THE OPTIMIZATION OF BUILDING DECONSTRUCTION FOR DEPARTMENT OF DEFENSE FACILITIES: FT. MCCLELLAN DECONSTRUCTION PROJECT

Bradley Guy[1]

ABSTRACT

Deconstruction is the selective dismantling of building structures to recover the maximum amount of primarily reusable and secondarily recyclable materials in a safe and cost-effective manner. Deconstruction is a labor intensive process and can be difficult to achieve in a time-efficient and economical manner for light wood-framed buildings. Deconstruction techniques that balance hand and mechanical labor must be developed to maintain the integrity of materials for reuse and obtain maximum salvage value per unit of cost and time-on-site. This project entailed the removal of three identical WWII-era two-story wood-framed barracks buildings at Ft. McClellan Army Base, Anniston, AL, using hand deconstruction, combined mechanical and hand deconstruction techniques, and a traditional demolition method, i.e., mechanical reduction and disposal, in order to determine "optimal" deconstruction techniques based on salvage value per unit of cost. The maximum practical materials salvage from the study buildings using 100% hand deconstruction techniques was 39% of the mass by weight. A combination of hand and mechanical techniques was discovered to have approximately the same economic efficiency as 100% hand deconstruction, measured as a ratio of gross cost per salvage value, with a 44.6% reduction in total labor-hours, and a reduction of only 7% of salvage materials by weight. These findings indicate the potential for greatly increasing wood-framed building deconstruction practice relative to the additional time-on-site and labor that is required, compared to demolition, while optimizing economic benefits. This paper describes the research methods and deconstruction techniques employed, and lessons learned to advance the practice of deconstruction to be more economically competitive and time-efficient.

KEYWORDS

demolition, deconstruction, building materials reuse, building salvage, building dismantling.

INTRODUCTION

The cost to the environment from the building industry's materials use and waste is enormous. The US Geological Survey performed a "materials flow" analysis showing that, excluding food and fuel, construction activities consume 60% of the total materials used in the US economy. This same study found that only 5% of these materials came from renewable resources in 2000, and that of all the materials consumed in the 20th century, more than half were consumed in the last 25 years (Wagner, 2002). In spite of the fact that on a basis of mass per unit of gross domestic product, materials consumption has become more efficient in the US, the total amount of materials consumption per capita has steadily increased in the last 50 years (Matos, G., Wagner, L.1998).

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[1] Bradley Guy is the Director of Operations, Hamer Center for Community Design, The Pennsylvania State University. He has a M.S. in Architectural Studies from the University of Florida, and a B. Arch. from the University of Arizona. Mr. Guy has acted as designer or consultant on numerous green building projects with a focus on the US Green Building Council LEED® Green Building Rating System. He has made presentations at national and international conferences of the US Green Building Council, the International Council for Research and Innovation in Building and Construction (CIB), and the United Nations Environment Programme Sustainable Building and Construction Group. Mr. Guy is an Associate of the American Institute of Architects, the President of the Building Materials Reuse Association, and a founding member of the Building Deconstruction Consortium, the Florida Green Building Coalition, and CIB Task Group 39—Deconstruction.

This study was produced under the title "Pollution Prevention Through the Optimization of Building Deconstruction for DoD Facilities: Ft. McClellan Deconstruction Project" with support from the Region 4 Department of Defense (DoD) Pollution Prevention (P2) Partnership Program administered by the University of South Carolina by the University of Florida, the Anniston-Calhoun County Fort McClellan Development Joint Powers Authority (JPA), and Costello Dismantling, Inc.

The US EPA estimated in 1996 that US companies generated 136 million tons of building-related construction and demolition (C & D) waste per year, of which 92% is from renovation and demolition, and the remaining 8% from new construction. The same study estimated that only 20-30% of C&D waste was recycled (Franklin Associates, 1998). With America's building stock rapidly aging and pressure rising to upgrade it, this waste stream can only increase. At the same time, the typical US home in 1900 was less than 1,000 square feet, while the typical home in 2000 was more than 2,000 square feet (NAHBRC, 2001). The US residential construction industry is producing 21st century homes that will produce even more materials waste per housing unit in renovation and demolition because of their increasing size (US Census, 2001).

Buildings in the US do not have life spans as long as might be expected. A study of building demolitions in Minneapolis/St. Paul, MN over a three-year period found that 30% of the demolished residential and commercial buildings were less than 50 years old, and that approximately 50% of the demolished buildings were less than 75 years old (O'Connor, 2004). Another predictor of the life span of US buildings is the average age of existing buildings. The US Department of Energy's commercial/institutional building stock was an average of 31 years old in 2002 (US General Accounting Office, 2003). The average age of all US residential structures in 2003 was 32 years old (US Census, 2004). A study of US public schools in 1998 found that the average age was 42 years, which is higher than other building types possibly because of a more aggressive dependency on renovation and repair than private sector buildings, for example. This same study found that most schools are abandoned by the age of 60 (US Department of Education, 1999).

As demand for building structures increases, and larger building structures are produced with relatively short life spans, the continued use of virgin materials will increasingly consume enormous amounts of material and energy, while the continued disposal of building debris will fill up landfills and bury potential resources rather than extracting their value for continued productive uses. Upstream impacts of virgin building materials consumption include the loss of forests as carbon sinks, the burning of fossil fuels in extraction, manufacturing, transportation, emissions of polluting by-products from manufacture, and increasing consumption of non-renewable resources. Downstream waste impacts include the contamination of air, soils and waters, economic losses through inefficient resource use, and the release of methane from landfills. Methane is a greenhouse gas twenty-three times more powerful than CO2 (EIA, 2004).

Deconstruction is a means to alleviate these environmental and ultimately economic losses, through the recovery of existing building materials at the end of their "first" lives and the reuse and recycling of these materials back into construction products. Deconstruction is the selective dismantling of building structures to recover the maximum amount of primarily reusable and secondarily recyclable materials in a safe and cost-effective manner. Wood-framed buildings are amenable to deconstruction by the nature of their "stick by stick" construction and the flexibility of dimensional lumber for reuse, remanufacture and recycling. Based upon species, quality and size, lumber can be reused as-is, remanufactured into value-added products or used as recycled feedstock for new products. According to the National Association of Home Builders, 88% of all new US housing built in 2003 used wood-framing as the exterior wall structure, making it the ubiquitous building material in the US (NAHB, 2004). Deciding how much wood framing materials are salvageable for reuse from an older and un-cared-for wood-framed building includes consideration for the species and number of growth rings per inch of the lumber, its dimensions, and overall condition. Condition factors include damage from wood-boring organisms, moisture damage, fire damage, extreme drying and hence low moisture content, painted surfaces, particularly the presence of lead-based paint, and the nature of the whole assembly. The assembly of the wood components will determine the accessibility of the materials and the difficulties in disconnecting them based upon use of screws, staples, glue, nails, bolts, and metal clips, for example. In any wood-framed wall, floor, or roof structure, some of the wood members will be too short to justify handling in the face of limited reuse options, have too many embedded nails for cost-effective removal of the nails, or have too much construction or deconstruction damage. This damage can include holes drilled for conduit or wiring in the construction process and then damage from the deconstruction process such as cutting, gouging, splitting, and breaking due to excessive force or inappropriate application of force.

FT. MCCLELLAN DECONSTRUCTION PROJECT

The purpose of the Ft. McClellan Deconstruction project was to develop optimal methods for removing one type of aged light wood- framed building, the surplus WW-II-era Army barrack, and to further develop data collection processes that are not now used widely within the demolition industry. Experimenting with, and documenting, different techniques using a single building type allowed for the comparison of deconstruction techniques that could serve as models for further deconstruction and materials salvage by the US Army. To a lesser extent, this project was intended to have application to residential light-wood framed buildings. In 1995 it was estimated that there were 250 million board feet of reusable lumber in WW-II-era Army building then slated for removal (Falk, 2002). While this amount will be lower at the current time, this does not account for other military branches or the private sector. The EPA estimated in 1996 that 250,000 residential dwelling units were demolished each year in the US (Franklin Associates, 1998). The US Forest Products Laboratory estimates that these 250,000 demolitions could produce 1.2 billion board feet of reusable lumber per year (Falk, 2002). Given that approximately 94% of existing housing in the US is wood-framed construction, deconstruction methods to recover reusable framing lumber has considerable application now and in the future (NAHB, 1994).

Exclusive of hazardous materials remediation costs, the ability to implement deconstruction in lieu of demolition as a building removal strategy is heavily dependent upon minimizing additional separation labor while maximizing reusable and recyclable products. The demolition contractor demolition costs are relatively simple as expressed in Table 1. The incremental costs and benefits of deconstruction can be more complicated, particularly when the deconstruction contractor is a non-profit entity. A bid for deconstruction necessitates higher labor and equipment costs for the separation process. These higher costs can be offset in three ways: reduced disposal costs; increased revenues (to either the contractor or the building owner) from salvage; and the ability of the private building owner to receive an income or corporate Federal tax credit by claiming a tax-deductible non-cash charitable contribution equivalent to the value of the recovered materials if a non-profit receives the salvaged materials for resale.

TABLE 1. Costs of Building Removal—demolition versus non-profit deconstruction

Demolition Contractor—Demolition Costs

Fixed Asset Costs of Waste Handling
rental or purchase of compactors, roll-off containers, dedicated trucks
+ ***Operational Costs***
personnel and equipment maintenance
+ ***Hauling Costs***
contract prices for hauling.
+ ***Disposal Costs***
total tipping fees at the landfill

= Total Demolition Costs

Deconstruction Contractor—Incremental Deconstruction Costs

Project Management Costs
additional costs to implement the program
+ ***Fixed Asset Costs of Materials Handling***
setting up collection and storage processes
+ ***Operational Costs***
cost of personnel and equipment maintenance for source separation of reusable/recyclable materials
+ ***Hauling Costs***
cost to transport reusable and recyclable materials to market
– ***Revenues***
revenue received from the sale of reusable and recyclable materials

= Total Deconstruction Costs

Total Potential Deconstruction Savings to Building Owner

Avoided Waste Hauling and Disposal Costs (reflected in bid or if paid separately from labor costs)
savings from reduced number of hauls and in tipping fees at the landfill
+ ***If Applicable, Tax Credit for Materials Donation***
"revenues" to Owner via tax credit for non-cash contribution to non-profit

It should be noted that high disposal costs favor deconstruction and high labor cost per unit of recovery are disincentives to deconstruction. Salvage revenues are the principal means to offset additional labor for deconstruction. Based upon the deconstruction of six wood-framed houses in Gainesville, FL where disposal costs were $34.00/ton, the revenues from salvaged materials was a greater proportion of the "return on investment" of deconstruction than the reduction in disposal costs when compared to demolition by a ratio of between 2.73 : 1 or 1.36 : 1, depending on the method of pricing the salvage (Guy and McLendon, 2005). In practical terms, the economic viability of deconstruction is a function of recovering the highest value of materials as labor-effectively as possible, in lieu of avoiding disposal costs, where disposal costs are not exorbitant. The level of disposal costs that would be required to make disposal savings more important than salvage revenues or tax credits, for light-wood framed deconstruction would be an important area for further research.

A factor unaccounted for in Table 1 is any cost specifically related to the duration of the building removal. An economic impediment for deconstruction on a redevelopment site is the time costs of money in financing and construction loan interests in the case of a site where the new construction will take place on the footprint of the existing structure. On a large site or a phased redevelopment an unwanted structure may be able to be isolated from the other construction activity and be deconstructed without delaying the overall site redevelopment (Guy and McLendon, 2005). Active military facilities where obsolete buildings are to be removed and not replaced, or on the case of closed Army facilities, where there is ample time to remove obsolete and abandoned buildings without immediate redevelopment demands, can potentially avoid time-costs and have a secondary benefit of reducing the costs of maintaining obsolete and abandoned buildings.

Based on the deconstruction of six light-wood framed residential buildings in Gainesville, FL, the materials with the highest return-on-investment of labor for light-wood-framed whole-building deconstruction are listed in Table 2.

TABLE 2. Highest value per unit of labor cost building components from residential building deconstruction in Gainesville, FL

1) Wood timbers and larger dimensional lumber
2) Electrical and lighting fixtures—lights, ceiling fans, switches, etc.
3) Plumbing fixtures—clawfoot tubs, sinks, etc.
4) Unpainted interior wood or exterior sheathing—1x8 and wider
5) Finished wood flooring—tongue and groove oak or heart pine

(Guy and McLendon, 2005)

The larger dimensional lumber (2"x6" and larger) and timbers (6"x6" and larger) listed in Table 2 are typically structural elements, requiring the complete structural dismantlement of a building to obtain. The remaining higher-value materials listed are elements that require minimal labor and do not impact the structure of the building. In the case of the wood-framed two-story barracks buildings such as those found at Ft. McClellan, the bulk of materials, and where disposal is to be avoided and off-setting salvage value is to be gained, are the light-wood framing members, at dimensions of 2x6; 2x8; 2x10; 2x12. These components require the complete and careful dismantlement of the buildings' structures to remove them, and are therefore relatively costly to recover. While relatively well-established materials markets exist for recycling concrete/masonry, road asphalt, and metals, and for disposal, only moderate markets exist for wood, with heavy timber the most valuable and smaller dimensional materials less valuable (Arruda et al., 2003). On the whole, light-wood framed buildings are less feasible for deconstruction unless the framing lumber and wood finishes are of a desirable age and species, such as heart pine, oak, Douglas fir, cedar, redwood, and cypress.

The value of smaller dimensional lumber is low because the material is problematic for reuse in structural applications without a grade stamp, and even if a high-grade species, a smaller sized piece of lumber has less economy of scale for re-milling than timber, which also provides enough depth to remove a depth beyond the nail penetrations for producing like-new and high-value flooring or other wood products. Other element such as single-glazed windows and lighting and plumbing fixtures may be subject to building and energy code requirements and may result in an unsustainable reuse, if causing future life-cycle inefficiencies that outweigh the energy savings from the reuse of the component itself (City of Seattle, 2001). In spite of these difficulties, the tremendous mass of windows, doors, siding, sheathing, flooring and framing lumber in US Army surplus WW-II era buildings requires that better options to disposal be developed.

If materials are not resold or redistributed on-site, or reused by the deconstruction contractor in new construction, transportation and storage costs may be additional costs for deconstruction. Ensuring that a building's materials are worth salvaging, having efficient resale mechanisms and markets, and decreasing processing effort, will increase the viability of deconstruction for any given building. Given that the typical WW-II era barracks buildings are a fixed condition, and disposal costs and reused materials markets and redistribution mechanisms are variable dependent upon geographic location, this project focused on the efficiency of the deconstruction process itself for a simple building type found on military installations throughout the US.

The major proposed outcome of this project was to determine if the use of mechanical equipment and 'panelizing' the buildings' assemblies could reduce labor effort while retaining a high rate of recovery of reusable materials. In this manner it was hoped that the deconstruction process for light-wood-framed buildings that do not enjoy the benefits of large dimension timber, or aged and unique species of lumber could be optimized to a point of maximum salvage per unit of labor cost and time.

BARRACKS BUILDINGS AT FT. MCCLELLAN

The Assistant Secretary of the Army for Installation Management estimates that there remain over 27.2 million square feet of surplus World War II-era wood-framed buildings still to be removed from active US Army installations (ACSIM, 2005). The implementation by the Department of Defense of the Defense Base and Closure Realignment Act of 1990 (BRAC), whereby entire facilities are decommissioned and turned over to local public redevelopment agencies for redevelopment in non-military uses, causes additional WW-II era building removal demands (Defense Base Closure and Realignment Commission, 2005). Ft. McClellan was closed by recommendation of the 1995 Base Realignment and Closure Commission (BRAC) in 1999. The barracks buildings demolished in this study were in the path of a new road to be built to facilitate mixed-land use redevelopment. The identical buildings in this study each weighed approximately 76 tons or 34 pounds per square foot. These buildings are lighter than a warehouse or other industrial-type building; therefore, the removal of just the current excess WW-II-era buildings on Army installations equates to very conservative estimate of 462,400 tons of building materials debris.

The buildings used in this study were comprised of raised floor system, balloon-framing, and roof rafters with joists, and were approximately 30' wide x 73' long. At one end was a slab-on-grade boiler room and common bathroom facilities at each floor. The other three-quarters length of the building was a single open room on each floor, with partial height partitions to form cubicles.

From observations by the author at Ft. Chaffee, AR, Ft. Campbell, KY, Ft. Hood, TX, Ft. Bragg, NC, and Ft. Ord, CA, two-story wood-framed barracks typically have exterior wall construction comprised of wood siding over 1x wood sheathing or one-half inch exterior drywall and ballooned-framed 2x4 studs at 24" on center. The original construction in Ft. McClellan barracks was an open cavity wall with the interior side of the exterior sheathing and exposed studs painted with lead-based paint (LBP). The underside of the second floor was also painted. At several of the aforementioned Army facilities this

PHOTOGRAPH 1. Typical case study building at Ft. McClellan Army Base

was not found to be the case, making it difficult to generalize the degree of painted structural materials that would be found at any given facility, after years of use, maintenance and potential renovations. In order to make an assumption about the presence of lead-based paint on framing materials in wood-framed buildings built before 1950, and to therefore make a determination as to whether the structural wall framing should be modeled as salvage or disposal, data regarding painted surfaces was used from other residential wood-framed building deconstructions and housing data sources.

During the deconstruction of six residential houses in Gainesville, FL built between 1900 and 1950, thirty-five samples from exterior siding and trim, and interior finishes and trim, were taken from the six houses to test for LBP. Eighteen of the samples contained LBP as defined by OSHA Lead Regulations (29 CFR 1926.26), with 72% of the positive samples on exterior elements, 22% on interior finishes and 5% on interior trim (Guy and McLendon, 2005). There were no instances of LBP on structural framing members. Based upon this limited sample with attendant geographic similarities, LBP was three times more likely to be found on exterior elements, such as siding and trim, than interior elements, such as trim and interior finishes, in pre-1950 light-wood-framed residential construction. As noted in Table 3, a national study found that the percentage of interior components in non-military housing with LBP was found to be low, and somewhat higher on exterior components, with approximately 29% and 30% of doors and windows respectively, having LBP in residential housing built between 1940 and 1959 in the US (Jacobs, 2002).

TABLE 3. Building components coated with lead-based paint by year of residential construction in the US (%)

Component type	1940–1959
Interior	
Walls, floors, ceilings	2
Windows	6
Doors	7
Trim	4
Other	2
Exterior	
Walls	18
Windows	30
Doors	29
Trim	16
Porch	25
Other	37

(Adapted from Jacobs, 2002)

Extrapolating from these two studies noted above, a judgment was made for this project that LBP on interior wall framing, structural sheathing, floor joists and sub-floor would not necessarily be the case for WW-II era Army barracks buildings throughout the US or in private residential light-wood framed buildings, and since the same care would be taken to dismantle the structure whether LBP was found or not, the salvage percentages calculated in this study include the exterior wall framing and sheathing, and the floor structures. The salvage calculations excluded exterior siding, window and door trim, and roof sheathing. The roof sheathing on these buildings and in other projects that the author has deconstructed in the Southeast US was found to be very brittle from weathering and unsalvageable regardless of whether LBP would have been found. As it happened, the exterior sheathing in roofs and walls was not painted in the case study buildings. During the actual deconstruction of the buildings at Ft. McClellan the wood framing LBP members were recovered as though to be reused, for purposes of labor-data collection, and then disposed of as construction and demolition waste.

METHODS

Reduction of labor-time and time-on-site is difficult for deconstruction when attempting to recover the maximum amount of materials in an undamaged state for reuse. Panelization, as used in this study, was the cutting of building assemblies into manageable sections for removal by either gravity or mechanical lifting equipment, and further processing into individual lumber components either in the building footprint or a nearby location.

To test the study hypothesis, three identical barracks were identified for use of deconstruction techniques ranging from piece-by-piece hand removal of materials to selective mechanical crushing of less valuable building assemblies in order to access more valuable building assemblies. One building was completely demolished using traditional demolition methods. These strategies were then documented, and evaluated.

Using data recorded during the buildings' deconstruction or demolition, assembly by assembly, four building removal scenarios were modeled to explore different combinations of hand and mechanical labor. The scenarios were developed by combining deconstruction techniques according to the major building assemblies within each building. Each scenario was then analyzed in terms of labor-time, labor and equipment costs, diversion by mass of materials, and salvage value.

BUILDING DESCRIPTIONS

The buildings made available for this project were identical two-story, wood frame, pre-WW-II-era barracks; similar in typology and construction to thousands of older barracks found on installations throughout the United States. Each barrack was 4,450 square feet and buildings were labeled Building 829, 830, and 844 respectively by the installation.

For the purposes of this study, the buildings were subdivided into building assemblies. A building assembly is a group of materials that are either structurally or functionally related. The assemblies, and the materials or parts of the building within each assembly, were defined as follows:

Windows and Doors: included all of the windows and doors in the building. This assembly also included the plywood window covers that were installed over the first floor windows, the screens, and the blinds.

Interior Partitions: referred to the light-framed partitions subdividing the main room on each floor of the barracks. The interior partitions did not completely extend to the ceiling or floor. They were built of sandwiched panels of drywall and plywood supported by 2x4 framing.

MEP: was the mechanical, electrical, and plumbing equipment in the building. This assembly included sinks, toilets, showers, light fixtures, wiring and conduit, ducts, air handlers, etc.

Hazardous: included all materials in the building that could not be disposed of as C&D debris, including mercury thermostat switches, lead-acid batteries in exit lights and emergency light fixtures, fluorescent tubes and ballasts.

Asbestos: was all asbestos-containing materials, including vinyl tile and sheet vinyl flooring, duct wrap, pipe insulation, and an insulating fiberboard panel behind the breaker box in each mechanical room. It should be noted that a sub-contractor performed the removal of asbestos containing materials prior to deconstruction and that the labor data for this project does not include asbestos abatement, which was equal for all buildings.

Interior Finishes and Framing: included all wall and ceiling interior finishes and the framing of non-load bearing interior walls. The non-load bearing walls were differentiated from the light interior partitions in that the walls extend completely from the floor to the ceiling whereas the partitions did not. Drywall applied to the interior surface of exterior walls, or the underside of the roof rafters or joists, was included in this assembly and not the exterior wall or roof assembly.

Roof: included one layer of asphalt shingles, building paper, 1x6 wood sheathing, rafters, joists, and beams. In addition to these main pieces, bracing tied the rafters and joists together.

2Wall: was the second floor wall structure, including exterior siding, diagonal wood sheathing, 2x4 framing, and the structural columns supporting the roof.

2Floor: was the second floor structure; including tongue and groove finish flooring, diagonal subfloor, floor joists, and beams. Also included in the 2Floor assembly was the poured concrete floor in the lavatory.

1Wall: was the first floor wall structure, including exterior siding, diagonal wood sheathing, 2x4 framing, and the structural columns supporting the second floor. 1Wall also included the skirting around the base of each barrack—vinyl skirting, styrofoam insulation, and wood framing.

1Floor: was the second floor structure; including tongue and groove finish flooring, diagonal subfloor, floor joists, and beams. Also included in the 1Floor assembly was the poured concrete floor in the lavatory.

Foundation: included the concrete piers and brick chimneys. Once the building was removed from the site, some time was spent clearing and grading the building footprint. For the purposes of labor analysis, this work was grouped within the Foundation assembly.

BUILDING ASSESSMENT AND INVENTORY

In-depth site investigations of each building were performed prior to deconstruction. The site investigations began with a visual survey and qualitative assessment of each barrack to understand each building's condition and structure, to identify materials, and to form judgments about appropriate deconstruction techniques.

Visual surveys were followed by intrusive inspections to identify hidden layers of materials and to determine the size, spacing, and geometry of the building structural elements. For this work, it was necessary to open small holes in walls and ceilings, to look in chases and plenum spaces, and look beneath the wood floors.

The building investigations also included detailed measurements of each building. Each exterior elevation and every interior wall, floor, and ceiling surface was measured. The building surveys and measurements were used to create a materials inventory for each building and this list identified the type and quantity of each material in a building.

The majority of the materials were concentrated in the roof and the two floor structures—making these assemblies the most important for developing panelization techniques, and for prioritizing where labor time is spent. In several scenarios the deconstruction technique for the 2x4 2Wall and 1Wall assemblies was to remove them as effectively as possible for disposal in order to gain access to the underlying floor structures.

ENVIRONMENTAL SURVEY

ERG Environmental, Inc. performed detailed environmental surveys for each building to be deconstructed to identify asbestos containing materials (ACM) and lead-based painted (LBP) surfaces. The LBP surveys included invasive inspections to sample painted wood within the exterior wall cavity.

All ACM materials were abated prior to deconstruction by a licensed abatement contractor. It was evident that the barracks originally did not have any interior wall or ceiling finishes in the main room on each floor such that the exterior wall framing and the interior side of the exterior wall sheathing were exposed on the inside of the building. During the actual deconstructions for this project, all materials with LBP were placed in roll-offs for disposal. This resulted in very low actual diversion numbers. For the deconstruction scenarios developed in this report it was assumed that certain materials were not painted, as noted previously. It was deemed more relevant (in terms of transferable results) to model deconstruction scenarios without such extensive interior framing lumber LBP for the purposes of a project analyzing technical building disassembly methods—given that the materials were recovered intact, whether lead-based paint was present or not.

DATA COLLECTION

The documentation goals in this project were to record the methods, sequence of work, the labor type and duration (which worker, doing what task, with what tools, for how long), equipment usage, both hours of operation and duration/costs of rental, and project outputs of salvaged materials and waste materials.

A data collection form was developed to facilitate the continuous recording of deconstruction labor/equipment activity. A daily narrative form was used to summarize activity and techniques for the day, along with any project inputs and outputs. The system used for data collection is shown in Appendix I.

DECONSTRUCTION TECHNIQUES

The deconstruction techniques employed in this project are described below. When naming a deconstruction or demolition technique, the format of "technique abbreviation" and "assembly or material" was used. For example, "HDec Window" designated the hand deconstruction of a window for salvage, and "PDem Wall" designated the demolition of a wall by cutting it into Panels (Panel demolition) for disposal. The technique definitions and abbreviations are as follows:

> *HDec (Hand Deconstruction)* was the removal of materials from the building by hand for salvage and reuse. It included the use of hammers, crowbars, or hand-held power tools such as circular saws or reciprocating saws. It also included the use of a man-lift, bobcat, or excavator provided that this equipment was used to transport workers or individual pieces of building materials. "Hand" work was removing the materials piece-by-piece from the building.

HDem (Hand Demolition) was the removal of materials from the building by hand for disposal. It included the use of hammers, crowbars, or hand-held power tools such as circular saws or reciprocating saws. The difference between deconstruction and demolition was that in "deconstruction" the materials were handled in such a way as to preserve them for reuse.

PDec (Panelized Deconstruction) was the removal of composite assemblies of materials from the building, some or all of which will be salvaged for reuse. It included the use of cutting tools to slice through multiple layers of materials in order to free large intact sections, or panels, from the building. This technique required additional processing to separate the individual pieces from the panel.

PDem (Panelized Demolition) was the removal of composite assemblies of materials from the building for disposal. It involved the use of cutting tools to slice through multiple layers of materials in order to free large intact sections, or panels, from the building.

(HS) (Hand Separation) was the process of separating a panel into its individual pieces using hand tools and labor.

(MS) (Mechanically Assisted Separation) was the process of separating a panel into its individual pieces using mechanical assistance along with hand tools. The one example from this project was the use of a Bobcat to separate floor joists from a composite panel of floor materials.

PHOTOGRAPH 2. Roof panelization

PHOTOGRAPH 3. Second floor panelization and laydown for hand disassembly

MDem (Mechanically Assisted Demolition) was the mechanical crushing of building materials for disposal. In this technique, the materials were removed from the building directly by a piece of heavy equipment and placed in a disposal container. A small amount of hand labor was used for limited salvage and for clean-up after demolition.

Lift (HS) was a technique uniquely applied to the roof structure using a crane to lower a section of roof to the ground where its constituent materials were separated by hand.

Drop (HS) was a technique applied to the second floor structure in which a controlled collapse of

PHOTOGRAPH 4. "Dropping" second floor by collapsing onto first floor

PHOTOGRAPH 5. Hand disassembly of dropped second floor

the second floor was used to facilitate the hand separation of its constituent materials.

Discussion

The labor-rates for each scenario model shown in Table 5 are listed in Table 4. Labor-rate is a measure of deconstruction productivity, i.e. building materials recovery measured by labor-hours expended per unit of building material recovered. These rates were calculated directly from the removal of each of the three case study buildings at Ft. McClellan using different deconstruction techniques on each of the building assemblies listed in the building descriptions. The project had two identical buildings (the third was demolished to create a baseline) on which to use different deconstruction techniques. A data collection form shown in Appendix I was used to collect information for the purposes of calculating labor-rates. The labor-rates are calculated as averages over the total duration of use of the particular deconstruction technique per the total materials that were removed of the specific type listed in Table 4. Total labor-hours in the specific deconstruction activity was divided by the total quantity of materials removed or processed using the appropriate metric of; square feet (sf), lineal feet (lf), or each (ea) for individual items, and provided a labor-rate measured in labor-hours per unit of material. Clearly there are many factors which influenced these labor-rates such as the skill of the workers, the time of day, and weather. Given that many of the deconstruction techniques that were used were experimental and specific to this project, it will require further repetition of these techniques on similar buildings in different locations, times of year and with different worker experience levels to develop a more universally applicable labor-rate for each technique.

In this project, a four-person crew from Costello Dismantling, Inc. was comprised of experienced demolition equipment operators and laborers. Additional day-labor was used, which might be similar to standard practice, but clearly a large data set must be developed in order to create a set of “standard” rates similar to R.S. Means® Building Cost Data Guide for many of the deconstruction labor-rates described (RS Means Company, 1999). Further care was taken when using the individual figures shown in Table 4 to model the four deconstruction scenarios described herein. Any technique applied to a structural element by necessity followed a specific sequence according to the structure of the building. For instance, the labor rate shown for the second floor (2Floor) Drop (HS) technique required that the first floor walls were prepared by hand deconstruction (Hdec) of the siding and sheathing, therefore an estimation of this technique requires the inclusion of hand deconstruction of siding and sheathing. Similarly, the labor-rate shown for Mdem Eyebrows, mechanically demolishing the eyebrows and eaves of the buildings’ roofs with the excavator, was only valid for that portion of the roof overhanging beyond the exterior walls. It might not be accurate to assume that this labor-rate would have held true for mechanically demolishing the part of the roof over the rest of the building (if this were even technically feasible without weakening the whole building structure or causing damage to the second floor walls).

Each labor-rate for a specific technique was also tied to the sequence of activities that preceded or followed it. Mechanical demolition (MDem) of wall sheathing/framing was shown to be approximately 10 times faster than panelized demolition (PDem sheathing/framing). The panelized demolition method required the drywall to be removed from the interior of the building first. Since the mechanical demolition method was a crude process performed by an excavator, the presence, or removal of the drywall was irrelevant. The time required to remove the interior drywall had to be added to the por-

TABLE 4. Calculated Deconstruction Labor Rates and Equipment Use Summary

			Equipment Use (fraction of labor time)					
Method	**Material**	**Labor Rate**	**Lift**	**Skid-steer**	**Excavator**	**Crane**	**Chopsaw**	**Chainsaw**
Windows and Doors								
Hdec	Plywood Window covers	0.0051 hrs/sf						
Hdem	Aluminum Windows	0.1164 hrs/ea						
Hdec	Doors	0.0500 hrs/ea						
Interior Partitions								
Hdec	Interior Partitions	0.0087 hrs/sf						
MEP								
Hdec	MEP	0.0019 hrs/sf of building						
Hazardous								
Hdec	Hazardous	4.4190 hrs						
Interior Finishes								
Hdem	Drywall	0.0061 hrs/sf		0.09				
Hdec	1x10 TG Wood	0.0041 hrs/sf						
Hdec	Framing	0.0085 hrs/sf						
Roof								
Hdem	Shingles/Sheathing	0.0251 hrs/sf	0.15	0.12			0.21	
Hdec	Rafters	0.0075 hrs/lf						0.07
Pdec (HS)	Shingles/Sheathing/ Rafters	0.0175 hrs/sf	0.31	0.06			0.22	0.09
Hdec	Bracing	0.0067 hrs/lf	0.44					0.44
Hdec	Joists	0.0035 hrs/lf						1.00
Pdem	Eyebrows	0.0412 hrs/sf	0.16	0.08				0.16
Mdem	Eyebrows	0.0103 hrs/sf	0.15	0.20	0.25			0.15
Mdem	Eaves	"						
Lift (HS)	Bonnet	0.0169 hrs/sf	0.44			0.13	0.26	0.23
Walls								
Hdec	Siding	0.0097 hrs/sf	0.50					
Hdec	Sheathing	0.0140 hrs/sf	0.50					
Pdec	Sheathing/Framing	0.0173 hrs/sf	0.14					0.86
Mdem	Sheathing/Framing	0.0018 hrs/sf		0.25	0.75			
Hdem	Vinyl skirting	0.0118 hrs/sf						
2Floor								
Hdec	Tongue and Groove	0.0167 hrs/sf						
Drop (HS)	Cut first floor framing	0.0073 hrs/lf		0.25				0.21
	Drop floor	0.3100 hrs/ea			1.00			
	HS Sub-floor	0.0056 hrs/sf						
	HS Joists	0.0018 hrs/lf						
	Clean-up	0.0018 hrs/sf		0.20				
Pdec (HS)	Sub-floor/Joists	0.0270 hrs/sf		0.04	0.17		0.14	0.14
1Floor								
Pdec (HS)	Sub-floor/Joists	0.0255 hrs/sf		0.13			0.21	0.31
Pdec (MS)	Sub-floor/Joists	0.0226 hrs/sf		0.15			0.12	0.11
Foundation and Site Clean-up								
Mdem	Chimney	0.0500 hrs/lf		0.50	0.50			
Mdem	Piers	1 hour		1.00				
Mdem	Concrete Stairs	0.1602 hrs/ea			1.00			
Whole Building								
Mdem	Whole Building	0.0052 hrs/sf		0.41	0.42			

TABLE 5. Types and Combinations of Deconstruction Techniques for Four Scenarios

Assembly/Material	Scenario 1: Hand Deconstruction	Scenario 2: Mech/Hand Deconstruction	Scenario 3: Mech/Hand Deconstruction	Scenario 4: Demolition
Windows and Doors	Hdem	Hdem	Hdem	N/a
Interior Partitions	Hdec	Hdec	Hdec	N/a
MEP	Hdec	Hdec	Hdec	N/a
Hazardous	Hdem	Hdem	Hdem	Hdem
Interior Finishes and Framing	Hdem	Hdem	Hdem	N/a
Roof				Mdem
Shingles	Hdem	Pdec (HS)	Pdec (HS)/ Hdec	
Sheathing	Hdec			
Rafters	Hdec			
Joists	Hdec	Hdec	Hdec	
Eyebrows	Hdem	Pdem	Mdem	
Eaves	Hdem	Pdem	Mdem	
Bonnet	N/a	Lift (HS)	N/a	
2Wall				
Siding	Hdem	Hdem	Hdem	
Sheathing	Hdec	Pdec (HS)	Pdem	
Framing	Hdec			
2Floor				
T&G Flooring	Hdec	Drop Floor (HS)	Pdec (MS)	
Sub-Floor	Hdec			
Joists	Hdec			
1Wall				
Siding	Hdem	Hdem	Mdem	
Sheathing	Hdec	Hdec		
Framing	Hdec	Drop Floor (HS)		
1Floor				
T&G Flooring	Hdec	Pdec (HS)	Pdec (MS)	
Sub-Floor	Hdec			
Joists	Hdec			
Foundation	Mdem	Mdem	Mdem	

tion of the work involved in cutting the wall sections into panels and removing them for estimating the "total" panelized demolition method.

Certain methods were also more time-effective than others based upon the labor-rates shown in Table 4, but that did not necessarily translate into cost-effectiveness because of the use of different pieces of equipment. The labor-rate for the panelized demolition (Pdem) of the eyebrows was found to be 4 times slower than the mechanical demolition

(Mdem) of the eyebrows but the mechanical demolition method required the use of more expensive per-hour mechanical equipment. This balance between faster but more expensive mechanical labor and slower but lower-cost human labor was found to be a key consideration in the results of this study as discussed in the conclusions.

It should be noted that the cost estimates for the heavy equipment used in this project were based upon rental costs and not ownerships costs. As noted in Table 4, the utilization of mechanical equipment is typically a fraction of the labor used in a specific deconstruction technique and given that the equipment can be used elsewhere, deconstruction techniques that include equipment, list equipment as a fraction of a labor-hour that is then used to get the equipment-rate for the purposes of calculating the equipment-costs. Mechanical heavy equipment is a high capital investment and firms that specialize in hand deconstruction do not typically invest in demolition-related equipment such as excavators and cranes. The more advanced equipment investments for deconstruction firms at the present time are typically limited to trucks, forklifts and skid-steer loaders (Greer, 2004). Demolition companies on the other hand may employ a range of heavy equipment from cranes, to excavators and bulldozers. Given that the prevalence of deconstruction firms that utilize both hand deconstruction and own heavy demolition-based equipment is limited, the decision was made to base equipment costs on rental fees which was the actual case for the deconstruction at Ft. McClellan. A future research agenda should be employed to better calculate the costs of equipment use based on ownership costs, which in turn would require a determination of the threshold for firm size and business activity that would justify this relatively high capital investment.

DECONSTRUCTION SCENARIO MODELS

The four deconstruction scenarios created for this study were: Scenario 1, 100% hand deconstruction; Scenario 2 and Scenario 3, each a combination of hand and mechanical-assisted deconstruction; and Scenario 4, a traditional demolition using heavy equipment with minimal to no attempt at materials recovery. The menu of removal techniques was derived from the deconstruction techniques that were actually performed on the buildings at the project site as shown in Table 5. In order to create the three non-demolition scenarios, a removal technique for each building assembly was selected and combined in a logical manner, as shown in Table 5. The labor and equipment rates for implementing these models were derived from the data collected from actually using the techniques on the buildings at Ft. McClellan, as shown in Table 4. Scenarios 2 and 3 are distinguished as follows: Scenario 2 used panelization of the lower one-half of the roof, and a crane to lift the upper one-half, including the peak, off and set it on the ground beside the building for further hand disassembly, whereas Scenario 3 used panelization of the lower one-half of the roof and hand deconstruction in-place of the upper one-half. Scenario 2 used panelization of the second floor walls, lowering them to the ground for further disassembly, whereas Scenario 3 used panelization of the second floor walls and their mechanical removal for disposal. Scenario 2 used the method of removing the siding and sheathing on the first floor walls and collapsing the second floor onto the first floor for further hand disassembly, whereas Scenario 3 used panelization of the second floor, lifting large sections with an excavator and setting them on to the ground beside the building for further hand disassembly. Scenario 2 used hand deconstruction of the first floor walls as an integral part of collapsing the second floor, whereas Scenario 3 used mechanical demolition to remove the first floor walls for disposal. Lastly, Scenario 2 used panelization of the first floor and removing the sections for hand disassembly, whereas Scenario 3 used panelization and removing the sections for processing using the skid-steer to remove the joists for salvage. Each of these methods was carried out discretely to calculate each accompanying labor rate , and then they were combined to make the two whole-building removal models. Scenario 4 was derived directly by the actual demolition of one of the buildings.

The set of techniques for an entire building removal were either used for the removal of the entire assembly or, over a large enough area or sufficient repetitions to assist in the calculation of an “average” rate. Other than the method of collapsing the second floor, which required the removal of the first floor wall sheathing and siding, each technique was carried out as a discrete activity and divisible from the activities that took place before and after it, in terms of equipment mobilization and other set-up. With each building measured and quantified before work began, the labor-rates per unit of material for each technique were multiplied by the total materials in the commensurate building assembly to yield the total labor time and equipment utilization needed to remove that entire assembly, for the purposes of the scenario models.

Multiplying the labor-rate by the labor-wage per worker type, whether it was hand labor or equipment operation, yielded the total labor-cost for removal. The labor-wages used in the project cost calculations were the wages actually paid to the skilled and unskilled workers on this project. The experienced demolition operators were paid union wages and the unskilled temporary hand-laborers were paid non-union wages A supervision factor was added on top of the worker labor-costs to cover project management costs. The supervision factor was calculated based upon the total time that the supervisors spent engaged in this activity relative to the total labor hours for all three building removals. Supervision added 14.23% to the total project time, or in other words, for approximately every 6 labor-hours of direct deconstruction activity, 1 labor-hour was expended in supervision. Determining the optimal ratio of supervision to labor was beyond the scope of this project, but it is the experience of the author that a ratio of 1 supervisor per 6 workers for deconstruction is a reasonable maximum and was approximately the actual ratio on this project. The sum of the labor and equipment costs (including the supervisor factor) was the total labor cost for each assembly deconstruction and subsequently for each whole-building deconstruction scenario.

Estimation of Labor and Equipment Costs per Scenario

Many deconstruction techniques in this study involved multiple workers employing hand and mechanical-assisted techniques at the same time. In this manner, the labor effort typically involved a “crew” similar to the many types of crews used in the R.S. Means® Building Cost Data Guide to calculate labor and equipment costs for construction activities (RS Means Company, 1999). As in RS Means, the labor-wage for each worker and the hourly cost for the equipment were averaged into a cost per hour per the crew type.

More generally the equation for any type of crew is: wage per hour for skill A + wage per hour for skill B...+ wage per hour for skill Z, divided by the number of different wages being used; plus the cost per hour for equipment type A + cost per hour for equipment type B...+ cost per hour for equipment type Z, divided by the number of different equipment costs being used; equals the labor and equipment cost per hour for this crew type.

It is possible for a multiple-person crew to have periods where one person is waiting or equipment is idling while other members of the crew perform sub-tasks, or simply where one person may work alone for some period and then have assistance during a discrete sub-task. This is accounted for in the labor-rate data collection protocol which measures each worker’s activities on 15 minute increments. For example, if a laborer did some part of a deconstruction task for 15 minutes alone and then was joined by a second person for another 15 minutes, the total labor-hours for this task is 1 laborer x 15 minutes + 2 laborers x 15 minutes = 45 minutes or 0.75 labor-hours. A 15-minute time increment is deemed the smallest increment of work-time feasible and meaningful to measure, and is based upon the National Association of Home Builders Research Center’s Riverdale Case Study Project productivity study methodology (NAHBRC, 1997).

The minimum increment of time for the rental equipment used in the field work in this project was paid for in increments of one day or one week, not by the hour as for the workers. The rental fees for one week were significantly less than the daily rate times five. Given this consideration, and using rental equipment, and even if not using rental equipment but making most efficient use of the equipment it became apparent that some judgment was critical to deciding upon the most cost-effective scheduling of the equipment and hence the subsequent scheduling of the deconstruction process. Decisions were made to either pay for a full week of use versus paying for several individual days and an additional delivery/pick-up charge, depending upon the progress and planned activities during each week.

While equipment usage might be noted for a phase of work, it is not necessarily needed for the entire duration and was shared among different activities in a dynamic manner. An example was that best practice for the shingle removal work was for the debris to be aimed into carefully placed roll-offs along the edge of the building. The debris that fell to the side was collected at the end of the day by the skid-steer loader. Therefore the skid-steer loader was not employed as a part of the "typical" crew for the asphalt shingle removal but contributes via its presence on the site for other reasons. This fraction of time is then included in the calculation of the cost of the skid-steer use for shingle removal, not as an equivalent time to the entire process.

Disposal/Diversion Analysis

The disposal/diversion portion of the analysis of the four scenarios identified where each material in the building inventory was directed after removal from the building. Materials were either Salvage, Recycle, Disposal, or Hazardous Disposal. The category to which a particular material was be assigned was dependent upon the material itself and its condition, other materials to which it may be attached, and the method of removal. For instance, if a wall assembly included drywall and 2x4 framing, but the method of removal was to remove it as a panel for disposal (PDem), all of this material was considered disposal because the panelized demolition method was not conducive to careful separation of materials. For hand deconstruction of the same wall assembly (HDec), all of the drywall was disposal, and the unpainted wood framing was divided between salvage and disposal, depending upon the actual portion of the 2x4 studs that were reuse-able.

To calculate the weight of a material, the quantity of material was multiplied by a unit weight. The unit weights were derived during the physical deconstruction portion of the project by using an industrial scale placed at the site, and weighing each different building material. For each scenario, the weights and volumes of the disposal or diversion stream were calculated via the actual salvage that was obtained for the specific technique employed at a specific assembly in the actual deconstruction process. The volume of disposed material was calculated by multiplying the weight of a material by a cubic yard per pound conversion factor. This conversion factor was calibrated to result in the volume of the material as it would be in a roll-off, including air spaces.

Disposal costs were figured for each deconstruction technique/assembly and at the level of the total building and included both disposal fees and transport costs. Disposal fees for non-hazardous C&D debris were charged at $25.00 per ton of material in Anniston, AL. Transport fees were charged at $165 per 40 cubic yard roll-off container. If a total removal scenario resulted in 42 cubic yards of debris, it was calculated as two roll-off removals, also known as "pulls" ($165 * 2 = $330), even though the second roll-off was not filled. While this results in an inefficient calculation of transportation costs, it does not change the calculation of disposal by weight and will return a conservative estimate.

Salvage Analysis

For each material identified as salvage during the disposal/diversion analysis, based upon the salvage that was obtained in the actual deconstruction processes, the quantity of salvage was multiplied by a unit value to get the salvage value of that material. Salvage values were tracked by individual building material, the total per building assembly, and the total for the model scenario. Salvage value assumptions were based upon 50% of the retail cost for each material in most cases. This is a common valuation for reused materials of no particular antique or architectural distinction, and not a high grade or age of lumber suitable for remanufacturing, as discovered by the author in conversations with many US non-profit building reuse companies.

Cost Analysis

The total cost analysis for each scenario was calculated from sum of the costs of labor, equipment rental, and disposal. An additional cost equal to 50% of these total direct costs was added to cover overhead, profit, and other contractor indirect costs. Abatement and hazardous materials disposal were added to each project scenario costs to provide a total costs for each building removal scenario. These costs would have been incurred through any building removal method, whether deconstruction or demolition, and may or may not be covered under a separate contract from the deconstruction or demolition contract, therefore were not used to calculate the deconstruction contractor indirect costs. The resulting costs were the gross cost for a building removal scenario. Gross costs were expressed as a total cost and as a cost per square foot of building to provide a uniform measure of effort/return between scenarios. The salvage value of all recovered materials was subtracted from the gross cost of each project, resulting in the net cost. Net costs are shown as dollars per square foot of building.

CONCLUSIONS

This project achieved a maximum of 39% landfill diversion by weight from the use of 100% hand deconstruction. This salvage rate was due to the conditions of the buildings from moisture damage, presence of extensive interior partitions and drywall not suitable for reclamation, and the disposal of roofing asphalt shingles and wood sheathing and exterior siding. This percentage may be less or more depending upon the specific building(s) being deconstructed, but in a sample of 6 residential structures deconstructions in Gainesville, FL, one and two-story and aged from 1900 to 1950, the lowest landfill diversion percentage by weight was 27%, the highest was 77% with an average diversion rate of 60% (Guy and McClendon, 2000). This would put the Ft. McClellan buildings at the low end of the spectrum for diversion potential of pre-1950 wood-framed buildings in the Southeast, based upon the Gainesville sample.

This project also did not require the use of Davis-Bacon Wage Act prevailing wages. In governmental projects where Davis-Bacon Act wages apply or where prevailing wages are determined through union wage levels, the discrepancy between hand-labor and equipment operator labor may be more or less pronounced. Average wages overall has a significant impact on the ability to implement deconstruction in general, and in relation to local disposal fees or potential salvage revenues. The minimum prevailing wages as determined by the US Department of Labor (non-union determination) for Calhoun County, AL for labor-types applicable to deconstruction as of June 13, 2003 were: carpenter—$6.83/hr; backhoe operator—$5.90/hr, and common laborer—$5.15/hr (minimum wage). In comparison, the union-determined prevailing wages for Boston, MA in 2003 for the same labor categories were: carpenter—$31.99/hr + $17.93 fringe; equipment operator—$33.31/hr + $15.83 fringe; common laborer—$18.73 +$6.33 fringe (US DOL, 2005).

In Boston, MA the prevailing wage-rate plus benefits for an equipment operator in 2003 was approximately 100% greater than the wage-rate for a common laborer, whereas in the Anniston, AL the minimum prevailing wage-rate for an equipment operator was approximately 33% greater. This relative difference will clearly make hand-labor used for salvage purposes potentially more effective in the Boston, MA area given the greater discrepancy between common laborer and mechanical operator wages, than in Anniston, AL. Paying a proportionately higher wage for an equipment operator to create waste in Boston, MA has less economic validity than in Anniston, AL which is compounded by the fact that mixed C&D debris disposal costs in Boston, MA averaged $105.00 per ton in 2004, excluding hauling, compared to Anniston, AL where the mixed C&D debris disposal costs were $25.00 per ton for this project (Institution Recycling Network, 2005). Average solid wastes disposal fees for the Southern US and Northeast US in 2004 were $30.97 per ton and $70.53 per ton, respectively (Repa, 2005).

Salvage values have some variability across the US, for instance reused of good quality lumber in the Southwest US will command a higher price, given the scarcity of its use in the housing stock, but based upon the author's experience in interviewing and visiting multiple building materials reuse store managers and facilities, respectively, there is less variability than labor and disposal costs. This is because reused materials, such as lumber and non-antique fixtures, doors and windows are priced typically between 33% and 50% less than prices for similar products sold by large national building materials supply chains.

As illustrated in Table 6 below, Scenario 1 is the 100% hand deconstruction scenario with 39% salvage by weight. Scenario 4 is the demolition method. Scenarios 2 and 3 are different combinations of hand and mechanical labor for the whole building removal. Scenario 1 required the most labor hours and recouped the most salvage in terms of value and mass. Scenario 2 reduced labor hours approximately 28% compared to Scenario 1, but was approximately 7% more expensive, and recouped slightly less salvage. Scenario 3, reduced labor hours 45% compared to Scenario 1, reduced costs 11%, and reduced salvage by 7% of mass, and 13% by value.

TABLE 6. Summary of costs and salvage

Method	Time labor-hrs	Gross $	Salvage $	Salvage % (wt.)	Gross $ Per SF	Net $ Per SF	Gross $/ Salvage $
Scenario 1 Hand Deconstruction	654	$23,460	$8,265	39%	$5.21	$3.38	2.84
Scenario 2 Mech/Hand Deconstruction	474	$25,142	$8,085	38%	$5.59	$3.79	3.11
Scenario 3 Mech/Hand Deconstruction	362	$20,803	$7,227	32%	$4.62	$3.02	2.88
Scenario 4 Demolition	35	$12,390	$53	2%	$2.75	$2.74	233.8

Net costs $ = Gross costs $ – salvage value $

Scenario 4, the demolition method, reduced labor hours 95% compared to Scenario 1, reduced costs 47%, and reduced salvage by 37% of mass, and 99% by value.

It is important to note that although Scenario 1 (the 100% hand deconstruction) took more time, it cost less than Scenario 2, which made greater use of mechanical equipment. This result highlights an important consideration, which is that hand labor is typically a lower cost per labor-hour than mechanical labor and salvaging potential is higher given the state of the art in materials and methods of 20th century construction and demolition equipment and methods. It was the intent of this project to determine if modifications in existing techniques could increase efficiency of the deconstruction process. In this present case, there was a balance between fewer labor-hours with mechanical labor, and the salvage that could be achieved, and the lower cost per labor-hour for hand labor with higher rates of salvage *(if project time is not a constraint).*

Scenario 3 was approximately equal to Scenario 1 in terms of gross costs per salvage value, and much more effective in terms of labor-hours. It was the "optimal" method devised in this experiment. However, even a 32% salvage rate for Scenario 3 took more than 10 times more labor-hours than Scenario 4, the demolition, at 40.5% greater gross costs and 9% greater net costs. Therefore, 32% of these typical WW-II era Army barracks buildings (in poor condition) could potentially be diverted from landfill in at no more than 10% additional net costs compared to demolition and disposal in the Anniston, Alabama USA region.

The most effective deconstruction at a 32% salvage rate by mass still had a net cost 9% higher than the demolition method, or in other words, there was not sufficient salvage value under the most effective deconstruction scenario to reduce the deconstruction cost to the point where it was comparable to demolition. Therefore, these buildings at Ft. McClellan Army Base, given their poor condition, were not economically viable for deconstruction, if the threshold measure to be used is that net deconstruction must cost no more than traditional demolition and disposal. While the 30% greater diversion between Scenario 3 and 4 is a large environmental benefit, if a building does not have the potential to achieve sufficient salvage value and avoided disposal compared to demolition and disposal, the economic case for deconstruction is lacking. This highlights the importance of the pre-deconstruction assessment and estimating costs and salvage before the project is undertaken—and consequently choosing buildings with a higher potential diversion rate than 30%, in this case. As noted earlier disposal fees were relatively low, and labor cost was relatively low, compared to other parts of the US, while salvage values were taken from national-scale retail building material commodity prices, albeit adjusted for the Southern region. With low disposal costs of $25.00 per ton, the value of the salvage relative to the expenditure of labor and equipment resources was the key driver for the economics of this study, in the absence of a second "value" in terms of tax-credits for donation of the recovered materials by the owner, in this case a non-profit organization.

In preparing for this research project at Ft. McClellan, these buildings were originally assessed to be relatively infeasible for deconstruction on an economic basis, and this assessment was proven correct. In light of this conclusion, a further area for research would be an estimation of the minimum amount of salvage that would be required to make a typical WW-II-era two story Army barrack deconstruction cost-effective using the most cost-effective deconstruction techniques, as well as an analysis of this project and others to determine the sensitivity of labor and disposal costs and salvage value in conjunction, at differing levels.

The cost of construction and demolition (C&D) debris disposal would have played a more significant role in relative cost between the salvage methods and the demolition method, if it were higher, as in other parts of the US. In the deconstruction and diversion scenarios every ton of recovered materials is both a revenue and an avoided cost. In Anniston, AL disposal was $25.00/ton compared to other locations in the US such as the Northeast where it is greater than $75.00 to $90.00/ton for C&D landfill disposal (Arruda at al, 2003). As noted previously, labor costs in the Northeast US are also considerably higher than in the Southern US, potentially causing certain thresholds for recycling cost-effectiveness, as a balance between these two factors of disposal cost avoidance per unit of labor cost. A further endeavor of study would be, while keeping labor costs the same, to determine the tipping fee costs that would have made this project cost-comparable to demolition in Anniston, AL.

Based upon this analysis of the techniques used on the three building's individual assemblies, an 'optimized' deconstruction of a two-story barrack such as those at Ft. McClellan might consist of the techniques listed in the second column in Table 7. Dollars spent on labor, equipment, and disposal (excluding asbestos abatement), and salvage value, a measure of cost-effectiveness for each of the techniques used in the building deconstructions is described in Table 7 as a ratio of costs-to-salvage per each assembly and technique. The lower the ratio number, the higher the salvage value obtained per the dollars spent. As can be noted, the cost-effectiveness ratios for two optimal methods for the 1Floor deconstruction are lower than the ratios for the optimal 2Floor deconstructions, which can be attributed to several issues, such as reach of the equipment and set-up for removing the floor panels at height.

Overall, floors are more cost-effective than any other parts of the building structure, and exterior walls are the next most cost-effective. However, the least cost-effective assembly—the roof—is the assembly which must be removed in a non-destructive manner to enable the salvage of the underlying wall and floor structures. In this manner the removal of the roof is actually an embedded cost for the removal of the floor systems making them less cost-effective than in isolation. The cost-effectiveness potential for assembles in a multi-story building can clearly be attributed to the height of the assemblies.

As shown in Table 7, 1Wall is more cost-effective than 2Wall, and 1Floor is more cost-effective than 2Floor, and all of these are more cost-effective than the roof. However roofs also have considerable mass and typically higher value materials than walls. A ratio of 1.0 would indicate that the salvage value is equal to the cost of removing the materials and the two floor systems either approach this value in the case of 2Floor, or exceed it in the case of 1Floor, i.e., 1Floor pays more in salvage than the costs to remove it, as an isolated assembly. This is also the assembly that is closest to the ground in a horizontal position, fundamentally the most cost-effective location for disassembly. A further area of study would be to employ the most cost-effective combination of techniques on a one-story building of similar construction to determine if in fact a one-story deconstruction would be more cost-effective, by reducing the height above the ground for the roof.

Table 7 indicates the most cost-effective removal techniques per each major structural assembly measured as a ratio of gross deconstruction cost per salvage value and includes the total labor-hours per each technique, as time is always a potential constraint or cost that may be measured by a building owner through costs not associated directly with the building removal as noted previously.

Overall the panelization techniques were most effective at either extreme of the building structure, the roof and the first floor, with hand deconstruction techniques relatively cost-effective for the assemblies in between, i.e. 2Wall, 2Floor, 1Wall. For every assembly the hand deconstruction technique required more labor hours, most egregiously for the second floor and roof which both required approximately 2 times more labor hours than the selective panelization technique. In a location with high labor costs this additional time would likely make the economic disparities more pronounced.

This study provided some basic information and direction that panelization techniques can provide cost-effective methods for building deconstruction

TABLE 7. Ranking of cost-effective deconstruction techniques per building assembly

	Most Cost-Effective Methods		Second-Most Cost-Effective Methods	
Building Assembly	Description and Cost-Salvage $ Ratio	Time (hrs)	Description and Cost-Salvage $ Ratio	Time (hrs)
Roof	Panelize roof sections, drop inside building and separate—5.7	77	Hand deconstruct—7.5	137
2Wall	Hand deconstruct siding, panelize sheathing/studs, hand separate—3.3	45	Hand deconstruct—3.5	53
2Floor	Hand deconstruct—1.2	148	Collapse floor and hand separate—1.3	72
1Wall	Hand deconstruct—3.2	64	Hand deconstruct siding/sheathing, leave studs for entire 2Floor drop—3.8	62
1Floor	Panelize, remove to flat area, run over with skid-steer to separate joists, then hand separate—0.8	66	Panelize, flip over onto remaining floor sections, then hand separate—1.0	81

with materials recovery. The most effective panelization technique compared to hand deconstruction was the panelization of the roof by cutting it into sections and allowing the panels to drop onto second floor for further separation by hand. Clearly, the simplest goal for effective deconstruction is getting materials from the building at height to grade level as quickly as possible and to access those areas with the greatest mass of lumber as effectively as possible such as flooring systems in light of other less valuable building assemblies that are supported by or supporting these assemblies. It is also evident by this research that a relatively high rate of salvage (greater than 30%) is required to make deconstruction cost-effective, which is a higher rate than the national average rate of C&D recycling at the present time. Encouraging markets for reclaimed lumber and increasing tipping fees will be important determinants in the growth of the deconstruction industry.

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APPENDIX I: DATA COLLECTION AND DAILY NARRATIVE

Introduction

The data collection method was based upon a data collection form. The form guided the documentation of each worker, where they are working in the building—including the assembly and the location at the assembly based upon material-type, what they were doing—be it demolition or deconstruction, and what equipment they were using. Each form covered 15 minutes of project time, and one was completed every 15 minutes from the start to the end of each workday. The forms were then entered into a spreadsheet format that allowed the data to be collated. Before the project began, the buildings were measured and labeled so that each activity could be directly attributed to an assembly and a quantity of materials. Once the collection forms were completed a detailed and quantifiable narrative was able to be completed for each building and more importantly for each activity and rate of activity to remove a given quantity and type of materials from the buildings.

Key to Form

Completed by: Was the name of person completing the data form.

Date: Was the date the form was completed.

Time: 15-minute intervals were used to record the project activities. When a worker changed activities during the 15-minute increment, the activity that consumed the majority of the 15-minute increment was recorded and the activity-lengths were therefore rounded to 15-minute increments.

Name: The name of each worker was noted, which organized the data collection and allowed tracking of an individual worker's activity through a day in order to develop an understanding of the deconstruction process. The name entry was also used to track the labor-skill and hence pay-rate commensurate to that individual, or also in the case of the Supervisory persons to determine the length of their supervision activity per varying tasks.

Building: Given that three buildings were being deconstructed, sometimes with at least one person working on each one at any given time, it was imperative to identify which building a person was working on because it was not possible to infer the building number solely by the activity description.

Room: A small plan of each floor of the identical study buildings was placed on the back of each data collection clipboard. Each activity time increment was then located by using the building key. The interior rooms were assigned numbers. Roof was labeled "Roof". The exterior of the building was labeled "Ext". Work that was not on or in the building was labeled "Site".

Location: This column was used to more specifically record where work was being done. If the

Completed by:				**Date:**		**Time:**	

	Name	Building	Room	Location	Activity	Assembly	Equipment
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

worker was on the "Roof", they were located by the side ("N" for north or "S" for south). If the worker was on the exterior, they were located by nearest side of the building (north, south, east, or west). If the worker was inside the building they were located by the surface of the room that they were working on such as "W" for wall, "F" for floor, "C" for ceiling, and "N", "S", "W, or "E" for wall surfaces.

Activity: This column was used to identify the type of work that was being done within a pre-established set of activities referenced as Technique Definitions and Abbreviations in the paper. In addition there were two "indirect" activity classifications as noted below.

P (Processing): Processing included all work to prepare the materials for reuse after they were removed from the building. This included de-nailing, cleaning, trimming, sorting, bundling, and loading for transport.

S (Supervising): Supervisory work was time spent by a job supervisor instructing, directing, coordinating, etc.

Assembly: This column was used to record the assembly of the building where the laborer or piece of equipment was working. For the purpose of data collection, the building assemblies were coded as follows:

Ext (separate from the building itself)

W&D (windows and doors)

Int (Interior partitions)

MEP (Mechanical, Electrical, and Plumbing systems)

H (Hazardous)

Int F (Interior framing and finishes)

R (Roof)

2W (Second floor walls)

2F (Second floor).

1W (First floor walls)

1F (First floor)

Fnd (Foundation)

Equipment: This column was used to record the tools that were being used. The most critical tools recorded were tools that required non-human energy to operate (electric saws or drills, as well as heavy equipment such as excavator, hi-lift, fork-lift, Bobcat, etc.). Hand tools were grouped generically. The intent herein was to calculate non-hand tool equipment requirements, time and energy usage. Some hand tools such as chain-saw and chop-saw were identified separately because of their high costs or requirement for intermittent rentals, if not owned by the contractor.