DESIGN FOR DECONSTRUCTION

contents

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Preface

The ultimate goal of the Design for Deconstruction (DfD) movement is to responsibly manage end-of-life building materials to minimize consumption of raw materials. By capturing materials removed during building renovation or demolition and finding ways to reuse them in another construction project or recycle them into a new product, the overall environmental impact of end-of-life building materials can be reduced. Architects and engineers can contribute to this movement by designing buildings that facilitate adaptation and renovation. This handbook presents an overview of basic Design for Deconstruction principles, and outlines the implementation of these principles in the design of Chartwell School in Seaside, California.

1. Overview

Most accounts of deconstruction begin with the amount of building debris that goes to the landfill. In part this is simply because debris is such an immediate, visible part of our experience. What was yesterday a functional building, is today a worthless pile of rubble sitting on the site for all to see. Even a modest kitchen remodel has the ever-present trash dumpster, as big as the kitchen itself, parked proudly in front of the house. As seen from the job site, the flow of materials is very simple, materials come from Home Depot, they're assembled into buildings, and the waste—whether construction, renovation, or demolition—goes into the dumpster. This simple linear view of materials flow is deeply ingrained from our everyday personal experience.

If we zoom out from the job site and look at the broader flow of materials, we all understand that downstream from the jobsite, debris in dumpsters goes mostly to landfills. And upstream from the jobsite, raw materials must first be mined or logged, then refined, processed and manufactured prior to showing up at our local supplier. In "The Ecology of Building Materials" Bjorn Berge illustrates this in a simple diagram: resources are extracted from the earth, refined and manufactured into useable materials, assembled into buildings, and eventually returned to the earth via landfills when the buildings are remodeled or demolished.

This may sound obvious, but overwhelmingly our everyday experience is with the downstream side. While we have all experienced trash, few people have really seen and experienced industrial mining, logging, and refining, so it remains less tangible, less real. As a result, we see debris as a downstream "waste" management issue.

However, the real benefits of deconstruction--including Designing for Deconstruction (DfD)--is about closing the loop of resource use. It is about reusing these "waste" resources to avoid logging or mining new virgin resources from our ecosystems. Designing for Deconstruction is about designing in such a way that these resources can be economically recovered and reused. In contrast to the conventional linear model of extraction, use, and landfilling, DfD envisions a closed cycle of use and reuse.

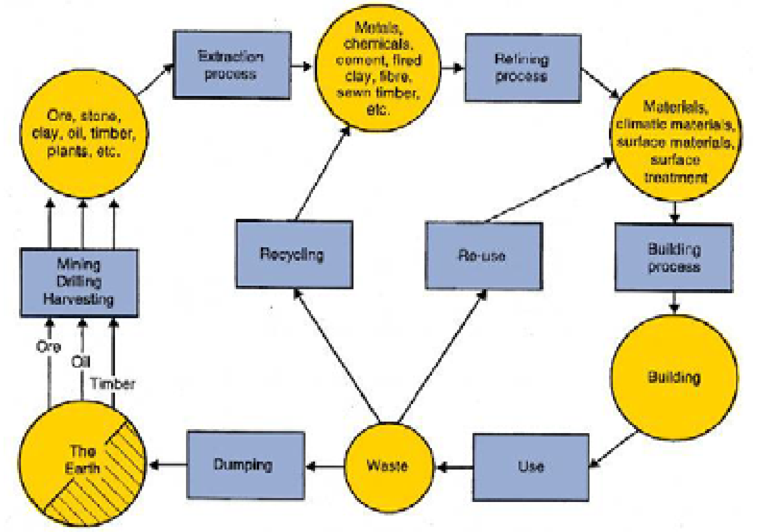


Figure 1.1 Conventional resource flows start with extraction from the earth, and eventually return those resources to the earth via landfills. DfD encourages the economical reuse or recycling of those resources to avoid additional logging or mining of virgin resources. Adapted from Bjorn Berge, "The Ecology of Building Materials"

Such a closed loop material cycle is illustrated below in figure 1.2 for the metal Lead. This is quite an impressive cycle, with new Lead production from virgin ore on the upstream end, and wasted Lead on the downstream end, both being small percentages of the total material flow.

But Lead is easy, buildings are not. The vast majority of lead is in car batteries. They are too heavy to carry around, so you get it changed at a garage where they keep your old battery for recycling. The Lead is relatively easy to extract from the battery case and is readily recycled, it has a low melting point reducing energy costs and environmental impacts, and it's a valuable commodity.

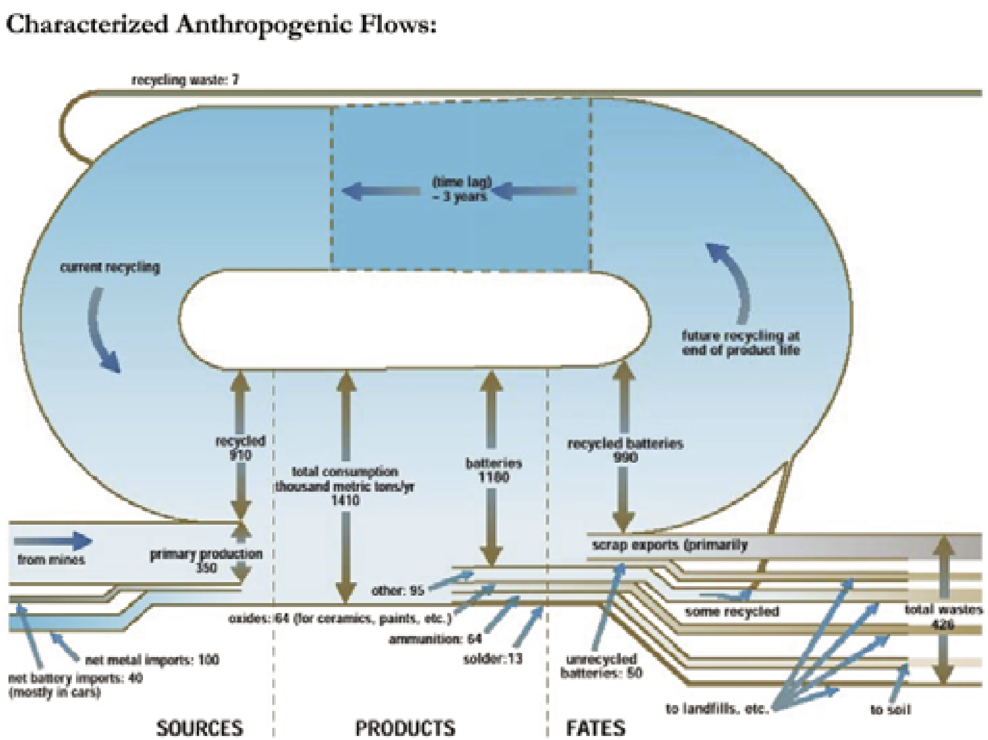


Figure 1.2 A closed loop material cycle for the metal lead

Buildings on the other hand are large, stationary, complex assemblies of relatively low value commodities. These materials are often difficult to separate, and many are not readily recycled. The value of a building is not so much in the materials themselves, but in the functional traits of shelter and the like that they provide when assembled together. Because of this, these materials retain more value when deconstructed and reused than when recycled. Much of what is called recycling is actually the down-cycling of a material to a lower grade use. Concrete can be "recycled", but only as low value aggregate, wood debris can be ground up for wood fiber or mulch, but thereby loses its most valuable properties.

If we look again at the resource flow diagram in figure 1.1, the smaller and tighter that this cycle of resource use is, the better. Each step along the way typically requires additional resources such as energy, transportation, or additional materials. If we can recover components and materials from buildings for reuse, this eliminates these additional inputs.

To understand why this matters, one needs to understand the staggering scope of material flows in construction. According to the US Geological Survey, an estimated 60% of materials flow in the US economy (excluding food and fuel) is consumed by the construction industry. Construction is one of the largest users of timber, and so shares responsibility for the logging impacts in our forests. Buildings are among the largest consumers of copper and steel, and so share responsibility for these mining and refining impacts. Buildings are the largest consumer of polyvinyl chloride (PVC), and so must acknowledge their share of its pollution and health impacts.

Virtually every step in a material cycle requires energy inputs, for extraction, refining, transportation, and fabrication; and along with the energy comes CO2 emissions, the primary greenhouse gas causing climate change. Manufacturing cement alone emits about 7% of global carbon emissions. It takes 110 tons of copper ore to produce a single ton of copper, with major energy inputs required to move this much earth and refine it into a pure metal. And moving thousands of tons of materials from their source to a construction site requires major transportation inputs. Many of these impacts can be avoided or reduced by reusing materials in a manner that preserves the embodied energy and carbon already invested in those materials.

As these huge material flows work their way slowly through buildings via renovation and demolition, we see that Construction and Demolition debris (C&D debris) currently makes up 25-30% of all solid waste produced in the United States, over 136 million tons in 1996. Discarding these materials rather than reusing them will continue to require extraction of huge quantities of new materials and the associated impacts on our ecosystems. We need a new mental model that clearly envisions these "wastes" as valuable resources harvested from existing buildings and used to build new ones.

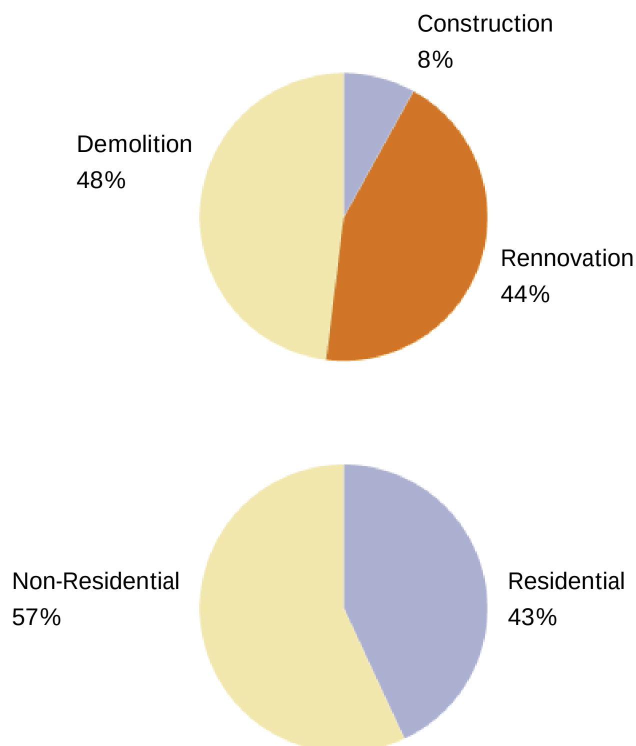


Figure 1.3 Construction & Demolition Debris

Characteristic of building-Related Construction and Demolition in the United States, U.S EPA, 1998.

The overwhelming majority of these resources are generated not from new construction, but from renovation and demolition. The challenge is that the buildings were not designed to allow these materials to be readily recovered. This is the task of Designing for Deconstruction, to figure out how to put buildings together so that they can be economically taken apart and the components reused.

By easing deconstruction and separation of components within buildings, it facilitates the development of closed loop material cycles. It improves the economics for manufacturers for innovative approaches such as products as "services" that are leased over time, or material take-back systems such as Armstrong's impressive closed loop recycling of ceiling tiles. And since deconstruction is a much cleaner form of dismantling than traditional mechanical demolition, local site environmental impacts such as noise, dust, and possible hazardous material releases are reduced.

There have been many elegant specialty construction systems designed over the years to encourage mass production, modular design, or the assembly of buildings from standardized parts and connectors. For a range of reasons, these whole-systems approaches have had limited success in the market. The future may hold great promise for a completely new system of construction. But the strategy in this handbook is to work with current common construction systems, optimizing them for deconstruction, rather than creating another new system.

Adaptability and Ease of Maintenance

Design for Deconstruction is often thought of only as it applies to a building at the end of its life. But Design for Deconstruction (DfD) is just one term among a number of Design for "_____", such as Design for -Adaptation, -Disassembly, -Reuse, -Recycling, -Reparability, -Product recovery, and -End-of-life. In fact some of the greatest benefits of Design for Deconstruction are during a building's lifetime, or actually extend a building's useful life.

By making building components easier and faster to remove, it is easier to adapt or change the building to meet evolving functions over its lifetime, the concept has been called Life Cycle building. This reduces the cost of renovation and extends a building's life by making it economic to remodel. Extending the useful life of an entire building is the highest form of salvage and reuse.

Some architects do consider alternate future functions that a building may have, and try to allow flexibility for this in their design. Important considerations include choosing a structural system that allows spaces to be reconfigured, or locating inflexible plumbing, stair or elevator cores to provide future flexibility.

Providing access and pathways for changes to building utilities and infrastructure can greatly simplify modifications or maintenance for a building. Utilities, such as telecom, electrical, and mechanical systems, are some of the most frequent components needing maintenance or upgrades. If these systems are accessible, whether exposed, above an accessible ceiling, or in an attic or crawl space, the speed and cost of changes is significantly reduced. If a component or material is designed for removal, it also facilitates access to utilities it may conceal.

Finally, DfD preserves some of the social and historical "content" of recovered materials and the building fabric which housed them. Like an industrial building converted to lofts, or salvaged lumber showing years of character, these materials have a history and tell a story that connects people to another age. Other components like a vintage fireplace mantle, stair-rail, or stained glass windows recall the culture and craft of the designers who made them. High quality, well-designed components such as these are highly valued and often recovered for reuse. The real challenge of DfD is to expand the range of materials and components beyond a few specialty items that can be cherry-picked out of a building, to the components and materials that make up the bulk of the building.

2. Lessons from the Field

Fort Ord Barracks Deconstruction

Wood Waste Diversion,
John Stephens, Jbsfortord@aol.com

In 2004 Wood Waste Diversion deconstructed this barracks building at the decommissioned Fort Ord in California. These are simple buildings with lots of valuable lumber, and few finish materials or adhesives to complicate deconstruction. Hazardous materials can be one of the biggest challenges, in this case asbestos and lead based paint.

Figure 2.1 Typical Fort Ord Barracks building to be deconstructed, part of the "urban forest" that is being harvested for new construction projects

Figure 2.2 Roof is removed to ground level where it is safer and faster to deconstruct

Figure 2.3 Roof is separated into planes of rafters & sheathing

Figure 2.4 Using a “snowplow” to remove asphalt roof shingles. Finding fast, economical tools and methods for Deconstruction is a key step to making it standard practice.

Figure 2.5 Removing sheathing from joists, the work is elevated for convenience

Figure 2.6 Removing joists from sheathing with custom made pry bars

Figure 2.7 Removing studs from sheathing using the Drive-By method

Figure 2.8 Pneumatic de-nail station with the "Nail Kicker" (www.nailkicker.com)

Figure 2.9 Reclaimed old growth lumber, denailed and planed, ready for new construction.

Figure 2.10 Reclaimed wood is reused for a new ceiling at the Cal State University Visitors Center, one of the new institutions at the former Fort Ord.

Mobile Lead Based Paint Removal System

Wood Waste Diversion
John Stephens JBSfortord@aol.com

Driving his kids to school at Fort Ord everyday, John Stephens would look at the hundreds of abandoned barracks and think what a waste of beautiful old growth lumber. Wouldn't it be better to salvage and reuse all this wood? One of main stumbling blocks was it was covered in lead based paint. John knew a planer was the most efficient way to remove the paint, the problem was capturing all the lead dust. So he set out to build an "airtight" trailer that would capture all the hazardous planer shavings. Working with Stan Cook at the Fort Ord Reuse Authority and funded by an EPA grant for deconstruction, he designed and built the Mobile Lead Based Paint (LBP) Removal System (patent pending). It has undergone extensive testing to ensure no lead is released into the atmosphere, and been certified by the California Air Resources Board. John now leases the equipment to large projects around the country.

Figure 2.11 Trailer is parked at the deconstruction site, it is negatively pressurized to contain lead paint dust.

Figure 2.12 Recovered lead painted siding is fed into the planer on one side of the trailer

Figure 2.13 Clean old growth Douglas Fir comes out the other side.

Figure 2.14 Clean, salvaged Douglas Fir, ready for another home.

3. DFD Principles and Strategies

What determines if buildings get deconstructed?

Deconstruction is often discussed primarily as a strategy to meet environmental goals, but it can meet social and economic goals as well. There must be an infrastructure of contractors skilled in deconstructing buildings, the cost of deconstruction and the recovered materials must be competitive with alternatives, and there must be a market for the recovered materials. Some of the key factors determining if buildings are deconstructed include:

- The local cost of landfill tipping fees
- The local cost of labor and equipment
- The ease of disassembly which affects labor cost
- The value of the materials recovered
- Having adequate time available for deconstruction

Landfill tipping fees - charges for depositing waste on a landfill - vary greatly by region from less than $10/ton to over $100/ton in states like Vermont or California. In areas with high tipping fees, deconstructing buildings can avoid substantial tipping fees, which can help offset the additional labor needed to disassemble the building. Labor and equipment costs also vary greatly by region, and significantly affect the economics of labor-intensive deconstruction.

The value of the materials recovered is also a key factor. The booming salvaged wood market has spurred increased competition for buildings containing large timbers or high quality old-growth lumber. The value of this lumber can command premium prices, up to $12/board foot. Many homeowners are willing to pay a premium for recycled wood that has a story and “character.” Salvaged components such as antique fireplace surrounds, light fixtures, hardware, and other ornamental pieces can be shipped to a national market and command high prices, as a quick search on E-Bay will show. The internet can facilitate connecting buyer and seller through local bulletin boards or services like the California Materials Exchange (www.ciwmb.ca.gov/calMAX). The value of many larger recovered resources depends on the robustness of the local recovered materials markets. Chicago has a very active market in salvaged bricks due to the large number of brick buildings with lime mortar there. The West Coast has dozens of salvaged wood dealers supplied by dismantled structures built from the forest resources of an earlier era. Designers can increase the likelihood that a building will be deconstructed if they choose quality materials that will have a high value in the future.

Deconstruction does take longer than demolishing a building with heavy equipment, if this is not considered, it likely will not happen. If demolition of an existing structure is part of a construction contract for a new building, the contractor will often want it down as quickly as possible to start on the new project and meet that schedule. It often makes sense to issue a separate contract prior to and separate from the new work to relieve some of the schedule pressure. If the building to be demolished is in use or generating revenue from a lease, these can present real obstacles.

The ease and speed of deconstruction is a key factor that this Handbook most directly addresses. How can architects, engineers, and builders put buildings together that are easier to take apart? Do the fastening methods allow disassembly, and are these connections accessible? Are there too many materials or are they assembled in a complex, intertwined manner? Are hazardous materials intermixed with the valuable ones? Are the components visible or identifiable on existing drawings? Are glues and composite materials avoided? The designers and builders of our structures have a major impact on how readily they can be deconstructed. Often a simple mental shift to just think about the ease of disassembly during design and construction reveals numerous strategies that can be easily adopted.

Deconstruction strategies:

- Maximize clarity and simplicity
- Minimize building complexity
- Minimize different types of materials
- Minimize number of components (fewer, larger elements)
- Minimize number of fasteners (fewer, stronger fasteners)
- Use mechanical fasteners in lieu of sealants and adhesives
- Simplify connections
- Make connections visible/accessible
- Separate building layers or systems
- Disentangle utilities from structure
- Use materials worth recovering
- Minimize toxic materials
- Minimize composite materials
- Use of modular building components/assemblies
- Provide access to components/assemblies (windows, etc)
- Provide access or tie-offs for work at height
- Accessible information:
  - Construction drawings & details
  - Identification of materials and components
  - Structural properties

Materials, Assemblies, and Building Systems

Design for deconstruction suggests careful thought about how materials, assemblies, and building systems interconnect. The following section describes important DfD principles – and questions to ask – at these three building levels.

Materials

Precautionary materials selection
Use materials worth or feasible for recovery
Minimize number of different materials
Avoid composites of dissimilar materials
Minimize toxic materials

In general, materials should be selected with caution. Abating hazardous materials can greatly increase cost, as industry experience with asbestos and lead paint have made very clear. There are good sources of information to assist architects and contractors in avoiding potentially hazardous materials, including GreenSpec, which provides a comprehensive list of carefully reviewed materials. If hazardous materials are required for performance reasons, consider tagging or identifying them so they can be properly handled at the end of their life.

Using fewer materials also simplifies deconstruction. Automobile dashboards used to be complex assemblies of numerous materials that made recycling impractical. Newer technology allows the use of a single resin for an entire assembly that can be readily recycled. DfD suggests that designers consider if possibly the same architectural effect or performance can be achieved by using fewer material types, or the same material in different ways? If more material types are necessary, the interface between materials should be carefully considered. When possible, consider the use of solid materials in lieu of composites of dissimilar materials, as composites complicate the separation of individual materials for reuse.

Assemblies

Minimize number of components (fewer, larger elements)
Minimize number of fasteners (fewer, stronger fasteners)
Use mechanical fasteners in lieu of sealants and adhesives
Simplify connections
Make connections visible/accessible
Separate building layers or systems
Disentangle utilities from structure

Defined as a collection of parts fitted together into a complete structure, assemblies are the building blocks of architecture. They dictate how materials and components come together. As such, design for deconstruction encompasses the field of disassembly. Only the optimal number of fastenings should be used, and the design process should question: can the assembly be structurally supported with fewer but stronger fasteners? Does consideration for the location of fasteners yield a more economical solution? At the material level, where and how do fasteners affect potential for reuse? Irreversible fasteners to avoid include glues and chemicals, as they damage materials being removed. Instead, consider the use of screws, bolts, and mechanical connections. Disassembly is simplified when there is clarity, not complexity, in how fasteners are used.

Design should also consider access to subassemblies, particularly those which need to be maintained, repaired, or modified on a regular basis. Access to a subassembly should not degrade materials or assemblies "above" it, such as not having to cut and patch drywall and stucco to replace a window. Connections should be simplified, readily accessible, and where possible exposed to serve as everyday clues as to the deconstruction process, or at least allow users to formulate questions about assembly and disassembly.

Modularity and prefabrication can promote reuse and recycling at a larger scale – whether modules of assemblies or their component materials. However, modules and components should be dimensioned for reuse. It only makes sense to modularize a particular assembly if it makes construction and deconstruction easier. And if modularity complicates assembly or if it involves the modularization of overly specific pieces, then it may in fact force creative reuse at best.

Building Systems

Consider building system relationships, efficiency, and articulation
Consider independent (self-supporting) assemblies

Stud-framed construction has traditionally been a quick-and-easy-to-build assembly performing multiple functions: load and shear bearing walls, exterior envelope, interior partition, and electrical and plumbing chase, to name a few. With so many roles, building systems are often modified to accommodate one another within a 6" thick wall. Disentangling these building systems makes it easier to maintain individual systems and facilitates adaptation or deconstruction; enclosure, structure, infill, substructure, mechanical and electrical systems can be separately articulated. Thus, for instance, the removal of an interior partition can be accommodated without disturbing electrical or structural systems.

Moreover, separating systems allows for more adequately addressing the environmental impact of materials used, relative to desired permanence or changeability. If a structural system is designed to last unchanged for over a hundred years, then a material with the appropriate durability and embodied energy (and emissions) can be selected for the structural system. Likewise, infill materials with a shorter lifespan or configuration can be selected and assembled with reuse or recycling in mind.

Building Information

Record drawings, exposed assemblies, and photographs of utilities before they are concealed behind drywall or ceilings, all convey building construction information and can significantly contribute to successful deconstruction. A deconstruction plan based on the construction process should document the DfD concepts included in the building.

4. Setting Priorities

Buildings are complex assemblies of multiple materials and components, which have widely varying lifespans, different methods of assembly, and a range of economic values if recovered. It is important to establish priorities for where to focus our design efforts for deconstruction. This is more complex than it appears at first glance, with a number of factors coming into play. These include:

- The quantity of a material
- The environmental impact of a material
- The ease of recovery
- The value of a material after recovery
- The lifespan of a material (or frequency of replacement)

To better understand these issues, we analyzed three buildings, each with different structural systems, one of structural steel, one of cast in place concrete, and one wood (see figure 4.1, 4.2, and 4.3). These projects were selected because the team had a thorough knowledge of these projects with detailed data readily available. The data reflect the particular design characteristics of each of these specific designs.

Figure 4.1 Global Ecology Research Center - Steel Frame

Figure 4.2 CSUMB Library - Concrete Frame

Figure 4.3 Chartwell Schoo - Wood Frame

We first quantified the materials used in each project. The major materials in each project were identified using the project specifications as a guide. To keep the data gathering tasks manageable, we excluded mechanical, electrical, and plumbing equipment (MEP), furniture, fixtures, and equipment (FF&E), and omitted materials that occur in small quantities. LEED green building rating systems established a precedent for this approach in its Materials Credit protocols.

Using a standard material take-off produced by our cost consultants for estimating purposes (see figure 4.4), we compiled the quantities of each of these materials in a spreadsheet. The quantities were all converted to consistent units based on weight, so the extent of various materials could be compared within and between each of the three buildings analyzed.

	Quantity	*Unit*	*Rate*	*Total*
Round, 26" diam.	[illegible]	*LF*		
Concrete	178	CY	150.00	26,671
Formwork, fiberglass	1,301	LF	35.00	45,535
Rebar (allow 405#/CY)	77,550	LBS	0.75	58,162
Round, 24" diam.	*798*	*LF*		
Concrete	93	CY	150.00	13,934
Formwork, fiberglass	798	LF	35.00	27,930
Rebar (allow 405#/CY)	40,516	LBS	0.75	30,387
CIP reinforced concrete pilasters at retaining walls				
Rectangular, 24" x 72" o/a	*56*	*LF*		
Concrete	6	CY	150.00	933
Formwork	112	SF	10.00	1,120
Rebar (allow 405#/CY)	10,855	LBS	0.75	8,142
Rectangular, 24" x 24" o/a	*42*	*LF*		
Concrete	2	CY	150.00	233
Formwork	84	SF	10.00	840
Rebar (allow 405#/CY)	2,714	LBS	0.75	2,035
Concrete walls at 4th floor office area	831	SF	35.00	29,085
Concrete parapet walls at roof level (non-structural)	1,638	SF	25.00	40,950
Premium for forming exposed interior walls	24,680	SF	3.00	74,040
Structural steel framing				
Penthouses, allowances				
Mechanical penthouse / plenum at fourth floor roof	4,880	LBS	1.00	4,880
Mechanical penthouse / plenum at high roof level	17,960	LBS	1.00	17,960

Concrete
Rebar
Structural Steel

Figure 4.4 Material Qualities taken from standard Cost Estimates

These material weights were then graphed as a percentage of the total materials in each project to provide a visual representation of the material breakdown for each project (see figure 4.5). The graphic shows that in these projects concrete completely dominates the total materials used on the basis of weight. These totals include concrete that is part of the site development. The other major material categories are also structural, including structural steel and rebar, and wood framing.

The Materials Quantity graph is shaded in a gradation of colors transitioning from dark blue to dark red. As indicated by the bar at the top of the graph, these colors indicate a rough estimate of what percentage of these materials at the end of their life can be salvaged and reused, recycled, down-cycled, or have no practical use at this time. Cast in place concrete is routinely crushed at the end of its life for reuse as engineered fill, road base, and occasionally for reuse as aggregate in new concrete. While often referred to as recycling, this is really a low value down-cycling the material. Even reusing crushed concrete as new aggregate is down-cycling because the greatest economic value and environmental impact of concrete is in the cement, which cannot be reused. Crushed aggregate even tends to require higher cement mix designs, offsetting some of the benefit and reducing virgin aggregate use. Steel is easily and very widely recycled, but little is currently salvaged for reuse in its existing form.

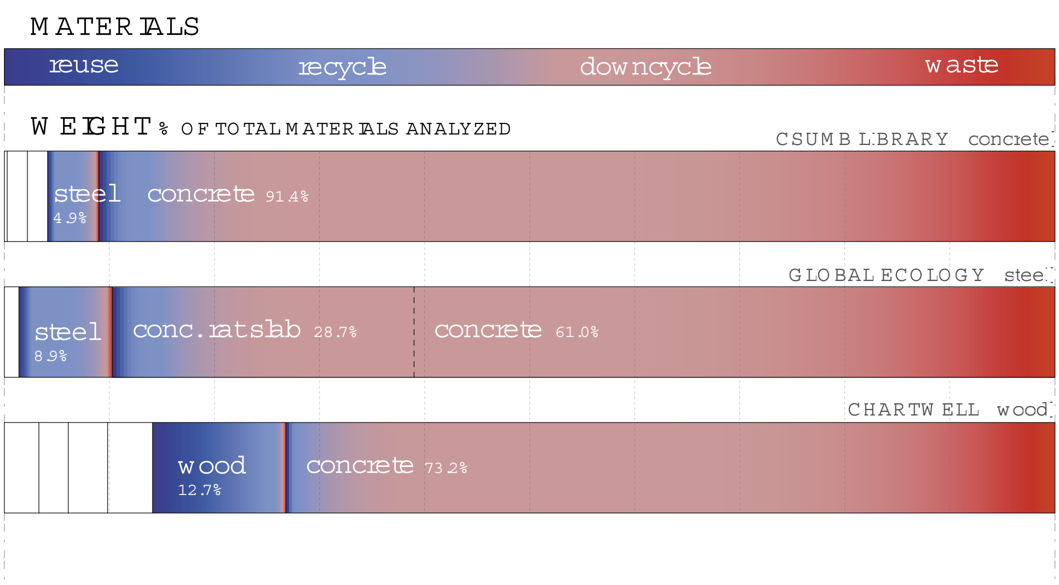


Figure 4.5 Weights of materials as a percent of totals for 3 projects with different structural systems

After establishing the quantities of materials in these three projects, we wanted to understand their relative environmental impacts. A true Life Cycle Analysis (LCA) would be desirable, but the data and tools in this field are still in their developmental stages and it is beyond the scope of this analysis. As a proxy for a true LCA, we chose to look at carbon emissions. Carbon emissions capture probably the most critical environmental issue: climate change. It also generally corresponds to embodied energy, and therefore the wide range of ecological impacts related to energy use. It does not address a host of issues including toxicity, impacts on forests, ecosystems, and biodiversity, etc; so when referring to the results, care should be taken to remember the limitations of this analysis.

The first task was to determine the embodied carbon per unit of material. This information was primarily extracted from the ATHENA Life Cycle Assessment software developed by the Athena Institute. To improve confidence in the data it was compared to a variety of other sources, including the paper "Carbon Intensity Ratios" by Richard MacMath and Pliny Fisk III of the Center for Maximum Potential Building Systems. The embodied carbon associated with each material is shown in figure 4.6.

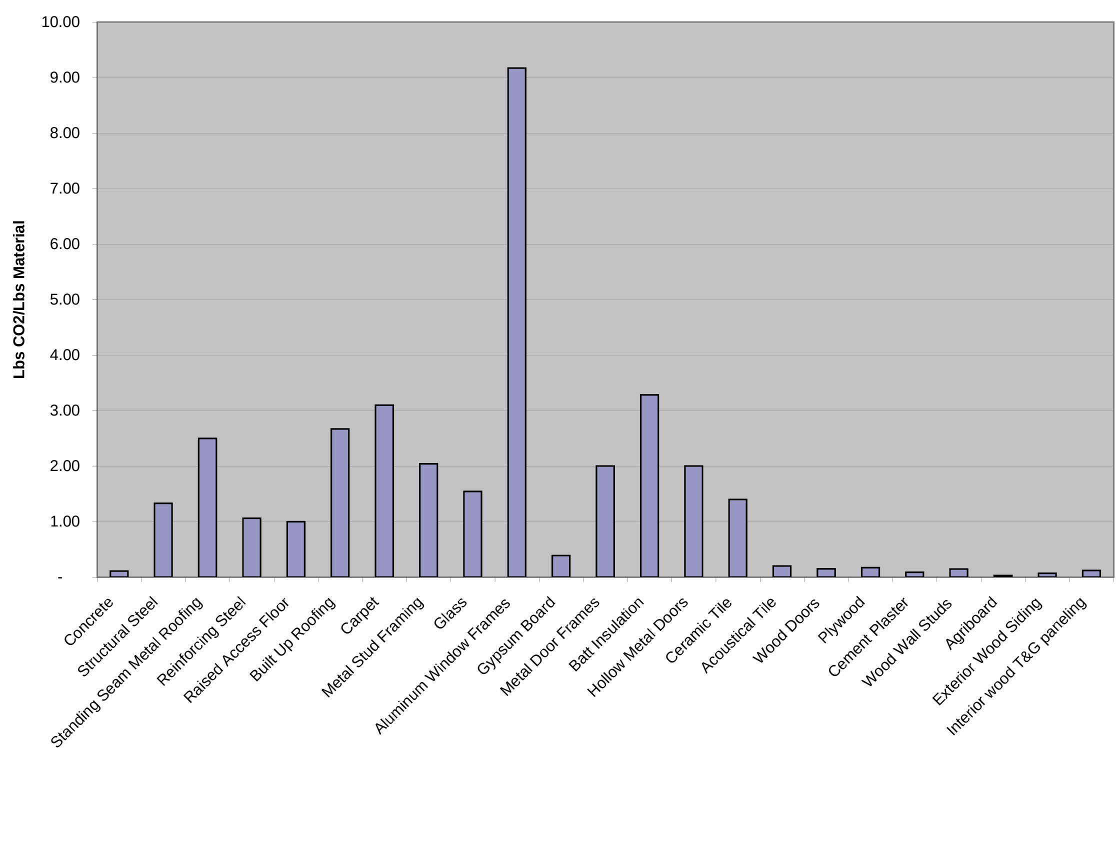


Figure 4.6 Pounds of Carbon per pound of material embodied in common construction materials.

It is instructive to note the wide variation between materials, with aluminum being close to a factor of 100 greater than concrete in lbs of CO_2 per pound of material. This can be deceptive in two ways: aluminum is a light-weight material used in limited quantities while concrete is a heavy material used in mass quantities.

The embodied carbon factors were then multiplied by the total weight of each material in the three projects, and divided by the square feet of each building to normalize the results. An example of the calculation is shown in figure 4.7, and the results for each building are graphed in figure 4.8 and 4.9.

	Tons of Material	CO2 Emission Factor	Tons of CO2	CO2 Percent of Total
Concrete	1,007.4	0.11	109.8	32.5%
Reinforcing Steel	24.6	1.06	26.0	7.7%
Structural Steel	17.4	1.33	23.1	6.8%
Standing Seam Metal Roofing	9.6	2.50	24.0	7.1%
Built Up Roofing	19.7	2.67	52.5	15.5%
Tile Carpet	4.3	3.10	13.5	4.0%
Metal Stud Framing	-	2.04	-	0.0%
Glass	12.9	1.54	19.9	5.9%
Aluminum Window Frames	2.0	9.17	18.3	5.4%
Gypsum Board	38.5	0.39	14.9	4.4%
Metal Door Frames	1.3	2.00	2.6	0.8%
Batt Insulation	3.1	3.28	10.2	3.0%
Hollow Metal Doors	1.1	2.00	2.2	0.7%
Ceramic Tile	1.6	1.40	2.3	0.7%
Wood Doors	2.0	0.15	0.3	0.1%
Plywood	37.5	0.17	6.4	1.9%
Cement Plaster	58.8	0.09	5.1	1.5%
Wood Wall Studs	106.0	0.03	3.2	1.0%
Agriboard	3.1	0.07	0.2	0.1%
Exterior Wood Siding	1.3	0.12	0.1	0.0%
Interior wood T&G paneling	23.6	0.15	3.4	1.0%
TOTALS	**1,376**		**338.2**	

Figure 4.7 Chartwell School Embodied CO2 Calculations

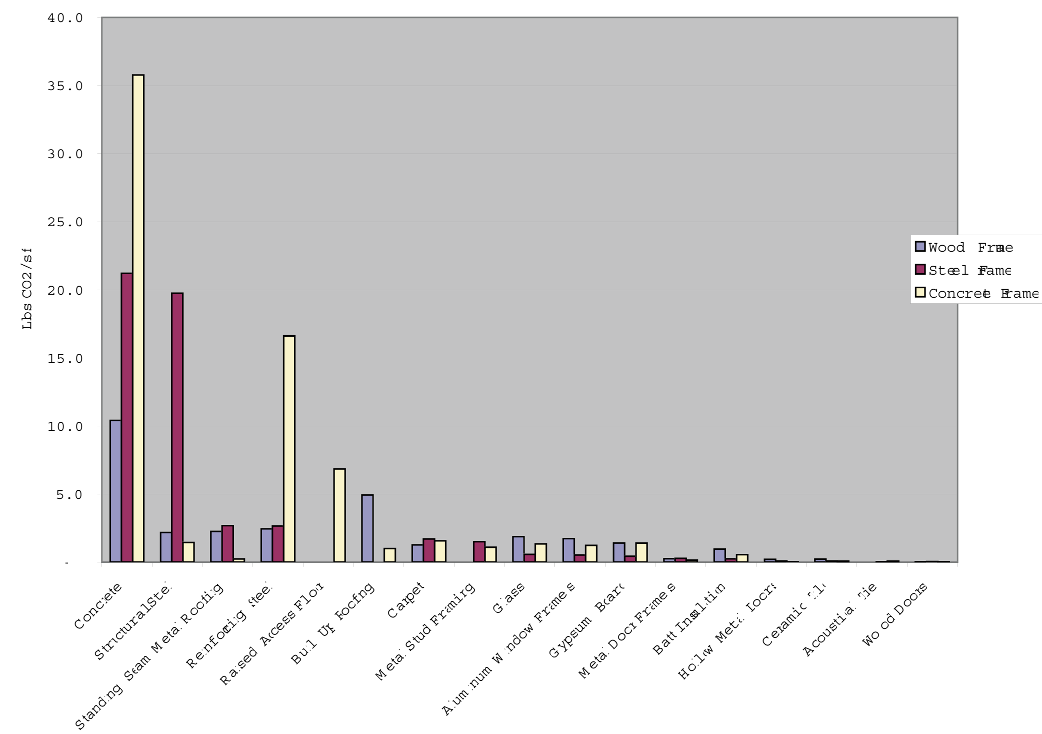


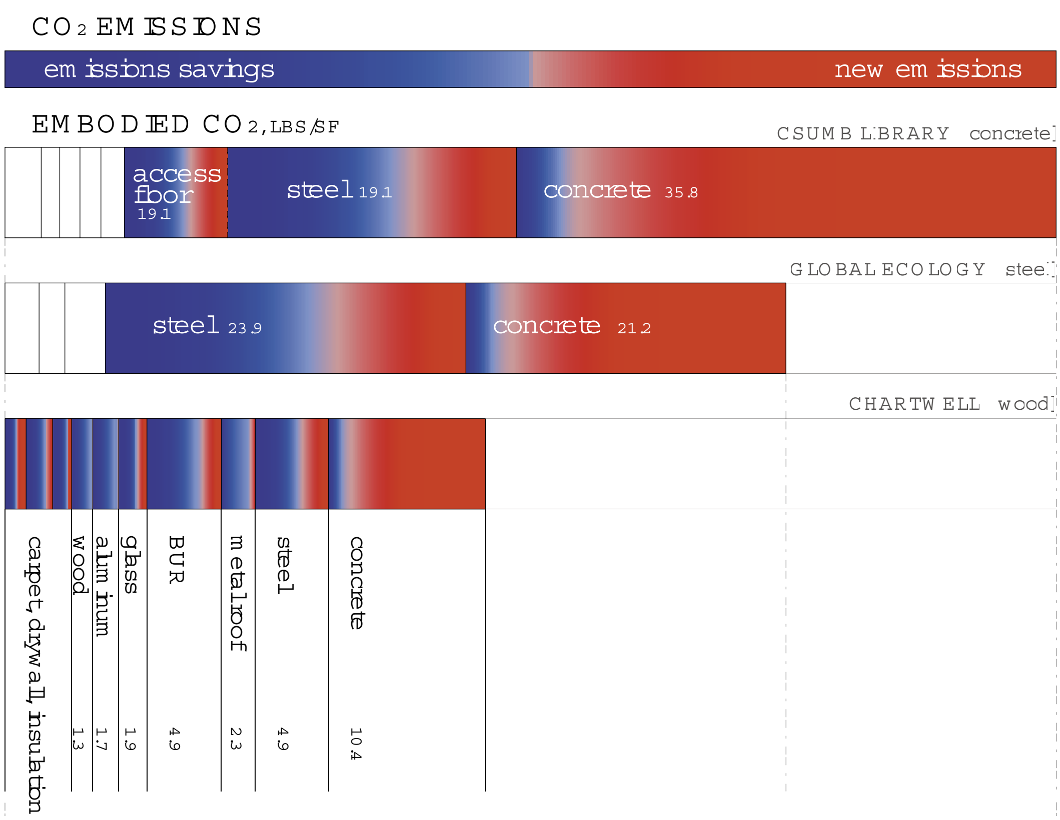
Figure 4.8 Pounds of embodied $C0_2$ per square foot for three projects.

The most obvious result from this analysis is the dominance of structural materials: concrete, steel, and rebar. Green building materials selection often focuses on interior finish materials, in part due to a desire to ensure good indoor air quality. Structural materials do present real challenges, as the choice of commonly used structural materials is limited, and there is currently a fairly limited repertoire of green solutions using these materials (eg: efficiency, modular design, high flyash/slag concrete, performance based design, etc). We believe this analysis suggests a renewed effort to expand the structural options design teams have at their disposal, and a continued study of how to design structural systems for disassembly and reuse.

Concrete poses a major challenge in this regard. While there are some precast structural components that can be deconstructed and reused, it is not clear how the vast majority of cast in place concrete can be reused in any significant fashion. The possibilities are easier to envision for structural steel. Only a few years ago, the salvaged wood market was still fairly small and fragmented. Now deconstruction and salvage of wood structures is big business, with competition and high prices for the best quality material. Graders now routinely inspect salvaged timbers and grade them for structural reuse, and many of the hurdles of only five years ago have disappeared.

To our knowledge, there are some salvage yards that take steel shapes for re-sale, but the market seems to be in its infancy. Reusing rather than recycling steel sections reduces the transportation cost and energy needed to get it back to the mill, and recycling steel uses about half of the energy required to refine steel from ore. The development of regional steel salvage yards and protocols for verifying the structural properties of the salvaged members is an important step towards wider acceptance of design for disassembly.

The embodied carbon results are also shaded from blue to red, indicating a rough estimate of the emissions that could be saved by salvaging and reusing or by recycling the materials. Steel, for example is approximately two-thirds blue indicating that a combination of some salvage and some recycling could reduce the carbon emissions associated with new steel by approximately this amount. For concrete, with limited salvage options and true recycling not available, only the emissions associated with mining, crushing, and transporting aggregates can be saved. This again points to the need for further research in how to design elements that use concrete in a manner that Capitalize on its durability, such that they can be disassembled and reused.



Chartwell School (Wood)	31.8 lbs CO2/sf
Global Ecology Lab (Steel)	51.8 lbs CO2/sf
CSUMB Library (Concrete)	69.4 lbs CO2/sf

Figure 4.8 Pounds of CO_2 per Square foot for three projects.

Wood is quite low in embodied carbon emissions since nature manufacturers the wood and manufacturers just harvest and mill it. On much of the west coast, framing lumber is not kiln-dried, which increases wood's embodied carbon. Wood in fact sequesters significant amounts of carbon, as long as the wood does not decompose or burn. And the planting of forests and sequestration of carbon is one of the important strategies for addressing climate change. On the other hand, the choice of carbon as a metric in this case does not reflect wood's potential ecological impacts due to poor forestry practices.

Salvaged wood requires very little additional energy to process, so new emissions are limited primarily to transportation. The key to retaining woods value through cycles of reuse is to maintain it for the highest and best use. The value of wood products vary by at least a factor of ten based on the size, cut, and character of the wood. Larger pieces retain more of their value as they offer the most flexibility for reuse or remilling and are easier to salvage than a large number of small pieces. Notching or drilling framing lumber for utilities creates defects in the wood that reduce its value and potential for reuse. These and other strategies from maintaining the value of wood are explored in the Chartwell School Case Study that follows.

5. Chartwell School Case Study

In 1998, the average public school building in the United States was 42 years old, an age where significant repair, modernization, or replacement is often required. In 1999 51% of schools reported plans for at least one major repair, renovation, or replacement of their facilities. The scope of these modernizations or replacements will have major financial impacts on school districts around the country, and generate significant environmental impacts due to demand for new construction materials and disposal of demolition debris.

To minimize these costs and impacts, durability, ease of maintenance and potential for adaptability are critical in school design. Ideally, as they reach the end of their life span, schools will be able to replace or upgrade various components with minimal impact to surrounding finishes and other still-functional components. School facilities should also have the ability to change and evolve over time, as class sizes, teaching pedagogy, or new technologies suggest changes.

The goal of this case study is to explore how a school can adapt to such changes faster, easier, and at a lower cost; and to create an inherently more deconstructable building to facilitate the reuse and recycling of its building materials.

Chartwell School is a K-8 school that educates children with dyslexia and related language learning disabilities. The school has a commitment to implementing and disseminating the latest, peer-reviewed scientific research on reading, while educating each student as a unique and valuable individual. It will be constructed on a 26-acre site on the decommissioned Fort Ord military base in Seaside, California. The school is committed to building a new campus that will provide a high performance educational environment for the students, while showcasing design principles that support and enhance learning. As part of its high performance goals, it has been designed to meet LEED Platinum standards under the U.S. Green Building Council rating system. It aims to be a model for development in the region by demonstrating and disseminating sustainable building practices that minimize ecological impacts while creating exceptional healthy learning environments full of fresh air and natural light.

The master plan for the school consists of four buildings organized around a courtyard as shown in figure 5.2. These include north and south classroom buildings, a library/administration building, and a multipurpose building. Phase I, the south half of the development, is under construction and due to be completed in August of 2006. The buildings are one story slab-on-grade with wood frame construction. The school includes extensive daylighting and energy efficiency measures to reduce energy use. A photovoltaic system on the roof is sized to produce all the electricity the school will consume over the course of a year (a grid-tied net-zero design).

Design for Adaptability

Chartwell's typical class size is extremely small, 8-10 students per class. As a result, the 600 square foot classrooms are much smaller than the 960 square foot classrooms found in a typical California public school, which are designed hold as many as 30 students. Even though the school's teaching model currently relies on small class sizes, their teaching needs and methods may change over time, and they may want larger classrooms at some point in the future. To accommodate such change, the interior walls between classrooms are non-structural partitions that can be removed without compromising the structural performance of the building.

In addition, the interior shear walls (primarily along hallways) have been "over" designed, so additional openings can be cut into the walls in the future. This will allow the school (or some future owner) to add a reasonable number of additional interior doors and windows in the future, without needing to add strength to the existing

shear walls to upgrade. Information Technology components, in particular, change quickly; it's difficult to anticipate what this infrastructure will look like just 10 years from now. To accommodate future changes and allow easy maintenance of the existing systems, thought should be given to how these changes can be made.

This was part of the rationale for exposing the view of much of the structure and most utilities at Chartwell School. If it's visible, access for changes is simple. Making the systems visible also facilitates teaching students how the building works, the relationship between their classroom activities and the utilities needed to support them, and how that utility connects back to the earth.

To provide a structure and organization to the utilities, a utility raceway was run the full length of the classroom building adjacent to the corridor (see figure 5.1). Teacher's cabinets are located along this walls, and the doors are recessed in from the hallway, which together were used to form a "shelf" for this continuous utility raceway. From a deconstruction perspective, there are several advantages to this. First, it disentangles the utilities from the structure, making it simpler to recover the utility piping and cables and to take down wall sections without a tangle of piping and cables. Second, by minimizing utility runs through the wood stud walls, it minimizes drilling of studs which leaves holes in the wood framing and reduces its value for recovery.

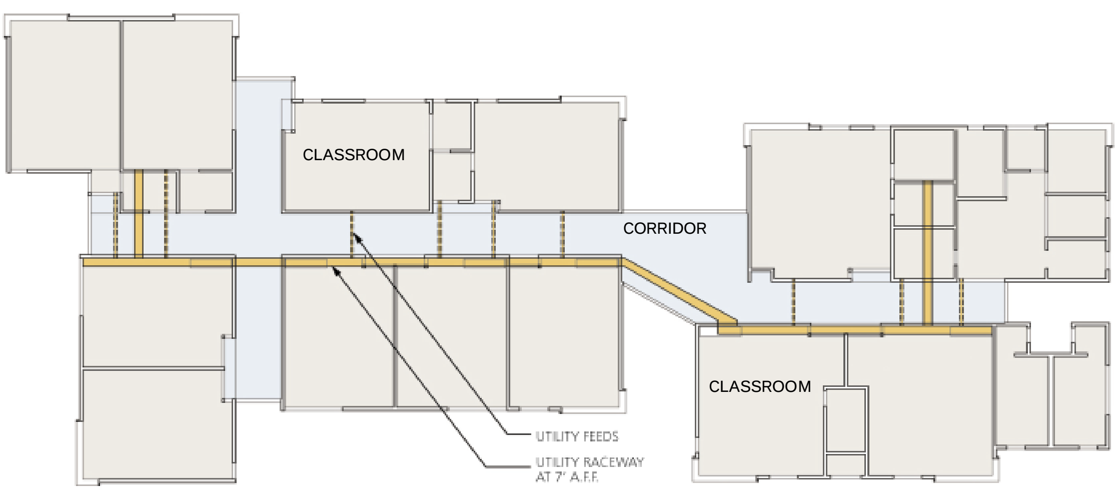


Figure 5.3 Utility Raceway

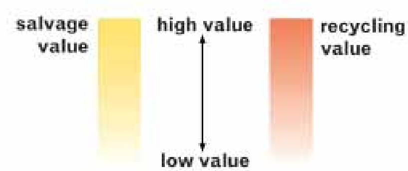
Design for Deconstruction

To understand the potential impacts of designing for deconstruction, it is valuable to understand the likely material life cycles for all the major components of the building. We began with a matrix of these major building materials (see figure 5.4), and estimated the quantities of these materials and embodied CO2 emissions as outlined in Chapter 4. We then estimated the relative ease or difficulty of salvage, and the relative value of that material after it was recovered. For example, concrete is easy to recover but has a low value, whereas interior wood paneling is difficult to recover but has a high value once recovered. This analysis helped us focus our detailing efforts on those valuable components, even if they are currently difficult to extract from the building. In this case, that meant a particular focus on wood structural and finish components, and much of the detailing below addresses these materials.

As noted previously, concrete is the dominant material both in terms of total weight and embodied CO2, yet the options for salvage or recycling are limited. The concrete at Chartwell School included foundations, slabs on grade, and extensive site paving. The site work has the fewest technical demands and offers the greatest opportunity for innovations. There are a number of alternative paving materials on the market, each with their own advantages and disadvantages, but that is not our task here. From a deconstruction perspective, concrete unit pavers are excellent for deconstruction. They can be removed and reinstalled to work on utility lines, or removed and reinstalled at another site. The fact that used paver bricks are often more valuable than new bricks illustrates the potential of this strategy. Unit pavers have traditionally cost quite a bit more than concrete flatwork, but as concrete and cement cost have escalated rapidly in California over the last three years, the premium is now quite small.

DISASSEMBLY MATRIX

The Matrix is a tool intended to help guide material specification and detailing throughout the design process. The salvage value of a material combines with the ease of recovery and the relative quantity to suggest, for example, that designing wood siding for disassembly is a priority. Similarly, the high embodied CO_2 content of concrete combined with overwhelming weight of material suggests that designing for ease of recycling is of high value.



SPEC SECTION	COMPONENT	EXPECTED LIFESPAN *	EASE OF RECOVERY AS DETAILED	SALVAGE OR RECYCLING?	VALUE AFTER RECOVERY	QUANTITY OF MATERIALS	WEIGHT PER UNIT	ACTUAL WEIGHT OF MATERIALS	EMBODIED CO_2/TON PER UNIT	TOTAL EMBODIED CO_2	SALVAGED MATERIALS AVAILABLE?
3300	Concrete Slab on Grade	100	easy	recycling	low	538 cy	2.025 tons/cy	1088 tons	0.15	163 tons	yes (aggregate and fly ash)
3320	Concrete Site Paving	50	medium	salvage	low	413 cy	2.025 tons/ cy	836 tons	0.15	125 tons	yes (aggregate and fly ash)
5100	Reinforcing Steel	100	easy	recycling	medium	28,443 lf	.88 lbs/ sf of concrete	9.5 tons	1.05	10 tons	no
6120	Agriboard	100	easy	salvage	medium	16372 sf	13 lbs/sf (8" panel)	106 tons	0 **	0	no
6170	Wood - Wall Studs	100	medium	salvage	medium	21,000 LF (or Board Feet)	27 pcf (Fir)	23.6 tons	0	0	yes
6200	Exterior Wood Siding	50	easy	salvage	high	2900 board feet or 241.5 cf	26 pcf (Redwood)	3.14 tons	0	0	yes
6200	interior wood T&G paneling	100	easy	salvage	high	1167 board feet = 63.6 cf	26 pcf (redwood)	0.83 tons	0	0	yes
6410	Plywood for Casework	50	medium	salvage	medium	892,069 cu. in	.022 lbs/cu in	9.8 tons	0	0	no
7210	Batt Insulation	50	medium	recycling	low	15,000 sf (wall) 4,500 sf (roof)	.28 psf (R-19)	3.1 tons	1.5	4.7 tons	no
7412	Standing Seam Metal Roofing	25	easy	recycling	medium	11660 sf 8745 lf	2.2 lbs / lf	9.6 tons	1.05	10.1 tons	no
8212	Flush Wood Doors	50	easy	salvage	low	12 doors (3'x7') 252 sf	5.3 lbs/sf	.67 tons	0	0	yes
8800	Glass	50	medium	recycling	low	7870 sf	3.28 psf	12.9 tons	1.3	16.8	no
9220	Cement Plaster	50	hard	NA	NA	9800 sf	12 psf	58.8 tons	0.2	11.8 tons	no
9250	Gypsum Board	50	medium	recycling	low	38,500 sf	2 lbs/sf	38.5 tons	0.2	7.7 tons	no
9300	Ceramic Tile	75	medium	salvage	low	1300 sf	2.5 psf	1.63 tons	1.4	2.3 tons	yes
9648	Bamboo Flooring	50	medium	salvage	high	4,609 sf	2.04 psf	4.7 tons	0	0	no
9688	Sheet Carpet	25	easy	recycling	low	11,898 sf	120 oz/yrd	14.9 tons	3.1	46 tons	no

* assuming adequate maintenance of weather envelope ** wood and other agricultural products sequester carbon

One possible expansion of the unit paver concept is illustrated in figure 5.2. Instead of factory cast small unit pavers, it is possible to site cast larger sections of paving that could be relocated with heavy equipment. Tongue and groove cold joints are commonly used in paving, and if spaced at an appropriate interval, could create interlocking pavers of a scale that could be moved and relocated. It seems worth further investigation if this kind of approach could work for constructing slabs-on-grade for buildings that could be reused at the end of the building's life.

For the structural wood frame, a few key principals guided the development of a structural system that would facilitate deconstruction. These included: use fewer but larger components to minimize the amount of labor; design in a repetitive modular fashion, simplify connections, use fewer high capacity fasteners with easy access for removal; and keep it simple and visible so it's readily understood how things come apart.

The first task was to design a simple modular frame, and optimize the material sizes. The entire school was designed on a 24" o.c. module rather than a more conventional 16" o.c. (see figure 5.3). The floor plan was carefully laid out on this module, so that room sizes, window and door openings, and interior partitions typically land on this module. Just this one step saves approximately 30% of framing lumber, often enough to pay for the additional cost of FSC certified lumber, which is used throughout Chartwell School. The stud sizes were then analyzed to optimize the size for various height members for the different wall sizes (see figure 5.4). In one case we realized that by lowering the roof height by 2" makes it possible to step down one stud size. In another case we chose to use a single 2x8 stud rather than double 2x6 studs.

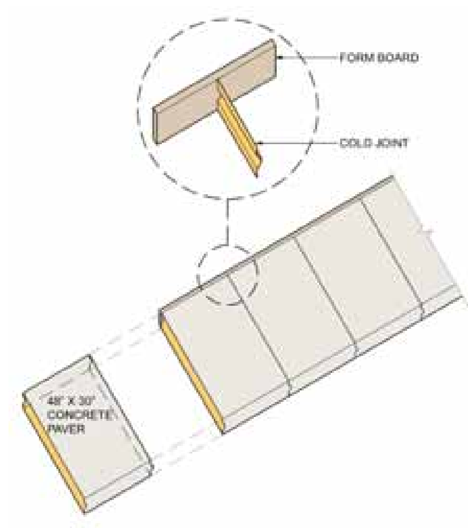


Figure 5.2

Conventional

Framing

2,618 bf

Figure 5.3

OVE

Framing

1,908 bf

Figure 5.4

One of the major challenges with recovering wood framing in California is the extensive nailing and hardware required to meet seismic requirements. Plywood shear panels are typically nailed to the entire exterior of a wood frame building, with 10d edge nailing at 4”-6” o.c. This heavy level of fasteners will be a major challenge to future deconstruction. We analyzed the number of fasteners with plywood turned horizontal rather than vertical, and with 24” o.c. framing rather than 16” o.c., but the differences are fairly modest. The detailing of wood frame walls in seismic zones for deconstruction warrants further investigation and probably needs a technology breakthrough. The development of improved machinery to assist with deconstruction is essential. To reduce the hand labor associated with removing siding or shear panels from studs, heavy hydraulic machinery that can pull a stud off in one operation would be a major step forward (see figure 5.5).

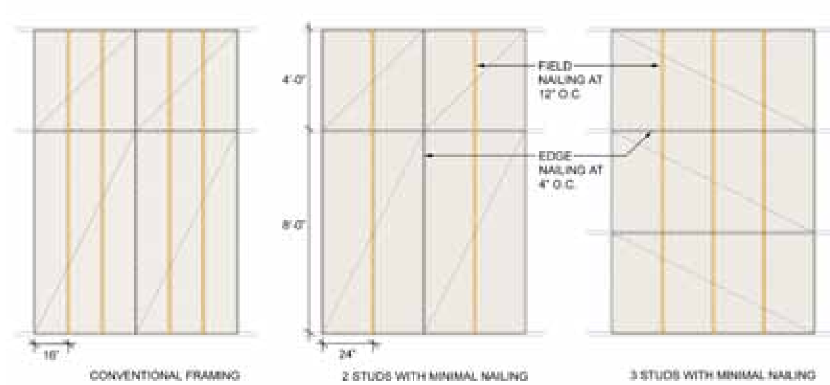


Figure 5.5 Plywood Nailing

The roof framing assembly presented some of the greatest opportunities to design for deconstruction. A typical roof assembly would include plywood roof sheathing, dimension lumber or wood I-joists framing with batt insulation, with a gypsum board ceiling below. To connect the roof diaphragm to the walls in seismic zones, extensive blocking and sheet metal hardware clips are required at the roof/wall interface (see figure 5.6). This creates a connection that is very strong, but very difficult to deconstruct. After exploring a number of options, Structural Insulated Panels (SIPS) were selected because they simplified this connection and the assembly in general. It combines the roof sheathing, insulation, and ceiling finish in this case in a single component. They come in larger sections and are fastened with large screws as shown in figure 5.7. The design intent is that these could easily be removed from the building and reused as whole components. By combining their ability to span, provide insulation, and provide interior and exterior sheathing, they seem like a valuable and flexible component that could be used in many different ways and would not likely be sent to a landfill.

Figure 5.6

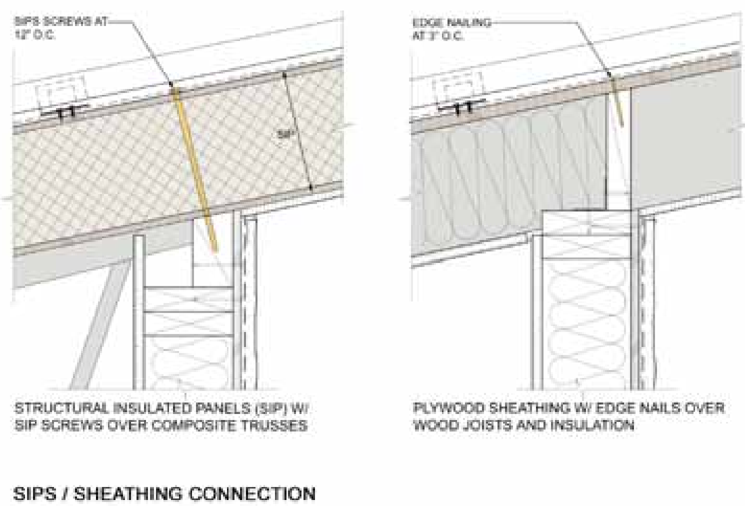


Figure 5.7

The 600 s.f. classrooms are 20' x 30' in dimension, and the structural framing would typically span the short direction. As noted above, however, there was a desire to keep the walls between classrooms non-structural so the classroom layout could be changed in the future. To span the 30' dimension would require either trusses to span the full length, or roof joists with a beam at the midpoint to reduce the span. The trusses can be designed to carry much higher loads, with fewer members and connections, so these were selected as the framing (see figure 5.8). With 24" o.c. wall framing, the roof framing is required to align with the studs since the top plates span too far to transfer the truss loads to the studs. This works well with the modular design of the school, and the trusses were spaced at 48" o.c.

The uplift forces on a roof can be quite large, so metal straps or hurricane clips are used to tie the roof structure to the walls. With fewer, larger members, in this case it required a 24 inch long strap secured with two lag bolts and 24-10d nails. This hardware again produces a very strong connection, but one that is difficult to disassemble. By working with the truss manufacturer, this connection was simplified to use two through bolts and a much smaller 8" strap to connect the top plates to the studs.

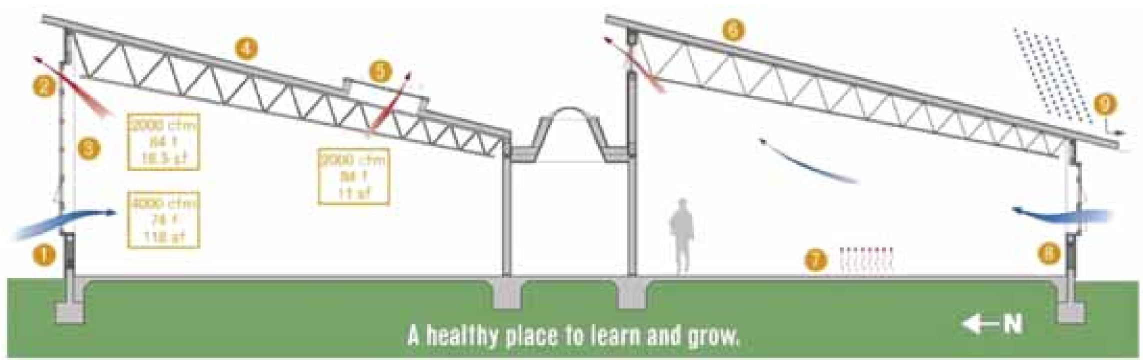
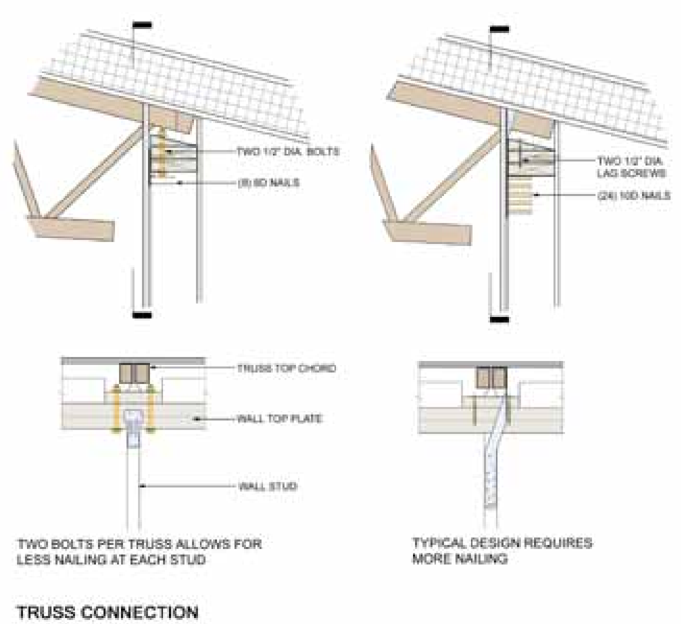
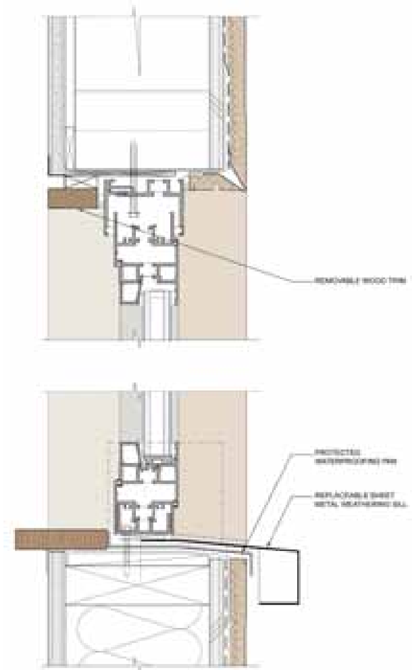


Figure 5.8

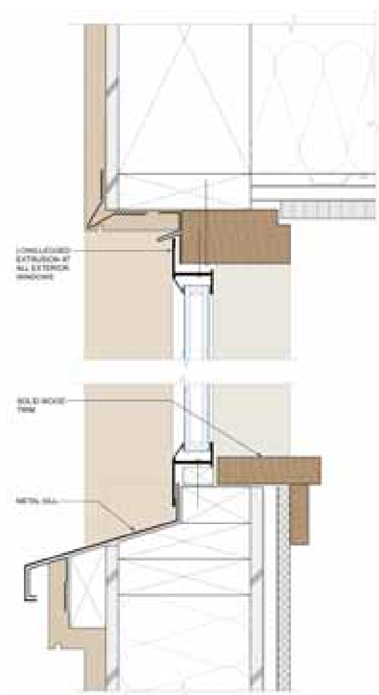


One of the staples of school modernizations is window replacement. In order to ensure a water tight and durable window to wall interface, the window is often buried below the exterior wall finish, cement plaster in this case, either as a nail on flange window, or with the exterior finish butting up against the frame. The interior finish often butts up against the interior of the window frame to provide a finished appearance without requiring interior window trim. This works well for installing the windows, but makes it difficult and expensive to replace them since these adjacent finishes must be removed.

Two alternate window details were developed to address the issue (see figure 5.13 and 5.14). In the first, the exterior finish returns as normal to provide the most water-tight seal, but the interior window is trimmed out with a wood jamb that can be easily removed, allowing the window to be removed from the inside. In this case a replaceable sheet metal weathering sill was installed that allows the base sill flashing to remain in place while the weathering sill is replaced. In the second detail, an unequal leg aluminum window is installed from the outside against flashing that is lapped under the exterior finish. This flashing ensures a water-tight connection between the window and cladding, but allows the window to be removed without touching the cladding.



REMOVABLE WINDOW : DETAIL A

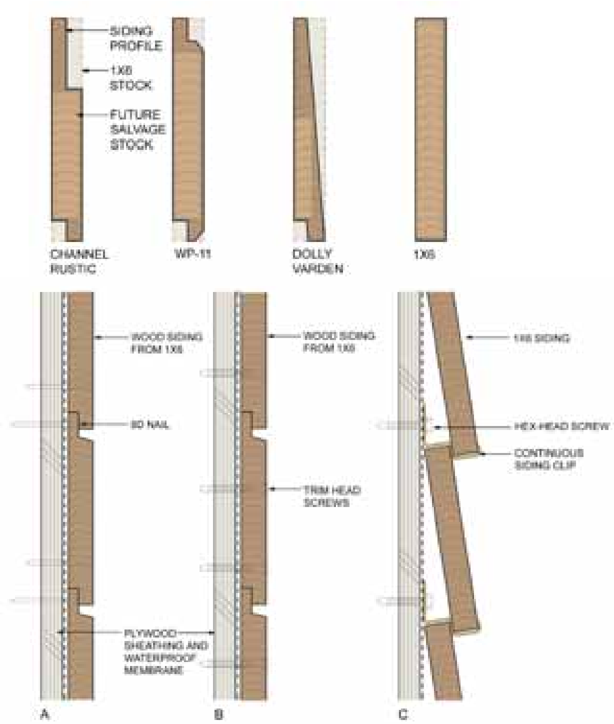


REMOVABLE WINDOW : DETAIL B

Some of the exterior finish at Chartwell School is old growth high grade redwood salvaged from large wine aging tanks (see figure 5.9) and supplied by Terra Mai. The wood is in remarkably good condition after years of use because it was held in place by metals bands that required virtually no fasteners and allowed it to be cleanly and easily recovered with very few defects. If the use of this material at Chartwell School could find a similarly non-invasive attachment method, perhaps now rare and valuable material can be salvaged again in the future. The first decision was what profile siding to use. The traditional siding pattern used at Fort Ord where Chartwell School is located is similar to WP-11 shown in figure 5.17. Quite a bit of material is lost as planer shavings in milling this profile. The intricacies of the profile such as tongues, grooves and chamfers are easily damaged during removal and are rarely feasible to remill. After looking at a series of siding profiles and the theoretical percentage of material that could be recovered after re-planing, a simple rectangular cross section was chosen as retaining the most value.

How to secure that profile is the next challenge. The first inclination is to replace nails with screws that can be removed. But screws are far from the ideal removable fasteners in construction. Even though the wood siding will not initially be painted at Chartwell, it is fairly likely that at some point in its life it will be painted over. This will conceal the screw locations and fill the head slots with paint making them very difficult to remove. While siding attached with nails can be readily pried off without knowing where the fasteners are located, even a single screw can be so strong that the wood fails before the screw yields when a board is pried off. And screws still leave a hole or defect in the wood after removal.

Figure 5.9



Exterior Siding Options

What is really needed is a something like the metal bands that held the salvaged wood together in the wine tanks—something non-invasive and easily removable. After quite a bit of experimentation, the clip shown in figure 5.10 was tested. It has a double bend, one bend to capture and hold the bottom of a siding board, and the second bend to secure the top edge. By using a hex head screw, removal at a future date is more reliable than a slotted head that could strip out. A mock-up demonstrated that the clip was surprisingly secure. If the small tab visible on the front of the siding was not desirable, it could seat into a small groove on the bottom of the siding.

The thickness of the clip provides a thin gap between the boards where they overlap, allowing ventilation and drying of the siding. This gap, however, also has a down side. In high fire risk zones, including the Chartwell School site, which is surround by undeveloped coastal oak forest, this gap reduces the fire resistance of the exterior wall. To minimize any added risk of fire, the detail was not used in the actual construction for the school. However, further development and use at a pilot project level appears warranted for this detail. The wood shown in this mock-up is recovered from a deconstructed bridge deck and supplied by Terra Mai.

A second exterior cladding attachment option is shown in figure 5.11. It conceptually uses a fastener system currently in use for decks, the Eb-Ty fastener. It is a football shaped polyethylene fastener that fits into slots in the edge of the board cut with a biscuit plate jointer. The boards are spaced approximately 1/8" apart with a trim head stainless steel screw installed through the clip to secure the boards. A similar clip could be engineered specifically for siding. The gap between the boards suggests a rain screen approach to this wall assembly. The disadvantage of this detail is that it requires cutting into the edge of the board, likely a continuous groove to reduce labor cost, and this reduces the recovery value of the boards to some extent.

Figure 5.10

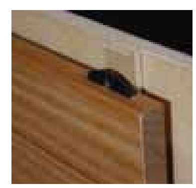


Figure 5.11

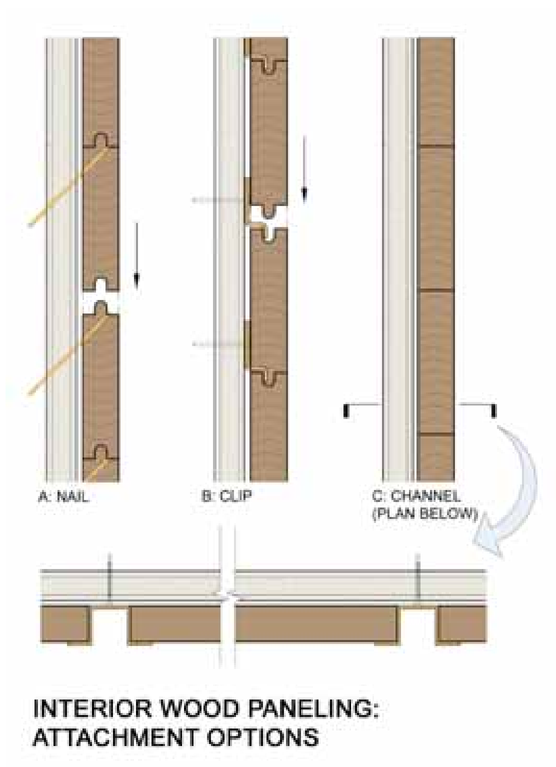



Figure 5.12-B


Figure 5.12

On the interior of the Multi-Use room at Chartwell School wood paneling is used as a wall finish to provide a durable and attractive surface. The wood is Douglas Fir recovered from the old barracks at Fort Ord shown being deconstructed in Chapter 2, and supplied by Pacific Heritage Wood Supply. Like the wood siding, this material maintains its value very well after recovery if it is reasonably free from defects. It is difficult to find new lumber asequal in quality and with the richness of color as the old growth vertical grain fir recovered from these buildings. Traditionally this material was installed as tongue and groove, being nailed at a 45 degree angle through the tongue to conceal the fastener. When removing this material, the thin tongue section inevitably breaks at the fastener, making it very difficult to salvage. A number of alternate attachment methods were examined for use at Chartwell School.

One option (see figure 5.12 and 5.12-B) is a thin metal clip that fits into the groove of a T&G profile. Clips often come with screws already engaged in the clip, so installation could be reasonably rapid. A mock-up demonstrated that this was quite a secure means of fastening, and could be readily removed by working in the opposite direction from installation. The downside of this technique is that, like the siding profiles discussed above, a fair amount of material is lost in planer shaving converting lumber to the T&G profile and the tongue and groove may not be desired for some unknown future reuse, leading to further loss of material. Also, when compared to the speed of a nail gun, the clips are fairly labor intensive increasing cost.

A second option (see figure 5.13 and 5.13-C) uses unmilled boards held in place by a hat-channel or similarly shaped reglet at the ends of the boards. The maximum practical length for boards held this way seems to be around 4'. The boards are full dimension with minimal loss of material from original milling, or from remilling for future reuse. The wood shown in this mock-up is resawn from 100 year old Douglas fir framing studs.

A third option for fastening interior paneling, and perhaps the most intriguing, is simply to use double stick tape (see figure 5.14). This is usually greeting with skepticism, and one of the lessons professional de-constructors repeat over and over is to avoid glues. Most important the tape must be engineered specifically for this function. It must be strong enough to hold the wood, but not so strong it cannot be removed. 3M makes a Very High Bond (VHB) tape rated at 200 pounds per square inch and used in a number of very demanding high load applications. That would clearly be overkill in this case, and not facilitate easy removal. However, if the foam the tape is made of was designed to yield at the correct force, a pry-bar could be easily inserted into the thin gap created by the thickness of the tape, and the board removed. The tape residue remaining on the board could be easily planed off, and there would be no defects or holes in the board. If it the paneling needed to be removed temporarily to access some utilities in the wall for example, it could then be simply reinstalled using new tape. This seems like a promising technology, though one that requires development and testing by a manufacturer.

Figure 5.13

Figure 5.14

Facilitating Deconstruction through Information

One of the key challenges of DfD is not knowing what the future will bring, and future deconstructors not knowing how the building was designed to encourage disassembly. How do we convey this information in a way that will be accessible in 50 to 100 years? Most commonly an owner receives a couple of extra sets of drawings and specs at the end of a project, a conformed record set if they are lucky. For owners that are not used to managing buildings with a professional facilities staff, these documents are placed in a closet, and slowly disappear over the years as they are referenced by various trades for repair, architects or contactors for renovations or additions, or just get lost in the shuffle. Some building departments keep plans on file in an accessible manner, but the quality, consistency, and thoroughness of these records vary from place to place. Architects usually keep originals in their office or secure remote storage, but many offices do not last as long as their buildings, and future owners may not even know who the architect was. The problem is compounded with rapidly evolving software platforms that make it difficult to read digital documents that are even 10 years old. How can we retain all this information in a form that is accessible in 100 years?

What is needed is a "library" whose job is to store, maintain, and make accessible all this information. Ideally it would all be digital, kept up to date by the library, and made readily accessible in digital form to the owner and whoever they designate.

At Chartwell School several efforts have been made to make this information available in the future. As described above, many of the systems are exposed to view, including many of the utilities and the roof framing, so drawings are less critical in these cases. Final conformed record drawings will be bound with a sturdy cover to protect the paper, and will include instructions to get reproductions rather than removing drawings from the bound original. Some elements are directly labeled with critical information. For example, the roof trusses are labeled with their key structural properties, for use by structural engineers to determine if they are adequate for a future application. Finally, permanent signage will be installed in the school's utility and maintenance rooms identifying the architects and engineering design team for future reference.

We hope and expect that in 50 to 100 years, deconstruction will no longer be the exception, but the rule. Deconstructing a building that had some forethought into that process will proceed faster, easier and at a lower cost than a conventional design. This can help shift our economy from a resource consumption based economy, towards a closed material cycle of use and reuse that minimizes environmental impacts while providing the resources needed to construct our built environment.

Additional Resources

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