to dry. However, it this gap also decreased the fire rating and, since the school is surrounded by California forest, the system was not used.

Finally, the designers understood the fact that in order to increase the likelihood and efficiency of disassembly of the school, future dismantlers will need to know how the building is designed for deconstruction. While they suggest a digital library for all such buildings would be a valuable resource, for their specific project they included a set of durable, informed drawings for the owners, kept in a designated storage space. In addition, the architects placed permanent signage in the maintenance rooms with reference to the firm and design team. Finally, structural pieces such as the roof trusses were permanently labeled with grades and structural properties for future users. Chartwell is a good example looking past the energy performance of a building to the entire life cycle. Through innovative ideas and forethought the building has become and will remain sustainable.11
Notes


2. Mark Webster and Daniel Costello. Designing Structural Systems for Deconstruction: How to Extend a New Buildings’s Useful Life and Prevent it from Going to Waste When the End Finally Comes. Greenbuild Conference, Atlanta, GA. November 2005. 1

3. EPA, 1


5. EPA, 9


6. Webster, 2

7. Webster, 3-4. These criteria are adapted from the list put forth by Daniel Costello, co-author of the article and professional building dismantler.

8. Webster, 5-6

9. Webster, 8-10.

10. Hood, et. al. 26-32

11. Hood, et al. This case study is interpreted from the Design for Deconstruction Chartwell case study document made with assistance from the EPA.

References


Athena Institute: http://www.athenasmi.org/


Energy Information Administration: http://www.eia.doe.gov/


U.S. Environmental Protection Agency: http://www.epa.gov/


Webster, Mark and Daniel Costello. Designing Structural Systems for Deconstruction: How to Extend a New Buildings’s Useful Life and Prevent it from Going to Waste When the End Finally Comes. Greenbuild Conference, Atlanta, GA. November 2005.

Figures

Figure 01: Enterprise Wood Products, website: http://www.enterprisewood.com/enterprise_wood_products_reclaimed_lumber.cfm?pid=26

Figure 02: Adapted from EPA Lifecycle Construction Resource Guide, pg 46

Figure 03: Adapted from EPA Lifecycle Construction Resource Guide, pg 47

Figure 04: Adapted from EPA Lifecycle Construction Resource Guide, pg 10

Figure 05: From Design for Deconstruction, Chartwell School Case Study, pg 27

Figure 06: From Design for Deconstruction, Chartwell School Case Study, pg 30

Figure 07: From Design for Deconstruction, Chartwell School Case Study, pg 31

Figure 08: Simbiosis News “Chartwell School - Seaside, California, US http://symbiosisgroup.net/2009/06/01/chartwell-school-seaside-california-us/

Figure 09: From Design for Deconstruction, Chartwell School Case Study, pg 35

Figure 10: From Design for Deconstruction, Chartwell School Case Study, pg 41

Figure 11: From Design for Deconstruction, Chartwell School Case Study, pg 43