

Sustainable Material Management in Minnesota's Built Environment:

Economic, environmental, and community impact
framework for assessing demolition, deconstruction,
and restoration of a building



2022 Sustainable Systems Management Capstone

Haley Hansen
Carmen Prantil
Kelly Martichuski
Nicole Witt
Kylie Differding



Acknowledgments

This report is a culmination of the hard work and effort of many people, both within the University of Minnesota and beyond. We would like to extend our gratitude towards our industry partner, the Minnesota Pollution Control Agency, and their Built Environment Sustainability Administrator, Melissa Wenzel, without whom our success in this project would not have been possible. We would also like to offer special thanks to Pat Huelman, who served as our University of Minnesota Capstone Advisor and provided valuable guidance and feedback. Our appreciation also goes to those who lent their knowledge and provided resources throughout this investigation, including:

Natalie Hunt, Teaching Assistant Professor at the University of Minnesota

Zhenong Jin, Assistant Professor at the University of Minnesota

Madeline Faubion, Graduate Student at the University of Minnesota

Petrina Rhines, Founder and Executive Director of Birch Group

Malique Vaz, Co-Founder of Birch Group

Allen Anderson, Videographer at Allen Anderson Media

Kevin Taylor, St. Paul Team 1 Manager at University of Minnesota Facilities Management

Andy Ristrom, Senior Project Manager at Bolander & Sons Co.

Jason Allen, Project Manager at Better Futures MN

Jeff Standish, Director of Environment at Ecotone Analytics

Shane Stennes, Director of Sustainability of the University of Minnesota

Richard Graves, Director of the Center for Sustainable Building Research

Denita Lemmon, Principal Architect at Miller Dunwiddie

Tom Nonnemacher, Executive Vice President and Project Principal at McGough Construction

Abstract

Construction and demolition (C&D) materials constitute a large portion of Minnesota's waste stream. These materials offer an economic and environmental opportunity if they reenter the market as a raw material according to the Environmental Protection Agency (EPA), which reports that the recycling and reuse of C&D material generates jobs, wages, taxes, and mitigates carbon emissions more than any other material stream (Delta Institute, 2019). Increased clarity on the diversion impacts associated with C&D materials from landfills can encourage dialogue about material management that may inform future policy and program strategies resulting in economic, environmental, and community benefits for the state of Minnesota.

With the support from the Minnesota Pollution Control Agency (MPCA), this Capstone project has worked to provide an estimate of the total impact – economic, environmental, and community – associated with three material management methods used during building end-of-life: demolition, deconstruction, and renovation. Increasing awareness and transparency on the impacts associated with each method allows for data to be provided to both the private and public sector to enable actors to reduce the rate of salvageable C&D materials currently being landfilled and increase local and state governments capacity to adopt policies and programs that encourage C&D material recycling or reuse as a result of recognized economic, environmental, and social benefits.

This report looks specifically at the Ben Pomeroy Student-Alumni Learning Center (Pomeroy Center) in order to quantify established metrics. The aim of this project was not to determine the end-of-life practice best suited for this building specifically but rather for the Pomeroy Center to serve as a model structure for the purpose of creating a framework for future economic, environmental, and social analyses performed on the building material management methods of Minnesota built environment projects.

The results of this study found that deconstruction is the preferred method based on net economic, environmental, and community impacts. Though the data and models available at the time of this study were fragmentary, its findings can serve as an estimated baseline for buildings of comparable scale and scope to understand the economic, environmental, and community impacts of various material management strategies. The findings remain useful in determining how to approach and determine the best building end-of-life material management method for future projects in Minnesota's built environment.

Table of Contents

List of Figures	6
List of Tables	7
Abbreviations	8
Introduction	9
Objectives	10
The Ben Pomeroy Student-Alumni Learning Center	11
Background	11
Historical Significance	11
Legacy of the Pomeroy Family	13
Methods	15
Assumptions	15
Overall Building Assumptions	16
Demolition Analysis Assumptions	17
Deconstruction Analysis Assumptions	17
Renovation Analysis Assumptions	18
Material Quantity Takeoff	19
Economic Analysis	19
Environmental Analysis	20
Community Analysis	22
Demolition	22
Background	22
Economic Analysis	23
Environmental Analysis	24
Community Analysis	26
Timeline	28
Deconstruction	29

Background	29
Economic Analysis	31
Environmental Analysis	32
Community Analysis	34
Timeline	35
Renovation	36
Background	36
Economic Analysis	37
Environmental Analysis	38
Community Analysis	40
Timeline	41
Conclusion	42
Impact Comparison	42
Economic Comparison	44
Environmental Comparison	45
Community Impact Comparison	46
Total Cost Comparison	46
Future Work	48
Addressing Study Limitations	48
Addressing Market Challenges	49
Addressing New Construction Practices	50
Resources	51
Appendices	58
Appendix A: New Construction Cost Estimation Resources	58
Appendix B: Demolition Cost Estimate	59
Appendix C: Deconstruction Grant Resources	60
Appendix D: Renovation Cost Estimate	61

List of Figures

Figure 1: Relative scale of U.S. C&D waste in 2018.....	9
Figure 2: Potential for building material reuse and recycling in the construction sector...	10
Figure 3: Ben Pomeroy Student-Alumni Learning Center, 2007.....	11
Figure 4: The Original Dairy Barn, 1938.....	13
Figure 5: Ben Pomeroy.....	14
Figure 6: Building material management analysis scope.....	16
Figure 7: Environmental analysis process flow diagram.....	21
Figure 8: GHG emissions calculation scope.....	22
Figure 9: Cost breakdown - demolition.....	24
Figure 10: Projected demolition timeline for Pomeroy Center based on Bolander & Sons Co. demolition quote.....	29
Figure 11: Projected deconstruction timeline for Pomeroy Center based on deconstruction quote from the Birch Group.....	35
Figure 12: Salvage potential versus salvage value.....	36
Figure 13: Projected renovation timeline for Pomeroy Center based on University of Minnesota project schedule.....	42
Figure 14: Building material end-of-life location - demolition.....	43
Figure 15: Building material end-of-life location - deconstruction.....	43
Figure 16: Building material end-of-life location - renovation.....	44
Figure 17: Alternative material management strategies' cost reduction potential.....	48

List of Tables

Table 1: End destinations for materials following deconstruction.....	18
Table 2: End destinations for materials following renovation	19
Table 3: GHG emissions breakdown by material - demolition.....	25
Table 4: Recyclable and reusable building materials.....	30
Table 5: GHG emissions breakdown by material - deconstruction.....	33
Table 6: GHG emissions breakdown by material - renovation.....	39
Table 7: Construction cost comparison.....	45
Table 8: GHG emissions comparison.....	46
Table 9: Community impact comparison.....	46
Table 10: Overall comparison of demolition, deconstruction, and renovation.....	47

Abbreviations

ACM	Asbestos-containing materials
AWAIR	A Workplace Accident and Injury Reduction
CARB	California Air Resources Board
CCI	Construction Cost Index
CVM	College of Veterinary Medicine
C&D	Construction and demolition
DfD	Design for deconstruction
ENR	Engineering News Record
EPA	Environmental Protection Agency
GDP	Gross domestic product
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
MAM	Metro Area Multiplier
MDH	Minnesota Department of Health
MEP	Mechanical, electrical, and plumbing
MPCA	Minnesota Pollution Control Agency
MtCO _{2e}	Metric tons of carbon dioxide equivalent
OSHA	Occupational Safety and Health Administration
PM	Particulate matter
SCC	Social Cost of Carbon
WHO	World Health Organization
VOC	Volatile Organic Compound

Introduction

According to the U.S. Environmental Protection Agency (EPA), an estimated 600 million tons of construction and demolition (C&D) waste were generated in 2018. This weight is equivalent to nearly 1,650 Empire State Buildings, or 8.5 million elephants (Figure 1), and is more than twice the amount of municipal solid waste created during the same year (EPA, 2020). Approximately 90% of the C&D waste generated is directly attributable to building demolitions (EPA, 2020). Despite the fact that approximately 70% of a deconstruction or demolition project can be recycled or reused (Figure 2), C&D materials are typically sent to a landfill as it is often the cheapest and most accessible waste management strategy available (Delta Institute, 2018). In Minnesota, over 80% of the 1.6 million tons of C&D waste generated in 2013 was landfilled (MPCA, n.d.). When C&D materials are landfilled, demand for materials to construct the new building must be met by creating new products. Extracting virgin resources to produce these new construction materials contributes to 11% of the world's carbon emissions (Zhong et al., 2021). With state emissions on the rise and an expected one-third of the existing building stock set to be demolished by 2050, there is mounting pressure for Minnesota to determine the most sustainable method for end-of-life building material management (Architecture 2030, 2021).

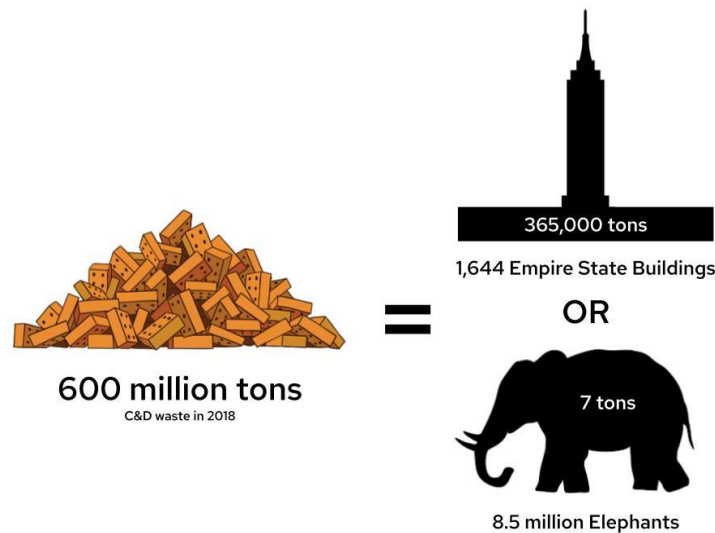
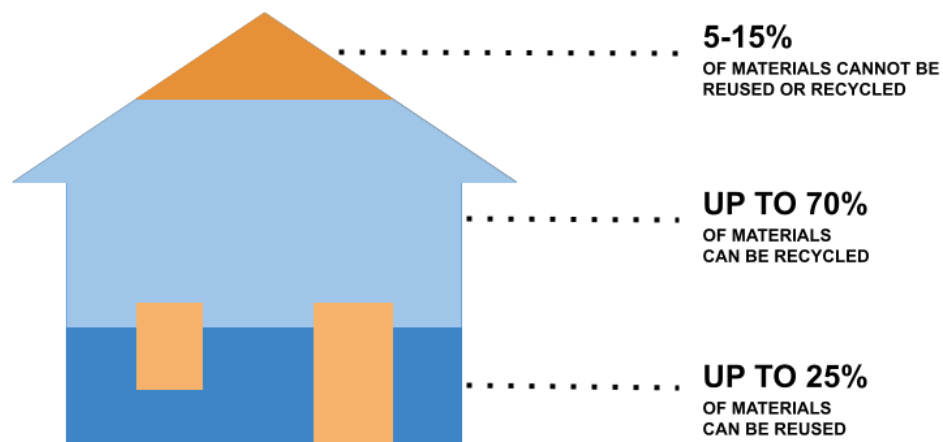


Figure 1: Relative scale of U.S. C&D waste in 2018



** adapted from Delta Institute, 2018*

Figure 2: Potential for building material reuse and recycling in the construction sector

To determine the prevalence of C&D debris generated in Minnesota, the Minnesota Pollution Control Agency (MPCA) conducted a Construction & Demolition Material Composition Study based on waste audit reports from 126 waste management facilities across the state in 2020. While the MPCA has acknowledged the growing presence of C&D debris as a result of building demolition, little formal data exists on the economic, social, and environmental impacts of C&D material management methods in Minnesota. This study aims to fill in current information gaps in the impacts – economic, environmental, and community – of C&D waste management in Minnesota, and help inform future decision-making processes for material management options for buildings within the state. The research included building end-of-life analyses for three building material management methods – demolition, deconstruction, and restoration/repurposing – focusing on the Ben Pomeroy Student-Alumni Learning Center (Pomeroy Center). This building serves as a model structure for the purpose of creating a framework for future economic, environmental, and social analyses performed on future building material management of Minnesota built environment projects.

Objectives

Our team identified the following objectives for the building material management analysis:

- Provide data on the project cost, greenhouse gas (GHG) emissions, and community health impact for demolition, deconstruction, and renovation of a building in Minnesota.
- Investigate potential cost savings in material management methods that differ from the current practice.
- Create a framework that can help to determine the best end-of-life strategy for buildings in Minnesota buildings moving forward.

The Ben Pomeroy Student-Alumni Learning Center

Background

The Ben Pomeroy Student-Alumni Learning Center was originally built in 1907 on the University of Minnesota St. Paul campus, located at 1964 Fitch Avenue, as the Dairy Barn for the College of Veterinary Medicine (CVM) (Figure 3). In 2007, the building was repurposed into an educational center by a local architecture firm, Miller Dunwiddie, and general contractor, McGough Construction. The building was renamed after a notable alumnus and professor emeritus at the University of Minnesota, Dr. Benjamin S. Pomeroy. Today, the 13,000 square foot Pomeroy Center features a large lecture room, cafe, student lounge, administrative offices, and several seminar rooms for the CVM. Much of the building has been restored to its original character while providing a great opportunity for current and future students of the program.



Figure 3: Ben Pomeroy Student-Alumni Learning Center, 2007

(Miller Dunwiddie, n.d.)

Historical Significance

The original Dairy Barn, built in 1907, was designed by distinguished architect Clarence Johnston Sr. He was well-known for his previous work designing marvelous mansions, academic buildings, churches, hospitals, and asylums throughout Minnesota (MNopedia, n.d.). Adding to his long list of projects, Johnston Sr. was responsible for the design of more than twenty buildings for the University of Minnesota including Walter Library, Northrop Auditorium, and Williams Arena (Brady, n.d.). Other notable works include the Minnesota State Fair Grandstand

and the Glensheen Mansion in Duluth (MNopedia, n.d.). Ultimately, Clarence Johnston Sr. had a tremendous impact on both the buildings on campus and throughout the State of Minnesota. His legacy is preserved through these buildings.

The animal barn was built long before safe labor practices were implemented. Construction work was done primarily by hand by hard-working individuals. Laying the brick walls that the original barn showcased required significant skill by the tradespersons (Heritage Manitoba, n.d.). The lack of regulations exposed workers to poor air quality, high volumes of sound, and long working hours. While the people who worked hard to construct this impressive building were not well documented, minority groups commonly made up a large portion of the construction labor pool during the 1900s. The non-white population comprised 11.1% of the total United States population in 1910 while African Americans made up less than 1% of Minnesota's documented population at the time (Randolph, 2005; United States Census Bureau, n.d.). The lack of adequate documentation from this time serves to be a major challenge in fully understanding and giving appropriate recognition to those who spent their lives doing this work. These workers spent endless hours enduring harsh working conditions to build this piece of history. Their stories deserve to be heard and passed down to future generations.

The Dairy Barn was used to house cattle and horses for the CVM for nearly 80 years after its construction (Figure 4). As time progressed and the program's needs changed, students and faculty members outgrew the Dairy Barn's limited space and outdated technology. The Dairy Cattle Teaching and Research Center, located at 1478 Fairview Avenue, was built on the University of Minnesota campus in the late 1980s to meet the growing needs of the CVM ("Nifty Ideas," 1987). After the students and equipment were moved to the new center, the additional barns that were once connected to the original Dairy Barn were demolished. The main animal barn was used primarily to store equipment for the CVM up until the early 2000s (Wickler, 2007). In 2006, the barn underwent a complete renovation and repurposing, reopening in 2007 as a learning center for the CVM. The building has stood prominent on the St. Paul campus for 115 years.



Figure 4: The original Dairy Barn, 1921

(“Dairy Cattle Barn. St. Paul Campus,” 2017)

Legacy of the Pomeroy Family

The renovated building was named after Dr. Benjamin S. Pomeroy, playfully referred to as ‘Mr. Turkey’ by his colleagues and students, a prominent member of the University of Minnesota institution and St. Paul community (Figure 5) (Lemay, 1979). Dr. Pomeroy is recognized internationally for his expertise in turkey disease eradication and control, accredited with advancing the understanding of more than 23 infectious disease agents in avian health (Poss, 2008).

Dr. Benjamin Sherwood Pomeroy’s father, Dr. Benjamin A. Pomeroy, immigrated to Minnesota from Canada in 1884 to open a veterinary clinic in Downtown St. Paul. While growing his veterinary clinic, Dr. Pomeroy Sr. had four sons with his wife, Florence. Three of his sons followed their father’s footsteps and became veterinarians (Burns, 2013; Poss, 2008). Dr. Benjamin S. Pomeroy completed his Doctor of Veterinary Medicine degree in 1933 and Master of Science Degree in 1934 from Iowa State University (“About Dr. Ben Pomeroy,” n.d.; Poss, 2008). Shortly after graduation, he began his career as a veterinary diagnostician in the extension division at the University of Minnesota CVM. Between working at the University and part-time at his family’s St. Paul clinic, Dr. Pomeroy received his Ph.D. from the University of Minnesota in 1944. He went on to serve as professor and chairman, and later assistant and acting dean, for the CVM Department of Veterinary Microbiology and Public Health, specializing in poultry medicine and disease (Lemay, 1979; “Pomeroy Named Poultry,” n.d.; Poss, 2008).

During his extensive time at the University of Minnesota, Dr. Pomeroy published more than 450 articles and advised 36 master's students and 31 Ph.D. candidates ("About Dr. Ben Pomeroy," n.d.). He was inducted into the American Poultry Hall of Fame, an elite group of industry experts, for his work on avian diseases (Geiger, 1977). His career's success was emphasized by over 30 awards and honors, including the Distinguished Service Award from the Minnesota Veterinary Medical Association, the Siehl prize from the University's College of Agricultural, Food and Environmental Sciences, and the All-University Honors (Christianson, 1999; Skemp, 1999; Poss, 2008).

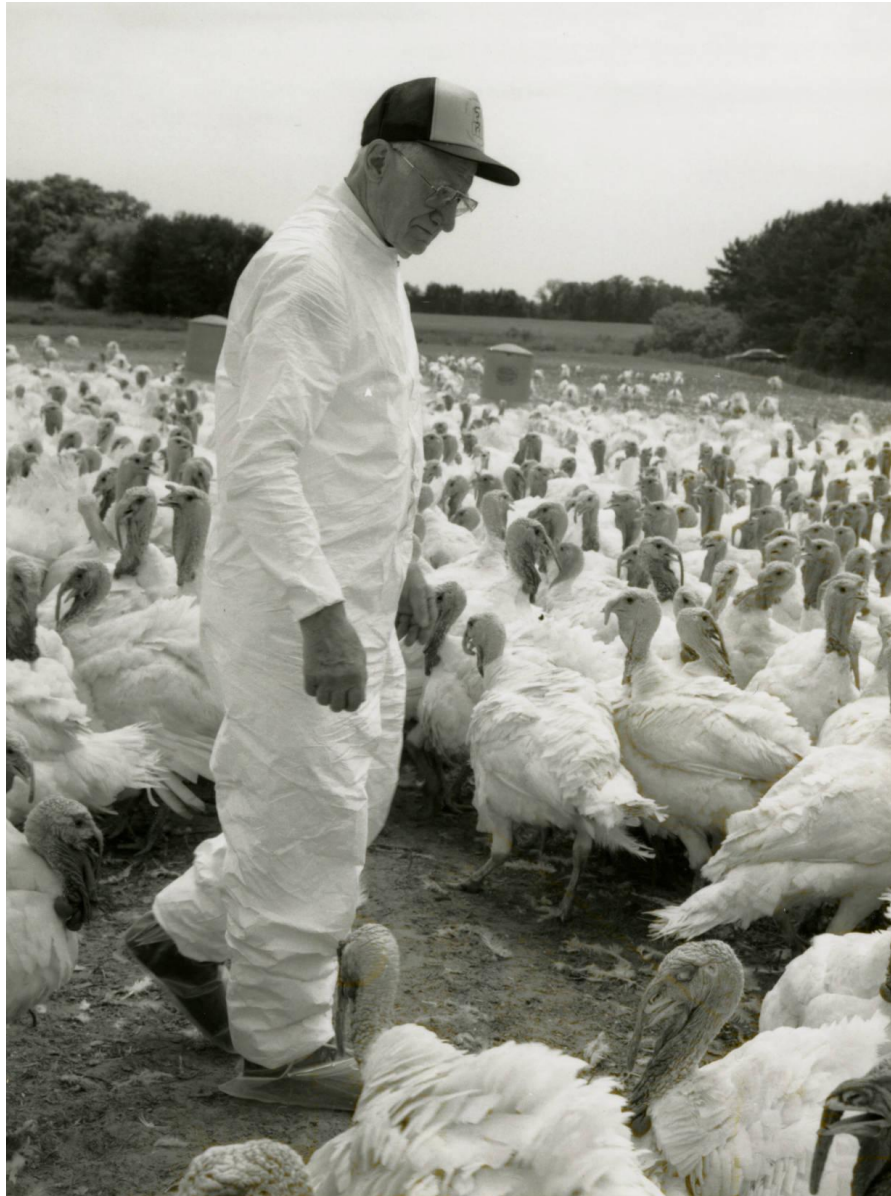


Figure 5: Ben Pomeroy
("Pomeroy, Benjamin S.," 2017)

Not only was Dr. Pomeroy an integral part of the local community, but his family was also very involved. His wife, Lottie Margaret Pomeroy, was a graduate of the University of Minnesota and worked at the CVM Library and Hastings High School. She served as president of the Minnesota Veterinary Medical Association Auxiliary, chairwoman of the Twin City Book Roundtable, and member of the Friends of the St. Paul Public Library. Dr. Ben and Mrs. Margaret Pomeroy regularly volunteered at their children's schools and their family church. Animals were integrated into nearly all aspects of the family's life. Ben frequently brought animals home to care for and took his children with him to conduct house calls. The entire family was invested in the University of Minnesota throughout their lives, with all four Pomeroy children going on to graduate from the university (Poss, 2008).

After retiring from the University of Minnesota in 1981 after nearly 50 years in the field, Dr. Pomeroy began legislative work. He lobbied passionately on behalf of veterinary medicine, agriculture, animal health, and the university for the next 23 years. He worked hard to raise funding to establish the Pomeroy Endowed Chair in Avian Health, the only endowed poultry chair in the United States ("About Dr. Ben Pomeroy," n.d.; "Chair in Avian," 1985; Poss, 2008).

Ultimately, Dr. Benjamin S. Pomeroy worked to advance and improve the field of veterinary sciences up until his death in 2004 at the age of 92 ("About Dr. Ben Pomeroy," n.d.). Just two years later, the decision was made to rename the repurposed Dairy Barn after the internationally-recognized veterinarian and longstanding university contributor ("Diary of Progress," 2006).

Similar to its presence on the University of Minnesota campuses, the Pomeroy legacy is also carried on through the Pomeroy Small Animal Hospital in St. Paul, Minnesota. Dr. Benjamin A. Pomeroy's grandson, Dr. Fred Pomeroy currently runs the family vet clinic that opened in 1886. Although the practice has transitioned from primarily horses to small animals over the past 130 years, the clinic remains in the original building that opened its doors to the community generations ago (Burns, 2013, Poss, 2008).

Methods

Assumptions

Assessing total cost for these three main management methods faces challenges due to the variation in procedure that can arise for a demolition, deconstruction, or renovation project depending upon the project context. Even when an exact procedure can be determined, agreement upon how much of the supply chain should be considered in estimating the total cost is rarely present. This report will limit the scope of analysis to the activities outlined in Figure 6.

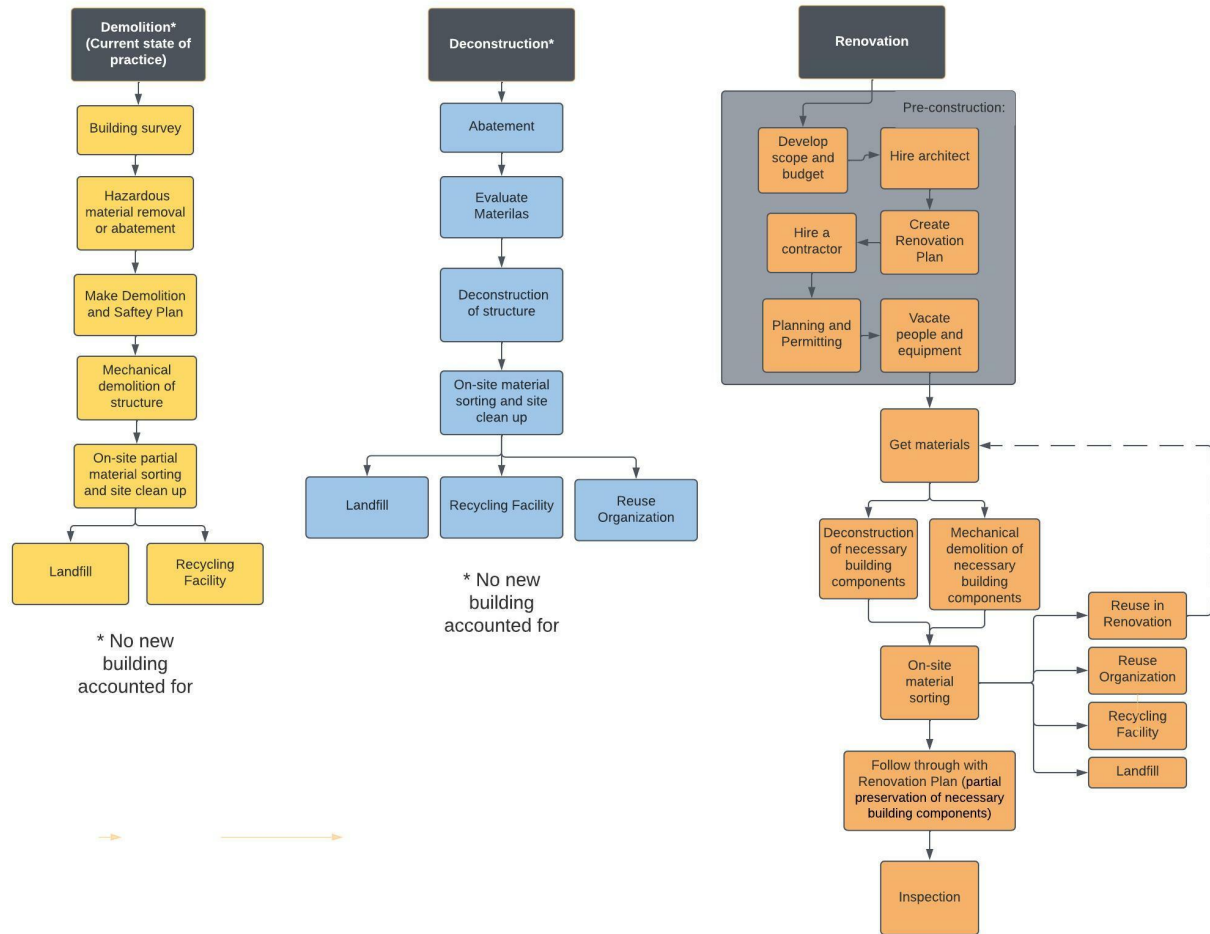


Figure 6: Building material management analysis scope

Due to the intimate relationship between total cost and project context, this analysis was based on several assumptions determined by the site and conditions of the Pomeroy Center. The assumptions made are as follows:

Overall Building Assumptions

The Pomeroy Center has a few unique features that were considered to be beyond the scope of a typical institutional building. As a result, we omitted the elevator, silo, cupola, commercial-grade kitchen, and landscaping from our cost calculations.

Additionally, a lack of information on interior furnishings – including the dimensions; quantities; and specifications of cabinetry; countertops; showcases; appliances; heating, ventilation, and air conditioning (HVAC) ductwork; and classroom furniture – hindered our ability to conduct a complete cost estimate. As such, the building material take-offs, from which economic and environmental cost estimates were calculated, assumed no interior furnishings or HVAC equipment to be present.

Due to these assumptions, it is believed that this report's results are an underestimation of the true cost.

Demolition Analysis Assumptions

There are two primary forms of demolition: wet demolition and dry demolition. Wet demolition is rarely used, practiced only on select projects that are contaminated with asbestos. Dry demolition is the most common form of demolition and can be broken down further into three types: hydraulic demolition, which is commonly used on residential, commercial, and industrial projects under 60 feet; wrecking ball demolition, which is used on multi-family and commercial buildings above 60 feet tall; and implosion demolition, used only on large commercial and industrial structures with close neighboring structures. Given that no asbestos has been reported present in the Pomeroy Center, we assumed the demolition procedure and activities would follow those in accordance with dry demolition. Understanding the frequency of use for each type of demolition in Minnesota and the scale of the Ben Pomeroy Student-Alumni Learning Center, this study looks solely at hydraulic demolition and based all cost calculations and impact analyses off of this process.

Additionally, the waste stream that demolished C&D debris ends up in depends upon the location of the project, as site proximity typically determines the waste facility selected for managing the materials following demolition. The quality and degree of waste sorting provided depend upon the waste facility selected. Understanding this variability, calculations for economic cost, GHG emissions, and community impacts were based on the assumption all materials were landfilled, with the exception of concrete which was recycled.

Deconstruction Analysis Assumptions

Deconstruction can occur in varying degrees; some projects are fully deconstructed while project managers may choose to partially deconstruct a building due to site or financial constraints. This study worked under the assumption that a full deconstruction project was completed. The total cost estimate, therefore, reflects full-scale deconstruction and may not accurately exhibit the total cost associated with a partial deconstruction project.

The end-use for building materials following deconstruction depends upon the firm conducting the deconstruction and the available local market for the removed materials. In instances where available markets could support a material being reused or recycled, it was assumed that the material was reused. Assumptions made regarding the material end-use following deconstruction are shown in Table 1.

Table 1: End destinations for materials following deconstruction

Landfill	• Fiberglass insulation • Vinyl flooring • Carpet & carpet padding • Concrete masonry unit (CMU) blocks • Ceramic tile
Recycled	• Concrete • Metal studs • Electrical boxes • Acoustical ceiling tile • Fluorescent lighting • Drywall • Asphalt shingle from roof
Reused	• Bricks • Wood trim from exterior siding • Wood architectural detailing • Dimensional lumber from original roof deck • Doors • Windows • Bathroom fixtures (mirrors, sinks, stalls, toilets, etc.)

Renovation Analysis Assumptions

The scale of renovation depends upon the condition of the building and intended future use. In some cases, the building is intended to be used for the same purpose and is in relatively decent condition. These projects require minimal renovation activities such as drywall patching, electrical rewiring, and painting. On a much larger scale, buildings may change function during a remodel. These projects require more extensive renovation activities such as the removal or addition of structural elements, finishes, and mechanical, electrical, and plumbing (MEP) systems. This study uses the 2007 renovation scope in which the barn was remodeled into a conditioned space, consistent with the characteristics of an extensive renovation. The total cost to renovate is based on the previous renovation completed by Miller Dunwiddie.

The end-use for building materials following renovation depends upon the parties involved and the available local market. Assumptions made regarding the material end-use following deconstruction are shown in Table 2. Our calculations also assumed that all materials added to the building (e.g., carpet, interior partition walls, bathroom fixtures, etc...) were virgin materials.

Table 2: End destinations for materials following renovation

Landfill	• Dimensional lumber from original barn stall framing • Brick from original silo • Windows • Doors • Existing interior equipment
Recycled	• Concrete
Reused	• Dimensional lumber from original roof deck and floor joists • Brick from original barn • Timber from original hayloft structural members • Stucco from original exterior siding • Wood trim from original exterior siding

Material Quantity Takeoff

In order to assess the environmental and economic impact of the three building material management methods, the square footage, volume, and mass of the building materials needed to be quantified. Using the 2007 remodel drawings, a comprehensive list was created detailing the quantities of existing and new materials, respectively, used in the renovation. Building and room dimensions were determined based on renovation documents and demolition plans provided by the University of Minnesota Facilities Management, Miller Dunwiddie, and McGough. Details not provided in these drawings, such as the linear lengths of the interior walls and areas of each room, were measured using the computer software Bluebeam. The total wall area for the first floor was calculated using first-floor ceiling heights and room perimeters. The second level of the Pomeroy Center served to be challenging, due to the unsymmetric geometry present in the one-and-a-half story walls and slanted ceilings. To determine these areas, the design software Sketchup was used to build a 3D model of the building enclosure to scale and derive the necessary dimensions. The measurements from this building area takeoff were combined with the architect's notes on floor and wall finishes, as well as materials used for the roof, windows, doors, and structural details. This resulted in a calculation of the total amount of each material (in cubic feet) used in the building. The material quantity takeoff was used primarily to calculate the GHG emissions associated with each material management method, as well as the calculation of a renovation cost estimate.

Economic Analysis

Economic cost determined for each material management method was based solely on the costs associated with permitting, sewer and water cuts, labor, equipment operation, transportation, waste management fees, and taxes. No grants, tax incentives, or historical value were included in the economic estimates. The total economic cost associated with the demolition process was determined based on a quote provided by Bolander and Sons, a heavy civil contractor with

decades of experience on demolition projects in the Twin Cities. Due to variability in design choices and construction costs associated with new construction, this quote considered demolition of the building only and does not account for the building of a new structure. The total economic cost associated with the deconstruction process was determined based on a quote provided by the Birch Group, a deconstruction firm based in Minneapolis, Minnesota. Again, due to variability in design choices and construction costs associated with new buildings, this quote considered deconstruction of the building only and does not account for the construction of a new structure. The total economic cost associated with the renovation process was determined based on the renovation documents provided by Miller Dunwiddie and McGough and the 2019 Engineering News Record (ENR) Square Foot Costbook, which factors in costs associated with materials, installation, and labor. The overall quantification of the building materials was determined by the aforementioned material quantity takeoff method and then used to calculate the costs associated with each material, resulting in a summed total economic cost for the building. Since detailed information on the new structure was provided, the economic calculations provided for renovation include partial demolition, as well as the construction of the new building.

Environmental Analysis

Environmental analyses for the three material management methods quantified impact based on emissions and energy use factors provided by the EPA Waste Reduction (WARM) model. Being a tool for general application, however, means that there are limitations and gaps within the model as it pertains to the built environment. For example, materials such as stucco, rigid insulation, and tile are not included in this model, and therefore could not be quantified. The EPA provides guidance on how to use proxies for materials that do not have direct emissions factors in the WARM model, however, these still fail to encompass all materials inventoried on the Pomeroy Center. This modeling limitation should be addressed by the EPA going forward in order to achieve more accurate environmental cost estimates in the built environment industry going forward.

To calculate emissions using the WARM model, the total weight of each material was determined from the material quantity takeoff and multiplied by the GHG emissions factors provided to get the total metric tons of carbon dioxide equivalence (MtCO₂e) (Figure 7). This study utilized Version 14 of the WARM model. As previously mentioned, limitations in the WARM model led to exclusion of certain materials in the environmental cost calculations.

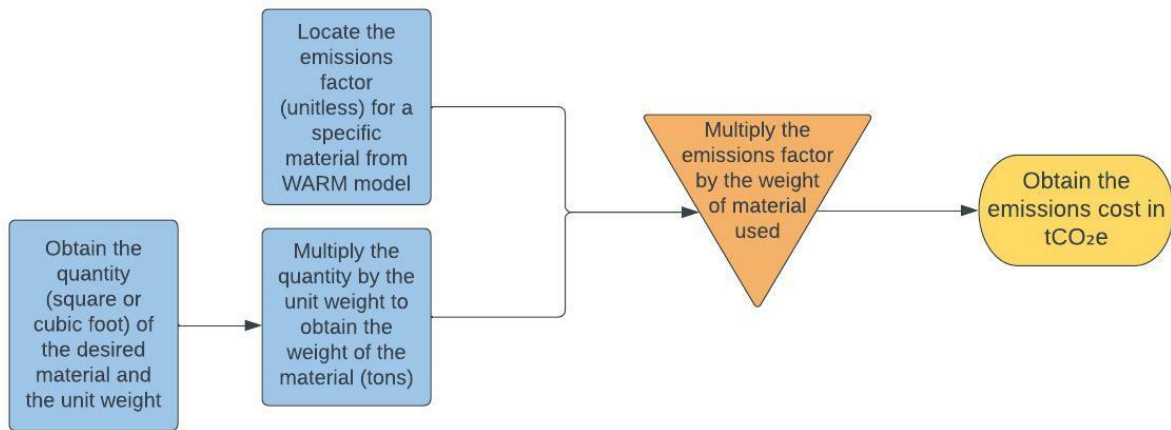


Figure 7: Environmental analysis process flow diagram

The GHG emissions calculation for demolition and deconstruction, respectively, considered the production of materials for the original building and removal of materials to their respective waste sites (Figure 8). These emissions calculations do not account for the production of new materials required for the construction of a new building. Estimations for new construction may be made based on proposed new designs and resources provided in Appendix A. The GHG emissions calculation for renovation considered the reuse or removal of materials to their respective end sites and the production of materials for the new building (Figure 8). These emissions calculations do not account for the production of materials for the original building due to limited data available regarding specific materials and their quantities present in the original Dairy Barn. As a result of both model limitations and scope assumptions due to limited data, we anticipate our results to be an underestimation.

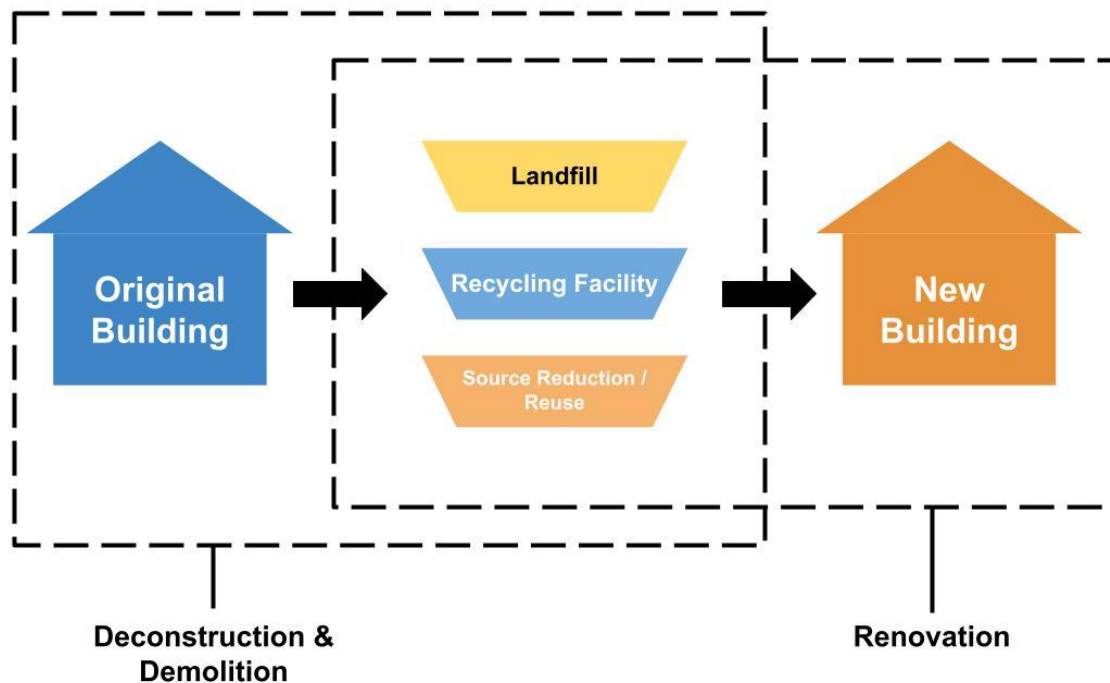


Figure 8: GHG emissions calculation scope

Community Analysis

Community analyses for the three material management methods determined impact based on a review of former construction projects of similar scale and scope. Demolition and deconstruction impacts were based upon a life cycle assessment framework for building demolition and deconstruction published by Michigan State University's Center for Community and Economic Development. Renovation impacts were based upon the 2007 Pomeroy Center renovation data provided by Miller Dunwiddie and McGough. Along with specific project data and frameworks, extensive research published by the Occupational Safety and Health Administration (OSHA), the World Health Organization (WHO), and EPA was used to determine community impacts. Looking at other building end-of-life projects with a similar scale and scope as well as general theoretical frameworks was determined to be the most accurate estimation tool due to the fact that no specific data on critical determining variables – including quantity and types of hazardous materials, site conditions, and safety precautions required on site – was provided for exact quantification.

Demolition

Background

Despite Minnesota's statutory waste hierarchy which establishes that reduction and reuse of materials should be prioritized for waste management, the most popular end-of-life practice in Minnesota's built environment remains demolishing a building, landfilling the materials from the

former structure, and building a new structure in its place using virgin materials (Hotz & Walsh, 2019). Demolition is centered around the expedient removal of a structure. The hydraulic demolition process utilized for analysis in this report consists of using hydraulic shears attached to equipment such as excavators, bulldozers, and cranes, to raze the structure. The debris generated is then taken off-site where it may be partially sorted. The bulk of the C&D debris is sent to a landfill and, in some cases, scrap metal, asphalt, aggregate, and concrete are separated out and recycled.

Economic Analysis

The total cost for the demolition and disposal of the Pomeroy Center was estimated to be \$115,000, including full building removal as well as the removal of the slabs and foundation footings (A. Ristrom, personal communications, March 18, 2022). Labor and equipment were the largest contributor to this direct cost estimate. Breaking it down completely, approximately \$44,000 was estimated for equipment and labor, including all operational costs and fuel; \$29,000 was estimated for disposal and recycling of demolition debris, concrete, and ferrous and non-ferrous metals; \$32,000 was estimated for trucking the various materials to their respective waste sites; \$5,000 was provided as an allowance for sewer and water utility disconnect services; \$2,500 was estimated for the removal of regulated materials such as bulbs, ballasts, freon, door closers, etc.; and \$2,500 was estimated for required permitting fees (Figure 9). Further details on how each of these categories were estimated can be found in Appendix B. The quote is based solely on building removal and does not look at restoring the ground at the site post-demolition. Costs associated with asbestos abatement are also not present in the estimate as that is dependent upon the underlying state of the building and the presence of asbestos. Given that the Pomeroy Center has been through a remodeling process recently, it is likely that any hazardous materials were completely abated already.

The landfilling costs were calculated based on cubic yardage of non-recyclable debris. This includes the exterior walls, interior walls, ceiling tiles, second floor joists and decking (if wood), insulation, roofing materials, etc. The concrete slabs and footings were also calculated by cubic yard. There are still costs associated with the removal, processing, loading, hauling and tipping of these materials.

Demolition Cost Breakdown

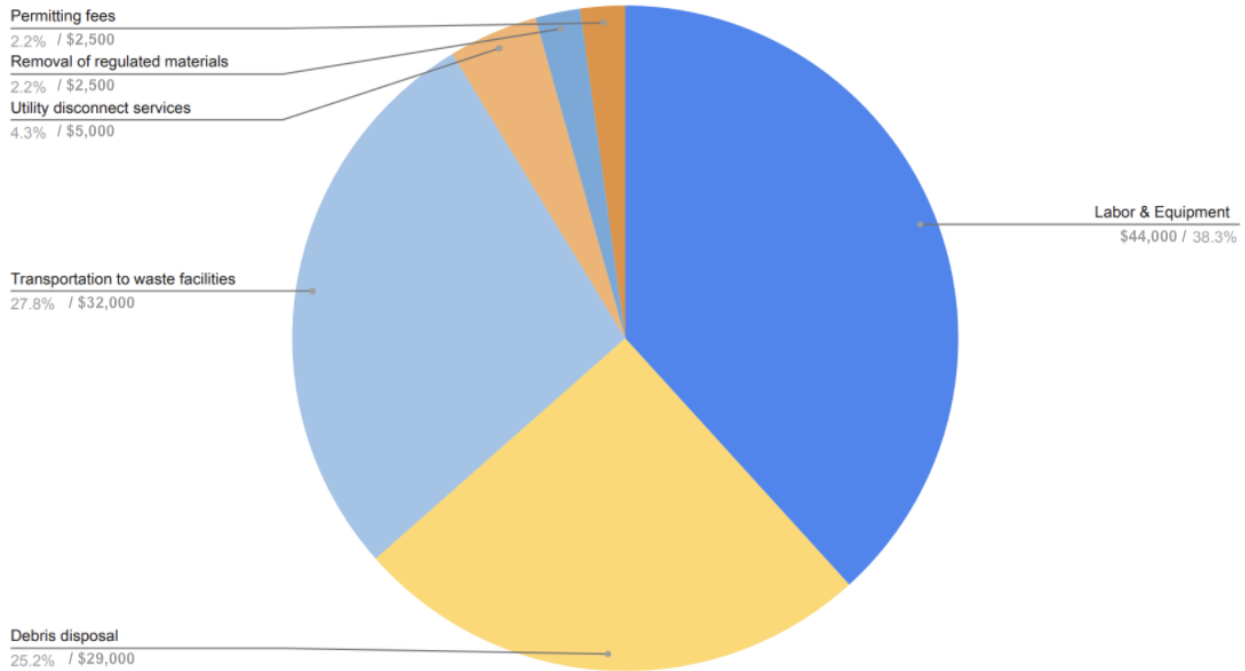


Figure 9: Cost breakdown - demolition

Environmental Analysis

The total GHG emissions associated with the demolition of the Pomeroy Center was calculated to be 141.5 MtCO₂e (Table 3). This is the equivalent of adding 30.5 gasoline-powered passenger vehicles to the road for an entire year (EPA, n.d.). This management method has the largest quantity of materials landfilled as well as the lowest quantity of recycled materials used. Despite this, GHG emissions remain negative for this process.

Table 3: GHG emissions breakdown by material - demolition

	Material	Emissions Factor (unitless)	Amount of Material (tons)	GHG Emissions (MtCO₂e)
Landfilled materials	Glass	0.55	1.47	0.817
	Dimensional Lumber	1.02	71.7	73.1
	Medium Density Fiberboard	1.35	0.699	0.944
	Mixed Metals	3.72	14.6	54.4
	Carpet	3.84	0.474	1.82
	Bricks	0.29	0.132	0.038
	Asphalt Concrete/Aggregates	0.13	8.06	1.05
	Asphalt Shingles	0.21	2.51	0.526
	Drywall	0.23	15.8	3.63
	Fiberglass Insulation	0.4	12.2	4.89
	Vinyl Flooring	0.63	0.684	0.43
Recycled materials	Concrete	-0.01	16.7	-0.167

While the main metric used to compare environmental impact in this study was GHG emissions, other environmental indicators that are difficult to explicitly quantify must also be considered. Particulate matter (PM) from demolition sites can be extremely challenging to quantify, but the activities that contribute to PM and their environmental impacts can be isolated. The California Air Resources Board (CARB) defines PM as “a complex mixture of solids and aerosols composed of small droplets of liquid, dry solid fragments, and solid cores with liquid coatings” which can vary in size and shape (2022). This report looks at PM_{2.5} and PM₁₀ emission size categories, as those are the most common. PM emissions are mainly attributed to equipment tailpipe exhaust, on-site handling and transportation of materials, and activity on unpaved workspaces (EPA, 1999). For the demolition process, pollution being carried off-site is also a frequent concern. This would likely happen in the event of rainfall during demolition, where rainwater would wash away sediment and materials (EPA, 2021). These pollutants can end up in

storm sewer systems and nearby waterways. Another potential source of water pollution during demolition is generated directly on-site. Demolition sites must be sprayed with water periodically for dust control. Without this, materials and waste are easily blown away into neighboring areas (City of Seattle, n.d.). Generally, enough water should be used to eliminate the dust, but not enough to induce runoff. However, there are situations where too much water is used, creating polluted runoff.

Community Analysis

One of the primary community concerns on demolition projects remains safety. Several precautions are taken long before any sort of construction or demolition even begins, including Phase 1 and Phase 2 Environmental Site Assessments which must be conducted with the owner prior to permitting. Phase 1 assessments review on-site records, photos, and past uses of the land going back up to 50 years to determine what, if any, hazardous materials could be present. If any possible hazards or contaminants are found, a Phase 2 assessment that builds on previous findings must ensue. Samples, including building materials and site soils, are taken and various lab tests are conducted in an attempt to find the root of the issues (Omega Environmental Firm & Remediation Services, 2020). These assessments are done in order to ensure that the building, along with the site on which it stands, is safe to be worked on. In addition to the environmental site assessments, engineering surveys may be conducted to check the integrity of the building and land (Block O'Toole & Murphy, 2021). This ensures that many of the structural aspects are safe for work.

Despite the pre-emptive safety measures taken, health concerns for both the public and workers remain on demolition projects. One of the main concerns when doing any sort of demolition is the possibility of lead exposure. Lead exposure can cause anemia, kidney damage, brain damage, memory loss, and death (CDC, 2021). In order to protect workers' health, workers must do “blood in and blood out” testing. All workers must receive a blood test at the beginning of the job – to serve as a baseline for how much lead is in their blood – as well as after the job has been completed to determine if any lead exposure has taken place. Limitations exist with this test, however, as lead contamination cannot easily be traced back to a single source and exposure may be present from multiple sources in a worker’s life (M. Differding, personal communications, February 27, 2022).

Besides exposure to specific hazardous materials, health concerns arise with the demolition process due to its inherently dangerous nature. In 2019, over 20 deaths in the United States were the direct result of demolition work. Most of these are attributable to employers' failure to do proper research and engineering surveys prior to the process (D'Amore Law Group, 2021). Another hazard of demolition is falling debris due to its use of large mechanical equipment such as cranes or wrecking balls (Block O'Toole & Murphy, 2021). Falling debris has the potential to cause very serious injuries for workers and passerbys. Equipment also poses a potential health threat due to noise levels. Over time, prolonged exposure to the high decibel noise produced by the operation of construction equipment can cause permanent hearing loss if protective measures

are not taken. Additionally, excessive exposure to noise and vibrations affects the cardiovascular, nervous, and endocrine systems (Zou et al., 2020).

In addition to impacting worker health, demolition also has numerous impacts on public health. This impact ranges from allergies to physical injuries to chronic diseases. Prior to the demolition process, inspections must be done to ensure that there is no asbestos, including Category 1 and 2 non-friable asbestos-containing materials (ACM) (EPA, n.d.). In instances where ACM are found, the material must either be removed or the asbestos abated before any other work can continue. This is due to the fact that asbestos is classified as a known human carcinogen and can result in increased cancer risk for workers and nearby community members if exposed to airborne particles (National Cancer Institute, 2021). ACM is typically found in old flooring, siding, roofing, and wall systems.

The presence of mercury is also of concern during building demolition. Mercury has a high-risk level associated with human health due to its toxicity. If mercury is present in materials, cautionary handling and proper recycling are required in order to prevent exposure to mercury vapor (EPA, n.d.). If mercury vapor is inhaled, it can lead to harmful effects on the nervous, immune, and digestive systems, as well as damage vital organs including the lungs and kidneys, resulting in potential fatality (World Health Organization, 2017).

Besides specific material-related hazards such as asbestos, lead, and mercury, the largest public health issue related to demolition is dust. When a building is broken down with mechanical equipment, dust resulting from the activity can contain air-borne cement particles and silica that can initiate asthma and other respiratory problems, eye and skin allergies, cardiovascular disease, esophageal and stomach cancer, and even neurological diseases including Alzheimer's, Parkinson's, and dementia (Azarmi & Kumar, 2016). Additionally, paint found in many homes and buildings constructed before 1978 contains lead which can create toxic lead dust when demolishing the building. The dust created from lead paint can stay in the area for long periods of time and can spread to the surrounding areas beyond the demolition site. A study conducted in Maryland found that dust fall during demolition was six times the allowed EPA standard for lead in paint, dust, and soil (Anuranjita et al., 2018). This is especially for homes and buildings in more populated areas, as the number of impacted individuals proximal to the dust range is greater.

Noise and vibrations also have a significant impact on the surrounding community. Machinery, traffic, and communication between crews produce a lot more noise and vibration than the surrounding area is used to. Vibrations from equipment operation can affect the structural integrity of surrounding buildings. When vibrating equipment is used, vibrations travel through the ground and are transmitted to the foundation and walls of nearby structures. As a result, cracks can form on load bearing walls or the foundation which negatively impacts the structural integrity of the building. It is important to inspect and monitor the structural integrity of the surrounding buildings prior to and after construction to minimize the damage to other buildings

(Yala et al., 2019). Vibrations from construction equipment can cause damage to lab equipment, interfere with lab results, and interrupt lectures in the surrounding academic buildings. Humans are much more sensitive to vibrations than structures are (Florida Department of Transportation, 2015; Yala et al., 2019). Disruptive vibrations and noise levels can negatively affect academic performance, communication, and human behavior of those occupying the surrounding buildings (Zou et al., 2020).

While this report looked primarily at the public and worker health impacts, many other factors also contribute to community impact for demolition, including but not limited to road and sidewalk closures, impact to neighboring property value, obstructions due to site debris or equipment, site security, and streetscape aesthetics. Research into the effects of these metrics on community impact should be considered going forward for a more comprehensive calculation of community impacts.

Timeline

Demolition timelines are expedited and remain relatively short regardless of the scale of the project. Planning and building preparation prior to demolition is typically the most time-consuming activity. In the case of the Pomeroy Center, it was estimated that site and building surveys would take 2 weeks, abatement and regulated waste removal would take 0 days, utility cuts would take 2 weeks, permitting would take 2-4 weeks, creation of an OSHA standard AWAIR plan would take 1 day, demolition would take no more than 10 days, and material sorting – which occurs consecutively with demolition – would take 5 days (A. Ristrom, personal communications, March 18, 2022; University of Minnesota, 2022). The project timeline can be seen in Figure 10. In total, demolition would take approximately 7.5 weeks. This timeline does not account for the construction of a new structure due to the variability in potential new build designs. The duration of the proposed new building's project schedule should be added to the calculated demolition timeline in order to provide an estimate for total project time required.

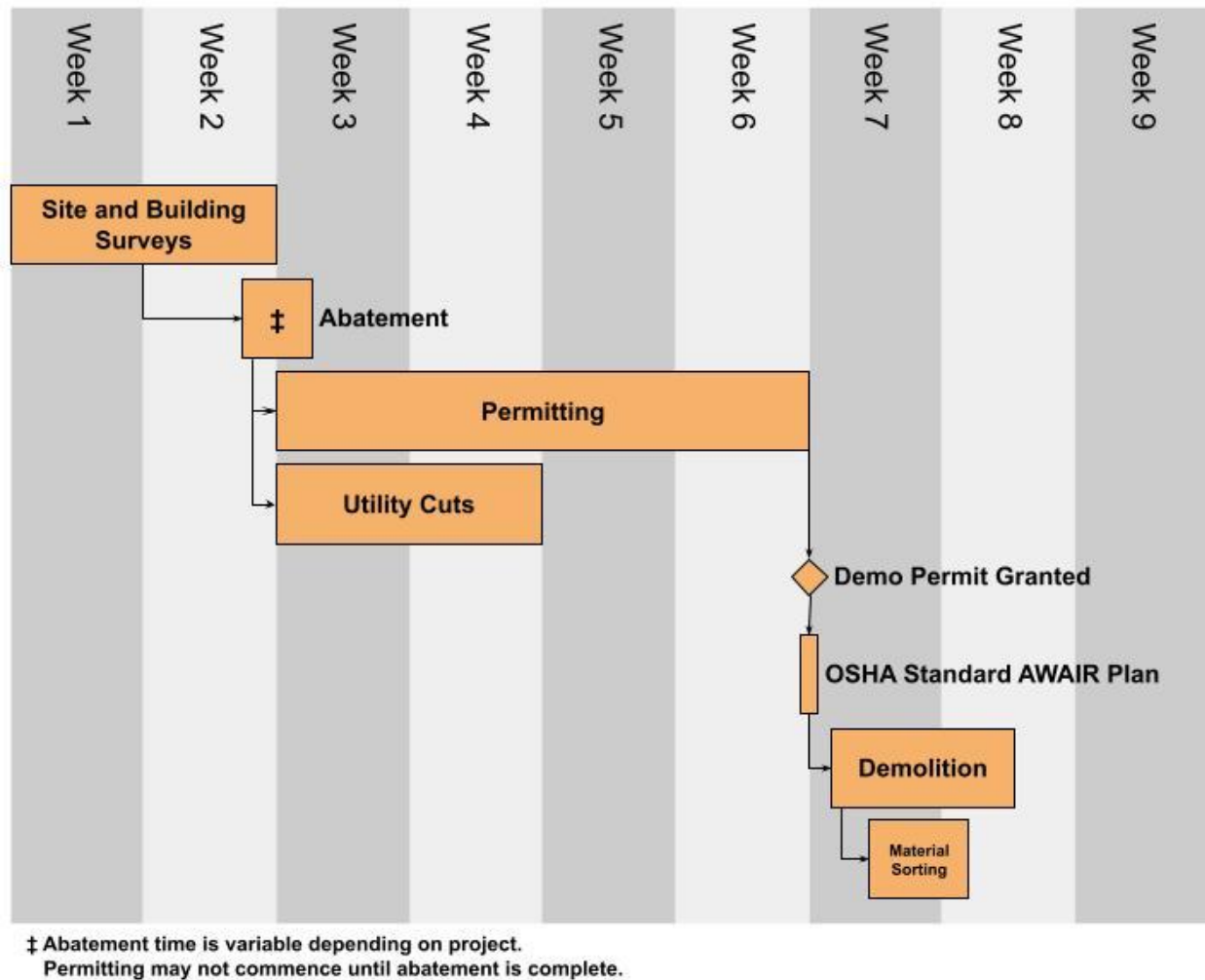


Figure 10: Projected demolition timeline for Pomeroy Center based on Bolander & Sons Co. demolition quote

Given the short timeframe in which a demolition project can be completed, it is often hailed as convenient and economical. Such expediency comes at a cost, however, particularly as it pertains to GHG emissions, public health, and the loss of potentially reusable materials. Each of these interrelated factors must be considered when determining the best end-of-life material management method for a building.

Deconstruction

Background

Many C&D materials conventionally sent to the landfill have the capability of being recycled or reused (Table 4). Deconstruction refers to the selective dismantling of a structure with the aim of recycling or reusing the majority of the building components. This process is often understood as “construction in reverse,” in which the windows and doors are first removed, followed by the

interior fixtures and finishes, then exterior finishes, and finally core structure beginning at the highest point and working down to the foundation. To ensure the materials make their way into the appropriate waste streams, C&D materials are typically sorted on-site for deconstruction projects. The need to preserve the integrity of the C&D materials that are reused and recycled also means that this process often is much lengthier and requires greater skill from laborers. Despite this, interest in this material management method has been increasing in recent years due to the widely-proclaimed environmental advantages of diverting C&D debris from landfills.

Table 4: Recyclable and reusable building materials*

Material	Examples	Recyclable	Reusable**
Appliances	Computers, refrigerators, stoves, washers	✓	✓
Architectural Detailing	Trim, board and batten, fireplace mantels	✓	✓
Bricks/Blocks	Clay bricks, pre-cast concrete, stone blocks	✓	✓
Carpet	Low-pile carpet, high-pile carpet, carpet padding	✓	✗
Concrete/Asphalt /Aggregates	Structural concrete, asphalt pavement, CMU blocks	✓	✓
Drywall	Gypsum board (asbestos-free)	✓	✗
Gates/Railings	Decorative gates, security gates, handrails	✓	✓
Glass	Windows, structural glass, mirrors	✓	✓
Interior Finishes	Windows, doors, countertops, cabinetry, built-ins	✓	✓
Landscaping	Branches, yard waste, shrubs, small trees, plants, sod	✓	✓
Lighting	Light fixtures, tracks	✓	✓
MEP	HVAC ducts, furnaces, air conditioning units, circuit breakers, electrical switches,	✓	✓

	sinks, faucets, toilets, bathroom stalls		
Metals	Metal exterior siding, piping, elevator cables, rebar, steel studs, window and door frames	✓	✓
Paper	Printer paper, newspaper, cardboard	✓	✓
Plastics	Plastic films, piping, construction pails and buckets	✓	✓
Wood	Dimensional lumber, formwork, flooring, painted wood, construction pallets	✓	✓

*Based on information gathered from Place Economics, 2021

**Depends upon condition of the material upon removal

Economic Analysis

The total cost for the deconstruction of the Pomeroy Center was estimated at \$205,640 (P. Rhines, personal communications, March 29, 2022; A. Ristrom, personal communications, March 18, 2022). A bid price of \$195,640 includes labor, deconstruction tools, equipment, transportation of salvaged materials, and the production of an environmental impact report, but excludes tax-deductible donations (P. Rhines, personal communications, March 29, 2022). Labor costs would consist of wages for three supervisors, nine workers, and contract fees with any subcontractors called on to assist in the completion of the project. Deconstruction tools and equipment includes an estimated four dumpsters for recycling and transportation of all the harvested materials. Building on the initial bid price, additional costs were added for utility disconnect services, which were estimated at \$5,000, permitting, which was estimated at \$2,500, and the removal of regulated materials, which was estimated at \$2,500 (A. Ristrom, personal communications, March 18, 2022). It is important to note that this bid did not include the cost for MSW handling, removal of septic tanks, site surveys, bonds, testing, restoration of land, street patching, Minnesota Department of Health (MDH) submittals, soil corrections, traffic control, dust control, or weather delays (P. Rhines, personal communications, March 29, 2022). Financial costs associated with environmental risks, such as soil contamination in need of remediation, were also excluded from this estimate due to the report scope, but should be considered when project-specific details are available in order to provide a more accurate total economic cost.

With regards to the appraisal process, a final materials list for the items salvaged following the deconstruction would be created, and the materials would be donated to the Birch Group. If an appraisal is secured based on the donation amount, the value of the donated materials would be comprised of the quantity and type of materials harvested. The appraiser would then use this information to produce a formal estimation of value, which would support a tax credit to be claimed by the project owner – in this case, the University of Minnesota. Considering appraisals

done on other buildings of comparable scale to the Pomeroy Center, tax credits of \$100,000 or more may be available. This credit can help to offset the increased construction costs associated with deconstruction.

While this study calculated the economic cost based on the assumption that no tax deductions or grants were utilized, such funds are available in the state of Minnesota and can be used to further reduce deconstruction costs. According to Birch Group, the tax write-offs can allow the building owner to profit from the deconstruction process if the building has many desirable items (P. Rhines, personal communications, March 18, 2022). To determine the costs associated with the tax exemption, an appraiser comes in before the deconstruction process begins and provides an estimate, which also looks at the embodied energy associated with the removal of the desired materials to determine its economic viability. The appraiser must then complete an IRS Form 8283 for the building owner to ensure the homeowner is able to claim the full benefits from the donation. An estimated 85 to 90 percent of a building can be recycled or repurposed. Typically desired materials include hardwood flooring, interior lumber, cabinets, appliances, doors, lighting fixtures, mirrors, air conditioning units, etc. (Jordan, 2016). As for available grants, owners can apply for up to \$5,000 per residential project and commercial building owners are eligible for up to \$10,000 (Ramsey/Washington Recycling & Energy, 2022). More information regarding state, federal, and private deconstruction grants can be found in Appendix C.

Environmental Analysis

The total GHG emissions associated with the deconstruction of the Pomeroy Center was calculated to be -146 MtCO_{2e} (Table 5). This is the equivalent of taking 31.5 gasoline-powered passenger vehicles off the road for an entire year (EPA, n.d.). According to the calculations provided by the WARM model, this management method contains the most GHG emissions savings. This is attributed to the fact that this method has the lowest quantity of landfilled materials. Additionally, the recycling of mixed metals has a significant impact on the overall emissions, as the energy required to recycle the material is considerably lower than the energy required to extract raw materials to produce new metals, resulting in a negative emissions factor that influences final results. Deconstruction also offers opportunities for embodied carbon in reused or recycled materials, resulting in the reduction of emissions associated with newly constructed materials.

Table 5: GHG emissions breakdown by material - deconstruction

	Material	Emissions Factor (unitless)	Amount of Material (tons)	GHG Emissions (MtCO₂e)
Landfilled materials	Fiberglass Insulation	0.4	12.2	4.89
	Vinyl Flooring	0.63	0.684	0.431
	Carpet	3.84	0.474	1.82
Recycled Materials	Concrete	-0.01	16.7	-0.167
	Asphalt Concrete/Aggregates	0.03	8.06	0.242
	Drywall	0.24	15.8	3.79
	Bricks	0	0.132	0
	Mixed metals	-0.64	14.6	-9.35
	Asphalt Shingles	0.1	2.51	0.251
	Dimensional Lumber	-2.03	71.7	-146
Source Reduction	Medium Density Fiberboard	-2.23	0.699	-1.56
	Glass	-0.53	1.49	-0.788

GHG emissions are the central value we are looking at for this project, but other sources of emissions and environmental impacts are also considered. PM emissions are present with deconstruction projects and although difficult to quantify, have an impact on air and water quality in the surrounding area. PM emissions are sourced from work done off-road (unpaved sites), on-site sorting and material handling, material transportation, and tailpipe emissions from equipment (EPA, 1999). Worthy of note is the fact that tailpipe emissions associated with deconstruction are typically significantly lower than those on demolition projects due to the fact that most equipment utilized in deconstruction are hand tools rather than large machinery.

Impacts on water quality due to deconstruction are similar to those following demolition. As materials are moved around and removed from the structure, they have the possibility of being housed outside for the duration of the project. If rain or high winds approach the site, this will pick up contaminants such as chemicals, debris, or housing materials and can carry them to nearby waterways. PM emissions have an adverse effect on plant and aquatic life, interrupting the life cycle when high levels of PM are deposited into waterways and absorbed. PM emissions not absorbed can lead to cloudy water. Additionally, metal and organic compounds found in PM

can disturb growth rates in plants and animals (California Air Resources Board, 2022). Although PM particles are very tiny in size, they have a notable impact on the environment during deconstruction activities.

Community Analysis

Many of the aforementioned worker health issues associated with demolition including lead exposure and asbestos exposure also apply to deconstruction. Of note, though, is the fact that the potential for hearing impairment due to construction noise levels is reduced on deconstruction projects. This is due to the fact that the majority of the labor involved is done by hand, reducing the use and noise of large mechanical equipment.

The hands-on nature of deconstruction poses the additional health concern of increased risk of injury, however. Since laborers are more closely involved in the operation of construction tools during this end-of-life building method, there is a higher likelihood that one may become injured as a result of improper tool use or inadequate safety training. Using deconstruction may also have a greater negative community health impact due to the fact that a deconstruction project takes significantly more time than demolition, exposing workers and community members to possible hazards for greater periods of time.

Many of the public health concerns associated with demolition including exposure to dust, asbestos, lead, and mercury remain true for deconstruction projects. It can be argued that deconstruction has a better impact on public health, however, as these issues are typically smaller in scale and community reach due to the careful and slow nature of the deconstruction process.

As aforementioned, many other aspects beyond public and worker health impacts contribute to community impact. For deconstruction projects this includes, but is not limited to, road and sidewalk closures, impact to neighboring property value, obstructions due to site debris or equipment, opportunities for job skills training, site security, streetscape aesthetics, and the creation of an affordable building material market. Research into the effects of these metrics on community impact should be considered going forward for a more comprehensive calculation of community impacts.

Deconstruction also offers the unique opportunity for skills development and training. The skills needed for deconstruction labor can be easily learned and transferred to various sectors of the industry. This means that unskilled or low-skilled workers can receive on-the-job (OTJ) training for the use of basic tools and techniques used in trades such as carpentry, construction, and building materials salvage (Kibert & Chini, 2000). Multiple Minnesota deconstruction organizations offer OTJ training through skill certification opportunities. Better Futures, for example, aids laborers in becoming OSHA certified, which is a prerequisite to working on sites with any environmental hazards such as asbestos or lead paint in all states. Other professional certifications in warehouse safety, janitorial services, contracting and project management, appliance recycling, and snow and lawn care equipment training and maintenance are also

provided by Better Futures (Better Futures Minnesota, n.d.). Including OTJ training is a core part of deconstruction that brings a multitude of positive community impacts. Research shows that skills training, in addition to regular paychecks, are linked to increased self-confidence in workers (Seldman, 2011). Moreover, jobs that require little skill and OTJ training are accessible for populations that are frequently underrepresented in the workforce, such as ex-offenders. Providing training can also add to a growing market for a circular economy in the built environment by fostering community-oriented enterprises including building material reuse stores or deconstruction service companies.

Timeline

Due to the need to maintain material integrity to allow for reuse, deconstruction is a slower process. Despite this, planning and building preparation prior to deconstruction still account for the most time. In the case of the Pomeroy Center, it was estimated that site and building surveys would take 2 weeks, abatement and regulated waste removal would take 0 days, utility cuts would take 2 weeks, permitting would take 2-4 weeks, creation of an OSHA standard Workplace Accident and Injury Reduction (AWAIR) plan would take 1 day, deconstruction would take 45 days, and material sorting – which occurs consecutively with demolition – would take 35 days (P. Rhines, personal communications, March 22, 2022; University of Minnesota, 2022). The project timeline can be seen in Figure 11. In total, demolition would take approximately 15.5 weeks. This timeline does not account for the construction of a new structure due to the variability in potential new build designs. The duration of the proposed new building’s project schedule should be added to the calculated deconstruction timeline in order to provide an estimate for total project time required.

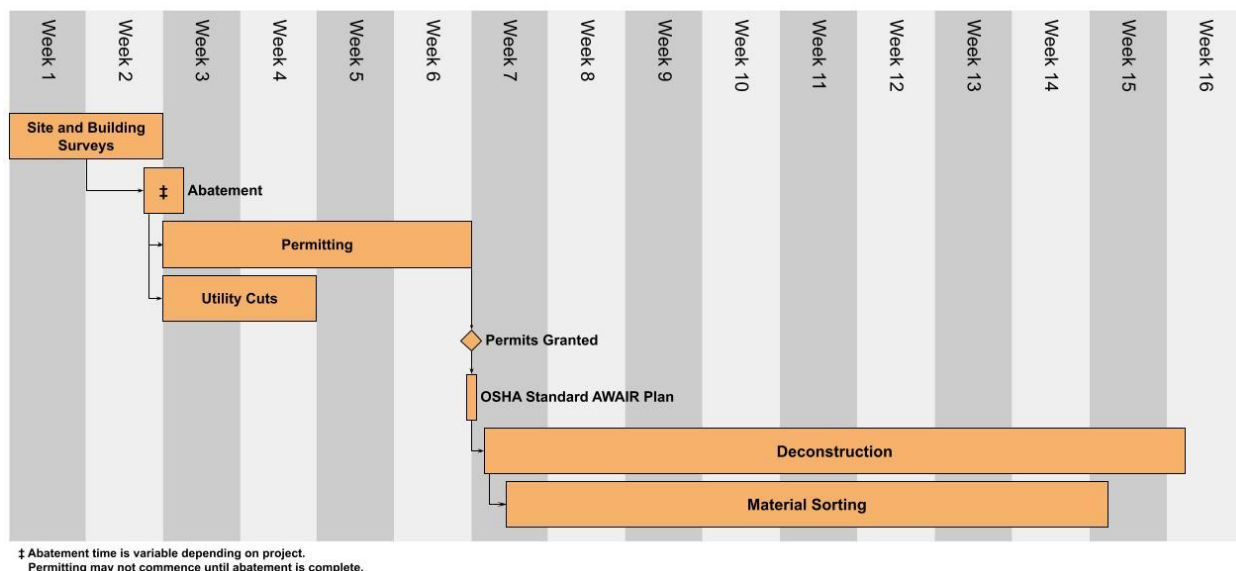


Figure 11: Projected deconstruction timeline for Pomeroy Center based on deconstruction quote from the Birch Group

Renovation

Background

Building restoration is defined as returning a structure to an unimpaired or improved condition (Merriam-Webster, n.d.). Commonly undertaken on historic structures, restoration can range from minor aesthetic fixes such as patching holes, refinishing surfaces, and replacing interior fixtures, to building repurposing in which the structure is partially deconstructed and then remodeled for a new use. In many cases, significant quantities of building materials can be salvaged for reuse in other buildings or applications. Selection of materials to be salvaged depends on both salvage value and salvage potential (Figure 12). Analysis of renovation costs for the Pomeroy Center was based on the repurposing of the original Dairy Barn completed in 2007. The existing concrete floor slab, windows, asphalt roofing, barn stalls, and equipment were all removed from the building. The renovation then entailed installing a new concrete slab, additional structural roof deck, floor joists, windows, doors, roofing, interior partition walls, plumbing, lighting, mechanical equipment, and all interior finishes into the existing building shell. The brick exterior, cupola, and original roof deck were also refinished.

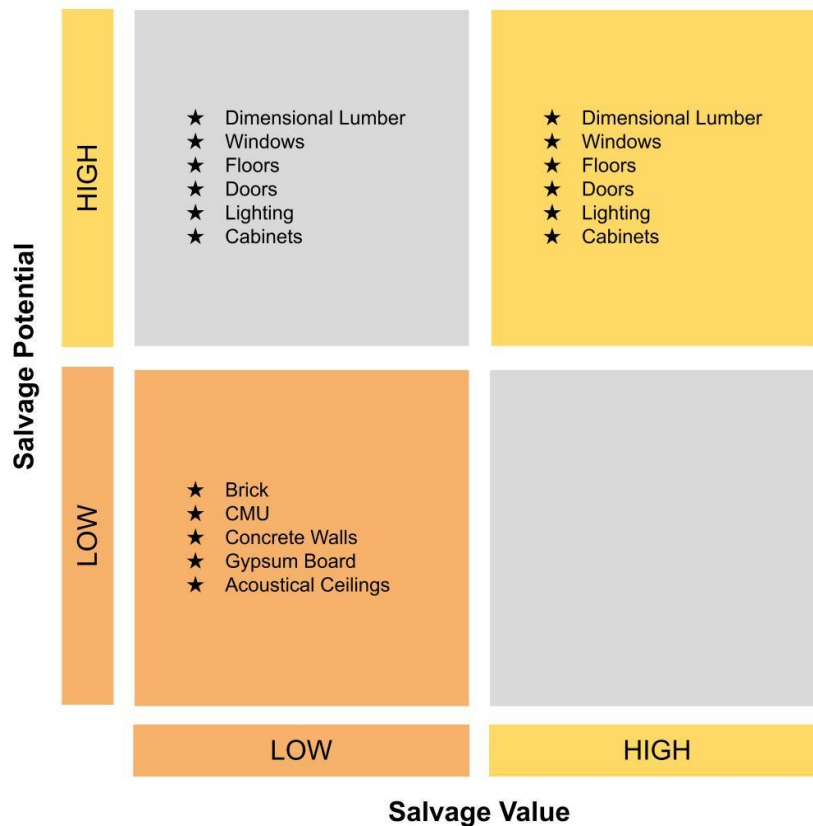


Figure 12: Salvage potential versus salvage value

Economic Analysis

In 2007, the total renovation cost, including partial demolition and the construction of a new structure, was approximately \$5,100,000 (“Ben Pomeroy,” 2006; Wickler, 2007). An alternative cost estimate was created to reflect current pricing and inflation. The procedure and detailed cost estimate is outlined in Appendix D. The total cost to renovate the building with today’s value of the dollar is just over \$7,100,000.

This report calculates the total cost based on the assumption that no tax incentives were utilized. However, various financial incentives are available through the government and private institutions that can reduce renovation costs on historic buildings. The federal government encourages preserving historic buildings with the Federal Historic Preservation Tax Incentives program. These tax incentives are available to attract private investment to historic buildings. Two tiers of tax credits are available through this program. A tax credit reduces the amount of tax owed by the property owner. A 20% tax credit is available for the certified rehabilitation of certified historic structures. To qualify, the building must be listed on the National Register of Historic Places or located in a registered historic district and certified by the National Park Service, and follow the Secretary’s Standards for Rehabilitation. Additionally, the building must be commercial, industrial, agricultural, or rental residential. Private residential properties do not qualify for this tax credit. Alternatively, a 10% tax credit is available for the rehabilitation of non-historic buildings placed in service before 1936. All buildings zoned as residential do not qualify for this tax credit. The project must meet the specified requirements and retain a portion of the original exterior walls and internal structural framework (National Park Service, 2012). In 2020, the Federal Historic Preservation Tax Incentives program generated \$7 billion in gross domestic product (GDP) and created nearly 122,000 jobs across the country. The program has generated \$195.2 billion in GDP since 1978 (National Park Service, 2021).

While the tax incentives available vary by state, Minnesota’s Historic Rehabilitation Tax Credit matches the federal 20% tax credit. The same requirements apply; however, the tax credit is awarded on the state and federal level. The state and federal taxes are both lower by 20% on accepted projects (State Historic Preservation Office, n.d.). The University of Minnesota Extension analyzed the economic impact of the Historic Rehabilitation Tax Credit in 2021. The study found that every dollar of the tax credit awarded generated \$11.30 of economic activity in the state. Additionally, the credit supported nearly 9,600 jobs during 2021 (Tuck & Foss, 2022). The amount of tax credit and requirements is dependent on the state. The majority of states have a historic tax credit available (Novogradac, n.d.). Additionally, South Carolina has an Abandoned Building Tax Credit that can be combined with the state and federal historic rehabilitation credits to provide a large tax deduction for qualifying projects. While South Carolina is the first state to implement the abandoned building tax credit, other states are looking into similar programs, and may be beneficial to consider in the state of Minnesota (Municipal Association of South Carolina, n.d.).

Third party grants are available through some organizations. The requirements and awardal of each grant program vary by organization. The Minnesota Historical Society has Minnesota Historical and Cultural Heritage Grants that are available for a variety of historical and cultural preservation projects and can be used for historic building preservation. The grant is available for educational institutions, nonprofit organizations, government agencies, and federally recognized tribes based in Minnesota (Minnesota Historical Society, n.d.). The National Trust for Historic Preservation has a grant program that is awarded to nonprofit organizations and public agencies for the planning of preservation projects (National Trust for Historic Preservation, n.d.). The Kinsman Foundation funds private architectural preservation projects along with other historic preservation projects of historic buildings, structures, and related sites (Kinsman Foundation, n.d.). Such grants and supporting organizations, among others, are available across the United States and may be considered by future Minnesota end-of-life building projects to make renovation more economically feasible. More information regarding state, federal, and private historical preservation or renovation grants can be found in Appendix E.

Preserving historic buildings has benefits beyond the immediate economic impact of a newly renovated building. Heritage tourism is an important part of the tourism industry across the United States. In 2019, tourism generated 18% of the total Minnesota sales tax revenue (Explore Minnesota, 2020). Embracing an area's historical and architectural resources can be a large source of revenue for the state and local community. Heritage tourism is more effective when a large area has historical value; in such cases, multiple buildings must be restored to create a historic landscape especially in downtown areas or historic districts of a city. Historic buildings attract new tenants and visitors that have the potential to revitalize the area. This contributes to the success of the local shops, restaurants and entertainment venues in the area. Rehabilitation projects also provide employment opportunities during the construction and operation of businesses (University of Kansas Center for Community Health and Development, n.d.; Wisconsin Historical Society, n.d.).

Environmental Analysis

Total GHG emissions associated with the 200 Pomeroy Center renovation project were calculated to be -153 MtCO₂e (Table 6). This is the equivalent of taking 33 gasoline-powered passenger vehicles off the road for an entire year (EPA, n.d.). Renovation projects have less material landfilled and a higher amount of source reduction than demolition, but have additional GHG emissions associated with virgin material production that sets the total emission value higher than deconstruction. Of note is the fact that several materials could not be quantified due to model limitations and lack of access to original data sets.

Table 6: GHG emissions breakdown by material - renovation

	Material	Emissions Factor (unitless)	Amount of Material (tons)	GHG Emissions (MtCO₂e)
Landfilled materials	Dimensional lumber	1.02	NA	†
	Metal	NA	NA	†
	Bricks	2.29	NA	†
	Medium Density Fiberboard	1.35	NA	†
	Glass	0.55	NA	†
Recycled materials	Concrete	-0.01	16.7	-0.167
Source reduction	Dimensional lumber	-2.46	71.7	-176
	Bricks	NA	0.132	††
	Stucco	NA	5.76	††
Production of virgin materials & transportation	Fiberglass Insulation	0.49	12.2	5.99
	Vinyl Flooring	0.61	0.684	0.417
	Carpet	3.82	0.474	1.81
	Mixed Metals (composite metals)	NA	NA	††
	Concrete	NA	16.7	††
	Asphalt Concrete/Aggregates	0.11	8.06	0.886
	Drywall	0.21	15.8	3.31
	Mixed metals (ferrous metals)	NA	NA	††
	Asphalt Shingles	0.19	2.51	0.476
	Medium Density Fiberboard	0.39	0.699	0.273
	Glass	7.08	1.49	10.5

†Cannot quantify due to data accessibility limitations

††Cannot quantify due to WARM model limitations

Other environmental impacts that are non-quantifiable have been considered for renovation projects aside from GHG emission calculations. Volatile organic compounds (VOCs) are a concern for renovation projects and are a precursor for PM emissions. VOCs are found in renovation activities such as painting, caulking, carpeting, and staining (EPA, 2021). They are known to be a source of secondary PM emissions, and therefore pose a negative threat for outdoor environmental health (Johansson, Karvosenoja, & Porvari, n.d.). To reduce the formation of these particles, renovation project managers should consider eliminating the use of these products or consider alternative products with low-VOC content. Water pollution is another impact worth considering. Materials removed during renovation projects have the potential to contribute to off-site water runoff, causing pollution in waterways. Since renovations are common with older buildings, lead exposure can also be a concern in the home as the renovation takes place. Buildings built before 1978 often contain lead paint and should be disposed of properly to avoid any lead contamination into soil or waterways (EPA, 2021). If lead is deposited into the soil, any source of water or wind can carry it to nearby waterways.

Community Analysis

Many of the aforementioned public and worker health issues associated with demolition including exposure to lead, asbestos, duct, mercury, and noise apply to renovation. Before a renovation begins, portions of the existing building are normally demolished to make room for the improvements. During the 2007 Pomeroy Center renovation, the majority of the interior wood and the entire concrete slab were demolished before the renovation could begin. Renovation commonly takes more time than demolition so the exposure time to the worker and public health issues discussed previously increases. The longer timeframe of renovation can also significantly interfere with the functioning of the surrounding buildings and people due to noise, vibrations, and traffic congestion. People in the surrounding buildings may become irritated over time if they are continuously being disrupted by the nearby construction activities. To reduce community and worker impacts, a health and safety plan must be developed for a renovation.

Aside from community health impacts of renovation, restoring historic buildings can have significant cultural and educational benefits. A historic building is a physical and visible link to the past. Creating an awareness of the history behind a building can promote community involvement and education (Preservation Connecticut, n.d.). Historic buildings can act as educational tools, teaching students, builders, architects, neighbors, and neighbors about what came before them (Vintage Millwork & Restoration, 2020). Celebrating the community's heritage and diverse cultures is essential to historic preservation (Milligan, 2007). Preserving rather than demolishing the built environment is respecting the people of the past, present, and future, creating a legacy and foundation for community pride.

As development continues to span far out from city centers, more and more buildings look alike. Local identities are kept intact by historic preservation. Preserving the aesthetic, architectural, and historic character of a community helps provide a sense of place and identity in the area. The

uniqueness of an area with historic buildings can help the community understand its past and how it got to be how it is today. Historic rehabilitation can even prevent suburban sprawl by reducing the need for new buildings. Since most historic buildings already exist in built-up areas, the need for constructing new buildings in the suburbs is eliminated (University of Kansas Center for Community Health and Development, n.d.).

As previously stated, metrics outside of public health, worker health, and preservation of history contribute to total community cost. For renovation projects this includes, but is not limited to, road and sidewalk closures, gentrification, impact to neighboring property value, obstructions due to site debris, opportunities for job skills training, site security, streetscape aesthetics, and the creation of an affordable building material market. Research into the effects of these metrics on community impact should be considered going forward for a more comprehensive calculation of community impacts.

Timeline

The timeframe of renovating a building greatly depends on the extent of work being done to it. In instances of minor aesthetic fixes, renovation may take as little as days or weeks. The Pomeroy Center's 2007 renovation, however, involved complete repurposing and large-scale renovations. The funding for this renovation was awarded in the spring of 2005. It took the University of Minnesota and Miller Dunwiddie approximately one year to develop the drawings and specifications for the new design and undergo necessary code review and permitting. McGough began construction in late March of 2006 and took approximately one year to convert the former Dairy Barn into the new student learning center ("Diary of Progress," 2006). In total, this repurposed renovation took two years to complete (Figure 13).

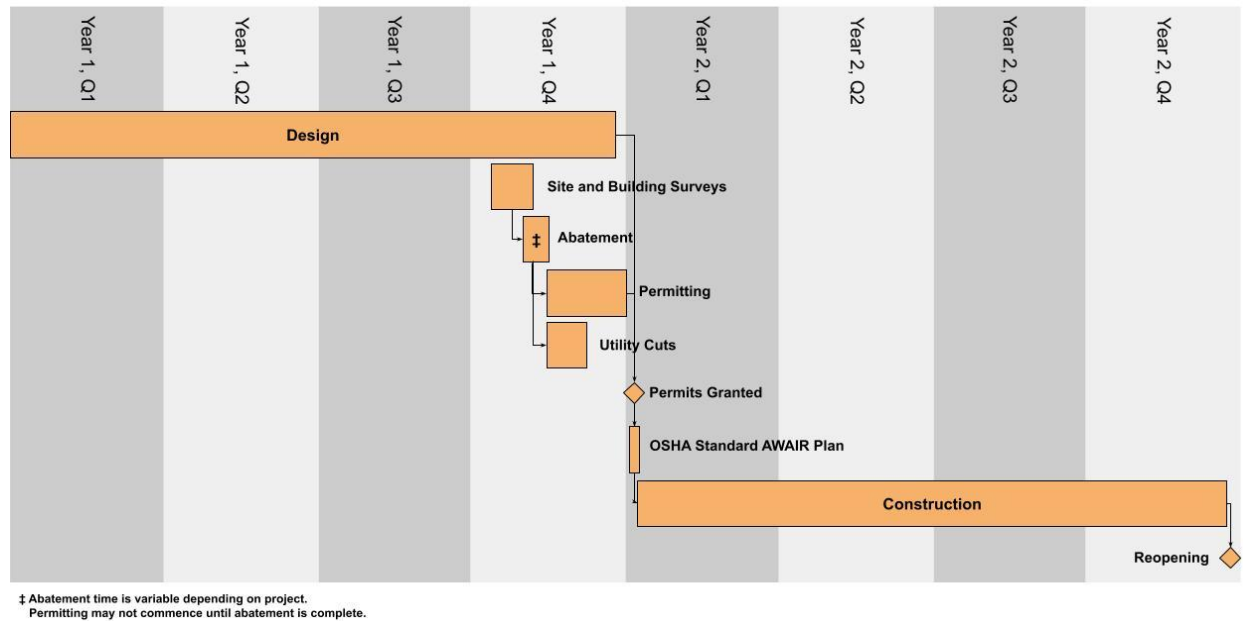


Figure 13: Projected renovation timeline for Pomeroy Center based on University of Minnesota project schedule

Conclusion

Impact Comparison

Based on this assessment, the breakdown of where materials end up in waste management following demolition, deconstruction, and renovation is shown in Figure 14, Figure 15, and Figure 16, respectively.

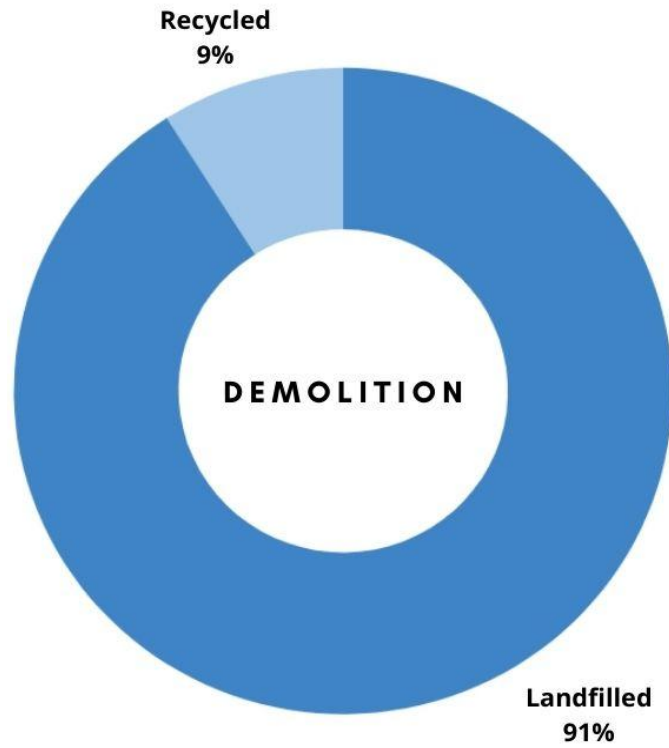


Figure 14: Demolition material end-of-life location

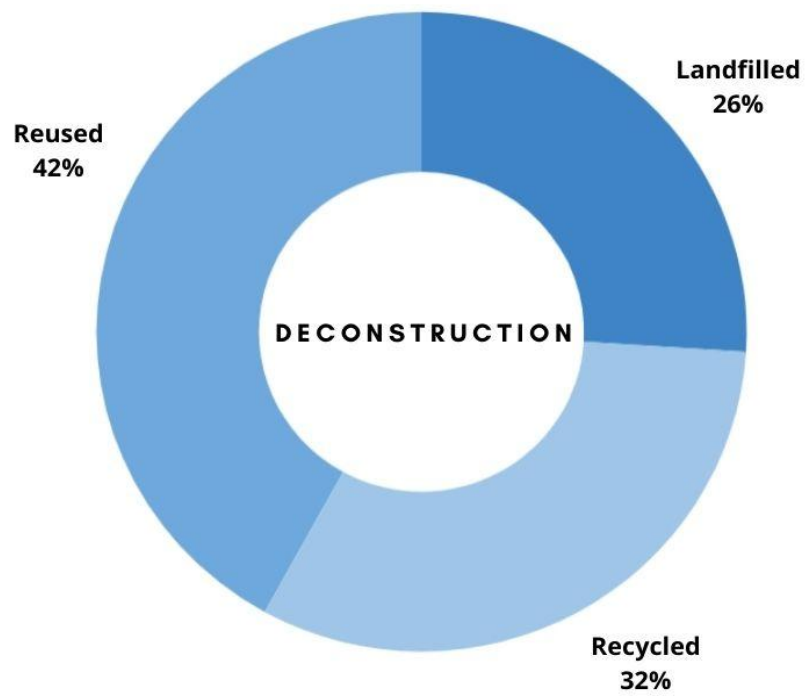


Figure 15: Deconstruction material end-of-life location

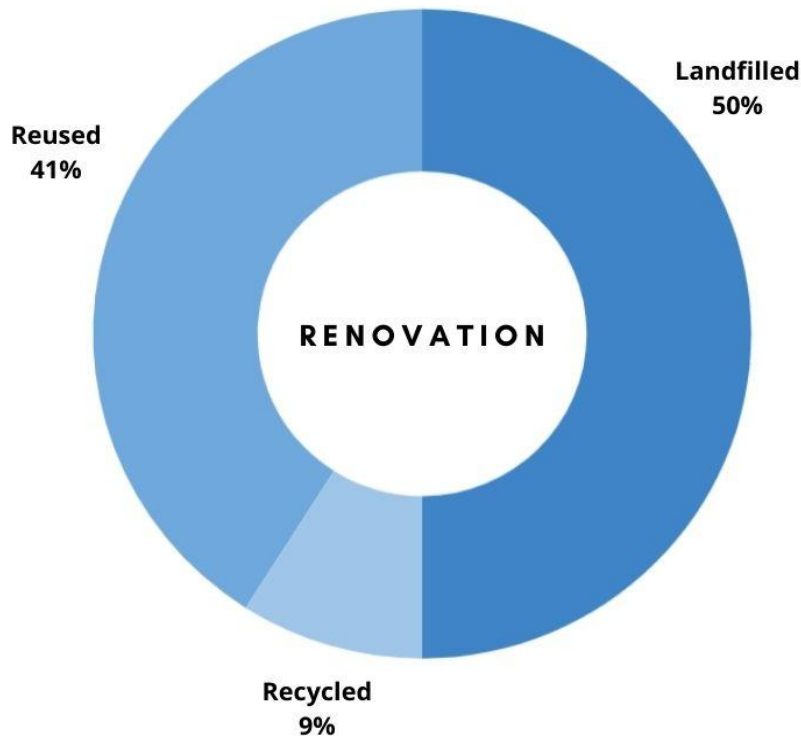


Figure 16: Renovation material end-of-life location

It can be seen that no more than 9% of waste was diverted from the landfill in the demolition of the Pomeroy Center. Deconstruction provides an opportunity for 74% of C&D waste to be diverted from the landfill, while renovation provides an opportunity for approximately 50% of C&D waste to be diverted from the landfill. To understand how this impacts the total cost of each material management method, a side-by-side comparison was done in each analysis category.

Economic Comparison

As can be seen in Table 7, the overall economic costs for each project have considerable variation. While renovation costs are much higher than demolition and deconstruction, the end point results in a building whereas the other two only account for the removal of that structure. The overall direct costs were highest for renovation, followed by deconstruction, and demolition which offered the lowest direct economic cost. Of note is the fact that these calculations did not take indirect costs – including the costs associated with emissions exposure, water pollution, the social cost of carbon, etc. – into account.

As aforementioned, this report made various assumptions for each of the studied building material management methods which have affected the estimated costs considerably. The project scope did not include any furnishings that the building had in its deconstruction. In most building deconstruction appraisals, the furnishings make a significant difference when determining the tax credits for donating materials to non-profit organizations; factoring these savings in would, in turn, alter the final cost estimation. Another important consideration when looking at the final

numbers is the end result of the practice. Based on available data, this study assumed that no new building was constructed following demolition and deconstruction, and a new structure was constructed during renovation. This was largely due to the fact that following the removal of an entire building, as is true in demolition and deconstruction, the plot can be used for a wide variety of uses. Thus, it did not make sense to include an estimation with a large degree of speculation regarding end use, design, and construction timeline. As a result, impact analyzes in this report did not consider the costs associated with the construction of a new building for demolition or deconstruction. If a contractor wishes to use this framework for future projects, an assessment for the cost of the proposed new building would have to be conducted and added to the provided cost of building removal in order to have an accurate total economic cost value to compare to renovation. Estimations for new construction may be made based on resources provided in Appendix A.

Table 7: Construction cost comparison

Demolition	\$115,000*
Deconstruction	\$205,640*
Renovation	\$7,100,000

** These costs do not account for the costs associated with building a new structure.*

Environmental Comparison

Since the WARM model factors in carbon sequestration, deconstruction and renovation were found to have negative associated GHG emissions. To compare emissions across all management methods, the approach with the most negative GHG emissions has the lowest environmental impact. As can be seen in Table 8, the overall environmental impact was found to be lowest for renovation. Demolition featured the highest environmental cost.

Similar to what was mentioned in the economic comparison, adding the impacts associated with the proposed new building will also apply to assessing the environmental impacts for more accurate comparison across all management methods.

Table 8: GHG emissions comparison for each management method

Demolition	141.5 MtCO ₂ e*
Deconstruction	-146 MtCO ₂ e*
Renovation	-153 MtCO ₂ e

* These calculations do not account for the emissions associated with building a new structure.

Community Impact Comparison

As can be seen in Table 9, demolition has the highest worker and public health risk, followed by renovation, and then deconstruction.

Table 9: Community impact comparison

Demolition	Dust - high exposure over short time Noise/Hearing impairment - high exposure over short time Worker injury - moderate risk over short time
Deconstruction	Dust - low exposure over prolonged time Noise/Hearing impairment - low exposure over prolonged time Worker injury - high risk over prolonged time
Renovation	Dust - high exposure over prolonged time Noise/Hearing impairment - high exposure over prolonged time Worker injury - moderate risk over prolonged time

Total Cost Comparison

While economic, environmental, and community costs are each important to understand in their own regard, a total impact evaluation that integrates all three paths is vital in determining the complete and long-term impacts.

The simplified approach taken in this study allows us to generate an idea as to what the various cost breakdowns would be for the Pomeroy Center and is meant to act as a framework for future projects. The goal is not to give an ultimatum on which path is the best option for all buildings; as the costs are highly dependent on the location, condition of the existing structure, salvageability of materials, etc., and can vary considerably. Therefore, we emphasize that the “best” option will directly depend on the context of the specific building being studied.

In the case of the Pomeroy Center, we found that deconstruction has the lowest associated total cost. Comparison between renovation and other building management methods is challenging, as its end result is different from deconstruction and demolition. It is, however, relevant if a

building owner is looking at building removal in order to build a new structure. In that case, it should be considered as an alternative. Again, it is emphasized that the goal of the report is to create a framework for future building evaluations, as no two buildings are alike and recommendations may vary considerably.

Based on our results, we found that deconstruction is the best in terms of GHG emissions. As stated above, this was determined by the WARM model which takes carbon sequestration into account. Unfortunately, this is not a factor in the economic considerations but should nonetheless be considered when determining the outcome for a building as climate change is a global concern.

As stated before, there are also considerable incentives to preserve historical buildings. This may be a factor in a future project that is looking to rebuild a building on the site of a current one rather than renovation.

Table 10: Overall comparison of demolition, deconstruction, and renovation

	Demolition	Deconstruction	Renovation
Definition	Razing of a building in such a way that the building components are not intended for reuse	Disassembling buildings with the goal of maximizing the reuse potential of its components	Returning a building to an unimpaired or improved state
Material end-use	Landfill Recycling facility	Landfill Recycling facility Reuse	Landfill Recycling facility Reuse
Project length (weeks)	7.5*	15.5*	104
Cost (US Dollars)	\$115,000*	\$205,640*	\$7,100,000
GHG emissions (MtCO₂e)	141.5*	-146*	-153
Public health concerns	High exposure	Low exposure	Low exposure
Worker health concerns	High exposure for a short period of time	High exposure for prolonged time	High exposure for prolonged time

* These values do not account for the impacts associated with building a new structure.

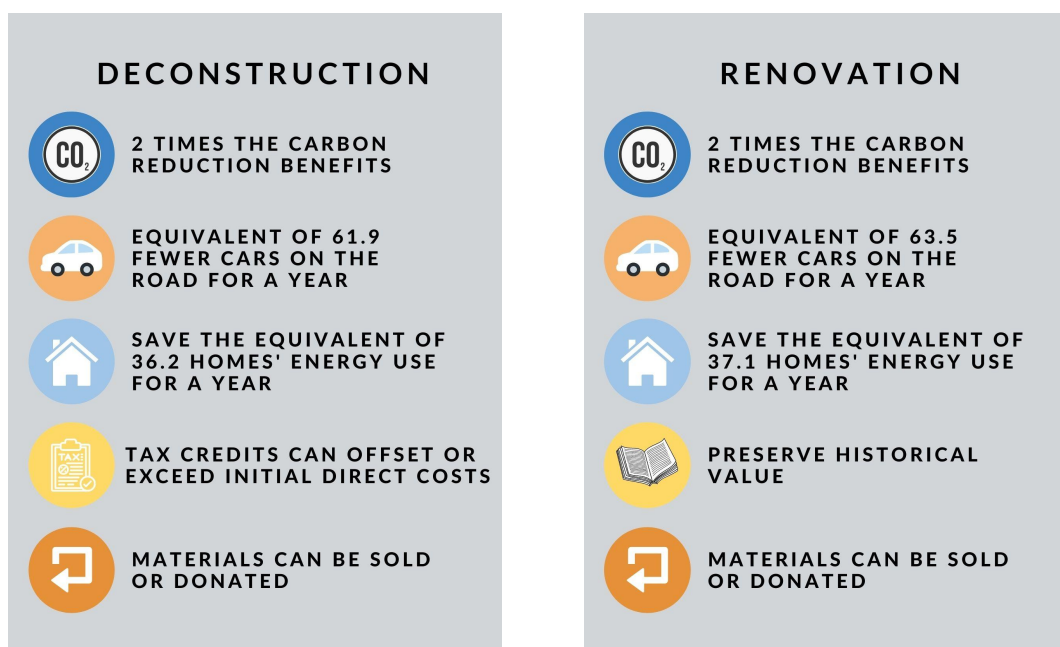


Figure 17: Alternative material management strategies' cost reduction potential compared to demolition

Future Work

In order to get a more accurate understanding of the total cost of each of the three material management methods, future work must be done to analyze the total impact of several limiting factors. Additional work must be done in all impact categories – environmental, economic, and community – to create a more comprehensive comparison.

Addressing Study Limitations

While the total greenhouse gas emissions was the main indicator for the environmental analysis, many other metrics could have been used if they had more sophisticated modeling or quantification. The Social Cost of Carbon (SCC) can be used to put the greenhouse gas emissions of each material management method in terms of economic value. However, the accuracy and effectiveness of the SCC is widely debated due to its assumptions and methods used. More research must be done in order to accurately monetize the environmental impact. The PM emissions and waterway impact of each method were not quantified at all in this study. Also, WARM model limitations should be addressed in the future. Materials such as stucco, rigid insulation, and tile are not included in this model, and therefore could not be quantified. Lastly, the WARM model takes into account carbon sequestration, which reduces the total amount of GHG emissions for each method. These modeling limitations should be addressed by the EPA going forward in order to achieve more accurate environmental cost estimates in the built environment industry going forward. Other supplemental emission calculators such as the Construction Calculator (EC3) or the SOUR Studio Carbon Calculator can be used to

supplement the missing data. It is important that these factors are quantified in future work of demolition, deconstruction, and renovation total cost estimates using a similar project scope.

Additionally, the total economic impact of each material management method has to be specifically analyzed to complete a full comparison. Some of the limiting factors in the total economic assessment were due the exclusion of building furnishings in the study scope. While this doesn't mean that our numbers cannot be used for an acceptable evaluation, it would alter the deconstruction favorably and demolition negatively in both financial and environmental terms. There are also certain limitations in understanding the appraisal values of the materials in the building along with market demand. There is typically a range of estimates provided by three different appraisers, and the middle value is typically accepted by project owners (P. Rhines, personal communications, March 18, 2022). This is relevant because it determines the tax break that building owners can expect when deconstructing their building. Given that we did not get the building officially appraised, our calculated value was based on an educated estimate which is subject to more error. The economic importance of historic preservation was also excluded from our study as it has not been quantified in the past. Additionally, the workforce impact, including number of jobs created and training, of each method should be studied further in depth. All of these factors should be considered in future work to fully understand the economic impact of the three building material management methods.

Quantification of community health impacts also remained challenging due to the lack of quantifiable metrics and resources on similar projects. While the public and worker health effects of lead, asbestos, mercury, and dust have been documented in past studies, a more comprehensive comparison of the effects is needed for the three material management methods. Such effects are heavily dependent on the site conditions, meaning each method may have to be estimated rather than explicitly measured. Factors such as gentrification, road and sidewalk closures, streetscape aesthetics, community pride, and historical importance are difficult to quantify, as their sources cannot easily be traced or isolated. Future research must be done to understand the total community effect of these factors for demolition, deconstruction, and renovation.

Addressing Market Challenges

The current market for deconstruction as a means of material management is greatly untapped in terms of its potential. There is currently a lot of enthusiasm on the part of deconstruction firms to expand their base, yet a general lack of knowledge in the public regarding the option of deconstruction. Thus, education and outreach are needed in order to expand the demand side of the market. As for the supply, there needs to be a balance in keeping up with demand while still growing the labor force. Moreover, greater emphasis should be placed on the potential tax savings, as the majority of the public holds the misconception that deconstruction's upfront cost is significantly greater than conventional demolition. As for renovation, there seems to be a general understanding on why it can be valuable in terms of preserving the historical significance of the building. It may also be a better outcome for a building if the intent is to build a new

structure on the same lot anyways. There are also a fair amount of historical grants that exist for choosing renovation over the removal of a significant building. Generating greater recognition and expanding the reuse markets associated with this practice are still required, however. The market challenges associated with mass-implementation of deconstruction and renovation for buildings in Minnesota should be considered in future work.

Addressing New Construction Practices

Lastly, this analysis limited its scope to existing construction. The findings show that deconstruction provides significant total cost reduction, and is worthy of pursuing for future Minnesota building projects. It is important to recognize that if deconstruction is pursued on a greater scale in the future, the long-term needs of this method must be addressed. This includes implementing a design for deconstruction (DfD) approach when planning and designing new construction in the state, in order to mitigate challenges and reduce costs associated with the material management method. Assessing the feasibility of adopting DfD principles across Minnesota, therefore, is a worthwhile topic to pursue in future work.

Resources

- About Dr. Ben Pomeroy.* (2006, March 2). College of Veterinary Medicine. Folder, "Pomeroy, Benjamin," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- Anuranjita, A., Berghorn, G. H., Bates, D., & Syal, M. G. (2018). Life cycle assessment framework for demolition and deconstruction of buildings. In *Construction Research Congress 2018*. American Society of Civil Engineers.
<https://doi.org/10.1061/9780784481301.034>
- Asleson, R. (1953, February 1). Veterinarian, 91, Still on Job – Sons Are, Too. *Minneapolis Tribune*.
- Architecture 2030. (2021). *Why the building sector?*
<https://architecture2030.org/why-the-building-sector/>
- Azarmi, F., & Kumar, P. (2016). Ambient exposure to coarse and fine particle emissions from building demolition. *Atmospheric Environment*.
<https://doi.org/10.1016/j.atmosenv.2016.04.029>
- Ben Pomeroy Student-Alumni Learning Center.* (2006, May 9). College of Veterinary Medicine. Folder, "Ben Pomeroy Student-Alumni Learning Center," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- Better Futures Minnesota. (n.d.). *Approach*. <https://betterfuturesminnesota.com/approach/>
- Block O'Toole & Murphy. (2021). *Why demolition work is dangerous work*.
<https://www.blockotoole.com/blog/2016/05/why-demolition-work-is-dangerous-work/>
- Brady, T. (n.d.). History on the Grounds. *Minnesota Alumni*.
<https://www.minnesotaalumni.org/stories/history-on-the-grounds>
- Burns, K. (2013, July 1). Historic hospitals. *American Veterinary Medical Association*.
<https://www.avma.org/javma-news/2013-07-15/historic-hospitals>
- California Air Resources Board. (2022). *Inhalable Particulate Matter and Health (PM2.5 and PM10)*.
<https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health#:~:text=PM%20can%20adversely%20affect%20ecosystems,alter%20plant%20growth%20and%20yield>
- CDC. (2021). *Lead: Health problems caused by lead*.
<https://www.cdc.gov/niosh/topics/lead/health.html#:~:text=Exposure%20to%20high%20levels%20of,a%20developing%20baby's%20nervous%20system>

- Chair in Avian Health Created*. (1985). Veterinary Medicine. Folder, "Pomeroy, Benjamin," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- Christianson, M. (1999, October). Dr. Pomeroy wins prestigious Siehl Prize. *The Park Bugle*. Folder, "Pomeroy, Benjamin," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- City of Seattle. (n.d.). *Dust Control and Water Usage*.
<https://www.seattle.gov/utilities/construction-resources/collection-and-disposal/construction-and-demolition/dust-control-and-water-usage>
- Dairy Cattle Barn. St. Paul Campus*. (2017, December 11). College of Veterinary Medicine. Folder, "Pomeroy, Benjamin," una563815, University Archives, University of Minnesota, Twin Cities. <http://purl.umn.edu/227188>
- Diary of Progress: Ben Pomeroy Student-Alumni Learning Center* (2006). College of Veterinary Medicine. Folder, "Ben Pomeroy Student-Alumni Learning Center," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- D'Amore Law Group. (2021). *Construction injuries and faulty demolition*.
<https://damorelaw.com/construction-injuries-and-faulty-demolition-what-you-need-to-know/>
- Engineering News Record. (n.d.) *Construction Cost Index History*.
https://www.enr.com/economics/historical_indices/construction_cost_index_history
- Engineering News Record. (2018). *Square Foot Costbook: 2019 Edition*. BNI Publications.
- EPA. (n.d.). *Greenhouse Gas Equivalencies Calculator*.
<https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>
- Explore Minnesota. (2020). *2020 Annual Report*.
https://mn.gov/tourism-industry/assets/AnnualReport_2020_tcm1135-485394.pdf
- EPA. (1999). *Estimating Particulate Matter Emissions From Construction Operations*.
<https://nepis.epa.gov/Exe/ZyNET.exe/9100KK1W.txt?ZyActionD=ZyDocument&Client=EPA&Index=1995+Thru+1999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX+DATA%5C95THRU99%5CTXT%5C00000027%5C9100KK1W.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8%2Fr75g8%2Fxf150y150g16%2Fi425&>

Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results+page&MaximumPages=1&ZyEntry=4#

- EPA. (2020). *Advancing Sustainable Materials Management: Assessing Trends in Materials Generation and Management in the United States* [Fact sheet].
https://www.epa.gov/sites/default/files/2021-01/documents/2018_ff_fact_sheet_dec_2020_fnl_508.pdf
- EPA. (2021). *Addressing Indoor Environmental Concerns During Remodeling*.
<https://www.epa.gov/indoor-air-quality-iaq/addressing-indoor-environmental-concerns-during-remodeling#tab-10>
- EPA. (2021). *Managing Stormwater and Dust at Demolition Sites*.
<https://www.epa.gov/large-scale-residential-demolition/managing-stormwater-and-dust-demolition-sites>
- EPA. (n.d.). *Asbestos-Containing Materials (ACM) and Demolition*.
<https://www.epa.gov/large-scale-residential-demolition/asbestos-containing-materials-acm-and-demolition>
- EPA. (n.d.). *Mercury-Containing Devices and Demolition*.
<https://www.epa.gov/large-scale-residential-demolition/mercury-containing-devices-and-demolition>
- Florida Department of Transportation. (2015). *Guide to Construction Vibrations*.
https://www.d4fdot.com/bcfdot/pdf/News_Releases/BrochureGuideConstructionVibrations.pdf
- Geiger, B. (1977, September 28). U bird disease expert inducted today into elite poultry hall of fame. *The Minnesota Daily*. Folder, "Pomeroy, Benjamin," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- Heritage Manitoba. (n.d.). *Historic Construction Materials & Techniques*.
<https://pdf4pro.com/cdn/historic-construction-materials-amp-techniques-3fdffc.pdf>
- Hotz, A. & Walsh, K. (2019). *Solid Waste Policy Report*. Minnesota Pollution Control Agency.
<https://www.pca.state.mn.us/sites/default/files/lrw-sw-1sy19.pdf>
- Johansson, M., Karvosenoja, N., Porvari, P., & Kupiainen, K. (n.d.). *Emission Scenarios for Particulate Matter Research And Policy Assessment in Finland*. U.S. EPA.
<https://www3.epa.gov/ttn/chief/conference/ei12/part/johansson.pdf>
- Jordan, W. A. (2016, August 25). Deconstruction can be a tax-savvy alternative to demolition. *The Washington Post*.

- Kibert, C. J., & Chini, A. R. (2000). *Overview of Deconstruction in Selected Countries*. International Council for Research and Innovation in Building Construction.
<https://www.iip.kit.edu/downloads/CIBpublication252.pdf>
- Kinsman Foundation. (n.d.). *Historic Preservation*.
<https://kinsmanfoundation.org/historic-preservation/>
- Lemay, K. (1979, January 2). 'Mr. Turkey' named acting dean of veterinary school. *The Minnesota Daily*. Folder, "Pomeroy, Benjamin," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- Merriam-Webster. (n.d.). Restoration. In *Merriam-Webster.com dictionary*.
<https://www.merriam-webster.com/dictionary/restoration>
- Milligan, M. (2007). Buildings as History: The Place of Collective Memory in the Study of Historic Preservation. *Symbolic Interaction*, 30(1), pp. 105-123.
<https://doi.org/10.1525/si.2007.30.1.105>
- Miller Dunwiddie. (n.d.). *Ben Pomeroy Student/Alumni Learning Center – University of Minnesota*.
<https://millerdunwiddie.com/projects/the-ben-pomeroy-student-alumni-learning-center/>
- Minnesota Historical Society. (n.d.). *Minnesota Historical and Cultural Heritage Grants*.
<https://www.mnhs.org/preservation/legacy-grants>
- MNopedia. (n.d.). *Johnston, Clarence H. (1859-1936)*.
<https://www.mnopedia.org/person/johnston-clarence-h-1859-1936>
- MPCA. (n.d.). *Construction and demolition waste*.
<https://www.pca.state.mn.us/waste/construction-and-demolition-waste>
- Municipal Association of South Carolina. (n.d.). *Economic Development Tools: Abandoned Building Credits*.
<https://www.masc.sc/Pages/newsroom/uptown/June-2019/Economic-Development-Tools-Abandoned-Buildings-Credits0529-4678.aspx>
- National Cancer Institute. (2021). *Asbestos Exposure and Cancer Risk*.
[https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/asbestos/asbestos-fact-sheet#:~:text=Asbestos%20has%20been%20classified%20as,3%2C%207%2C%208\).](https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/asbestos/asbestos-fact-sheet#:~:text=Asbestos%20has%20been%20classified%20as,3%2C%207%2C%208).)
- National Park Service. (2021). *Federal historic preservation tax incentives generated \$7 billion in GDP and 122,000 jobs in 2020* [Press Release].
<https://www.nps.gov/orgs/1207/htc-economic-report-2020.htm>

- National Park Service. (2012). *Historic Preservation Tax Incentives*. U.S. Department of the Interior. <https://www.nps.gov/tps/tax-incentives/taxdocs/about-tax-incentives-2012.pdf>
- National Trust for Historic Preservation. (n.d.). *Find Preservation Funding*. <https://forum.savingplaces.org/build/funding>
- Nifty Ideas From U of M's New Dairy Barn*. (1987). Folder, "Ben Pomeroy Student-Alumni Learning Center," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- Omega Environmental Firm & Remediation Services. (2020). *What is the difference between Phase I, Phase II and Phase III Environmental Site Assessments?* <https://www.omegaenv.com/environmental-consulting-firm-blog/what-is-the-difference-between-phase-i-phase-ii-and-phase-iii-environmental-assessments/>
- Place Economics. (2021). *Treasure in the Walls: Reclaiming Value Through Material Reuse in San Antonio*. City of San Antonio Office of Historic Preservation. <https://www.placeeconomics.com/resources/treasure-in-the-walls-reclaiming-value-through-material-reuse-in-san-antonio/>
- Pomeroy, Benjamin S.* (2017, December 14). College of Veterinary Medicine. Folder, "Pomeroy, Benjamin," Pomeroy-Benjamin-01, una573390, University Archives, University of Minnesota, Twin Cities. <http://purl.umn.edu/221758>
- Poss, P. (2008). Benjamin Sherwood Pomeroy. *American Association of Avian Pathologists*. <https://www.aaap.info/assets/documents/Bio%20-%20Pomeroy%20-%20Benjamin%20Sherwood.pdf>
- Preservation Connecticut. (n.d.). *Benefits of Preservation Designation*. <http://lhdct.org/handbook/benefits-of-preservation-designation1#:~:text=Cultural%20Welfare,a%20strong%20sense%20of%20place.>
- Ramsey/Washington Recycling & Energy. (2022). *Deconstruction Grants*. <https://recyclingandenergy.org/deconstruction/#:~:text=Funding%20available,that%20use%20deconstruction%2Fsalvage%20techniques>
- Randolph, T. (2005, February 17). Black Tradesman Helped Build Minnesota's State Capitol. *Minnesota Public Radio*. http://news.minnesota.publicradio.org/features/2005/02/21_randolph_blackcapitol/
- Seldman, N. (2011). Deconstruction As Community Development Tool. *BioCycle*, 52(4), 26. <https://www.biocycle.net/deconstruction-as-community-development-tool/>

- Skemp, A. (1999, June 30). U professor receives award in agriculture. *The Minnesota Daily*. Folder, "Pomeroy, Benjamin," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- State Historic Preservation Office. (n.d.). *Minnesota Historic Structure Rehabilitation Tax Credit*. <https://mn.gov/admin/shpo/incentives/state/>
- Novogradac. (n.d.). *State HTC Program Descriptions*. <https://www.novoco.com/resource-centers/historic-tax-credits/state-htcs/state-htc-program-descriptions>
- Vintage Millwork & Restoration. (2020). *The 4 Major Benefits of Historic Restoration and Preservation*. <https://vintagemillworkrestoration.com/blog/the-4-major-benefits-of-historic-restoration-and-preservation/>
- Tuck, B. & Foss, N. (2022). *Economic Impact of Projects Leveraged by the Minnesota Historic Rehabilitation Tax Credit: Fiscal Year 2021*. <https://extension.umn.edu/community-research/minnesota-historic-rehabilitation-tax-credit>
- United States Census Bureau (n.d.). Part I. - Growth and Geographic Distribution: 1790-1910. <https://www2.census.gov/prod2/decennial/documents/00480330ch02.pdf>
- University of Kansas Center for Community Health and Development. (n.d.). *Section 7: Encouraging Historic Preservation*. Community Toolbox. <https://ctb.ku.edu/en/table-of-contents/implement/physical-social-environment/historic-preservation/main>
- University of Minnesota. (2022). *Application Requirements for Demolition Permits*. <https://bcd.umn.edu/permit-applicationplan-review/application-requirements-demolition-permits#:~:text=An%20average%20time%20may%20vary,completeness%20of%20the%20plan%20submittals>.
- Wickler, A. (2007, February 21). Vet center to open on St. Paul campus. *The Minnesota Daily*. Folder, "Ben Pomeroy Student-Alumni Learning Center," Information files collection, ua01158, University Archives, University of Minnesota, Twin Cities.
- Wisconsin Historical Society. (n.d.). *Your Historic Building and Heritage Tourism*. <https://www.wisconsinhistory.org/Records/Article/CS4191>
- World Health Organization. (2017). *Mercury and Health*. <https://www.who.int/news-room/fact-sheets/detail/mercury-and-health#:~:text=Health%20>

0effects%20of%20mercury%20exposure&text=The%20inhalation%20of%20mercury%20vapour,induce%20kidney%20toxicity%20if%20ingested.

- Yala, A., Bowers, W., & Lovenstein, A. (2019). *The Impact of Construction Vibration on Adjacent Structures*. J.S. Held.
<https://jsheld.com/insights/articles/the-impact-of-construction-vibration-on-adjacent-structures#:~:text=before%20flexible%20components-,Vibration%20Analysis,construction%20and%20monitored%20during%20construction>
- Zhong, X., Hu, M., Deetman, S., Steubing, B., Lin, H. X., Hernandez, G. A., Harpprecht, C., Zhang, C., Tukker, A., & Behrens, P. (2021). Global greenhouse gas emissions from residential and commercial building materials and mitigation strategies to 2060. *Nature Communications*, 12(1), 1–10. <https://doi.org/10.1038/s41467-021-26212-z>
- Zou, C., Zhu, R., Tao, Z., Ouyang, D., & Chen, Y. (2020). Evaluation of Building Construction-Induced Noise and Vibration Impact on Residents. *Sustainability*, 12(4). <https://doi.org/10.3390/su12041579>

Appendices

Appendix A: New Construction Cost Estimation Resources

Listed below are additional resources for estimating the direct costs associated with new building construction.

- [RLB Intelligence Construction Cost Indicator](#)
- [2021 U.S. Commercial Construction Cost per Square Foot](#)
- [2022 U.S. Commercial Construction Cost per Square Foot](#)
- [Construction Cost Estimates for 2-3 Story U.S. College Classrooms](#)
- [Residential Construction Cost Calculator](#)

Appendix B: Demolition Cost Estimate

Calculations for the demolition quote were based on the following average costs for transportation, disposal, labor, and equipment.

Trucking costs around \$130-\$140 per hour including drivers' wages and fuel. A straight truck can haul about 14 cubic yards (CY) of debris in a single haul. Long trucks, also referred to as semi-trucks, can typically haul 20 to 22 CY in higher-sided steel end dumps (A. Ristrom, personal communications, March 18, 2022). The total cost associated with hauling will differ depending on the project, as the distance to the closest landfill and recycling plant that can accept the materials, their disposal or "tipping" rates, and the amount of debris generated will all depend on the specific project site and context.

Demolition debris disposal rates should be figured at roughly \$15/CY, and recycling rates for concrete rubble should be estimated at about \$6/CY based on the current market (A. Ristrom, personal communications, March 22, 2022). These rates do not include processing, loading or hauling the debris. Similarly to hauling, the exact values associated with debris disposal and recycling will vary depending on the project as the the closest accepting waste facility and their respective rates will change depending on the project site and scope. In some instances, it may be cheaper to truck the materials farther if a cheaper tipping rate is available at a greater distance. Alternatively, fluctuating or high fuel rates may drive up rates associated with trucking costs, making it more economical to pay a higher tipping fee for a disposal facility closer to the project site.

Labor and equipment required for the job were determined based on the volume of materials that needed to be wrecked, processed and loaded into trucks. A standard demolition size excavator, such as a CAT 336 which weighs roughly 80,000 lbs, costs about \$265/hour to fuel and operate (A. Ristrom, personal communications, March 18, 2022). Using this machine would also require a laborer on the ground to spray the demo area with water from a fire hose to control dust, assist in cleaning up the area with brooms and shovels, and keep an eye out for safety concerns or pedestrians that may wander too close to the active site. Employing this laborer adds another \$98/hour to the cost (A. Ristrom, personal communications, March 18, 2022). That means before materials are even transported from the site and disposed of, there is a direct cost of about \$365/hour for demolition, plus fees associated with mobilization, supervision, upfront pre-demo costs such as hazardous material abatement or encapsulation, etc.

Appendix C: Deconstruction Grant Resources

Listed below are additional resources for local, state and federal deconstruction tax incentives and grants.

- [Ramsey/Washington County Deconstruction Grant](#)
- [Hennepin County Deconstruction Grant](#)
- [Minnesota Redevelopment Grant Program](#)
- [U.S. EPA 2022 Healthy Communities Grant Program](#)
- [U.S. EPA Region 5 Sustainable Materials Management Grants](#)
- [U.S. Department of Housing and Urban Development Section 3 Grants](#)

Appendix D: Renovation Cost Estimate

In order to calculate the adjusted cost estimate with current pricing, the material quantity takeoffs were combined with the material unit prices from the 2019 Engineering News Record (ENR) Square Foot Costbook. The ENR unit costs reflect the 2019 pricing for the entire United States. ENR publishes a Construction Cost Index (CCI) to compare the average pricing of different years (Engineering News Record, n.d.). Additionally, ENR publishes a Metro Area Multiplier (MAM) to calculate the pricing for a specific location (Engineering News Record, 2018). To update the 2019 pricing to the current cost, the unit prices were multiplied by the ratio of the average 2019 CCI to the February 2022 ENR CCI. In the case of the Pomeroy Center, the CCI ratio was multiplied by the MAM for St. Paul, MN. The year and location multiplier calculations are listed below.

$$\text{Unit Cost Multiplier} = \frac{CCI_{\text{current year, 2022}}}{CCI_{\text{past year, 2019}}} * MAM_{\text{location, St. Paul}} = \frac{12683}{11281} * 1.12 = 1.26$$

For each material, the calculated quantity was multiplied by the 2019 unit cost and unit cost multiplier to get the total cost. The materials reused from the original animal barn were deducted from the total cost estimate as the materials were already in place onsite. By reusing a large portion of the existing exterior and interior structural framework, the new material and installation costs were smaller than if the building was built completely new. The cost for each material was combined with lump-sum estimates for portions of the project that were not calculated using unit pricing, including mechanical, plumbing, electrical, fire protection, site construction, furnishings, appliances, miscellaneous materials, the silo, general conditions, insurance, permits, and contingency. These are all portions of the renovation that the general contractor charged the University for but are not included in the analysis. Such costs were estimated based on a similar project, the Ramsey County Library located in Shoreview, MN, in which a full cost estimate was conducted. The total cost estimate also included the cost to clean up the original animal barn and demolish the existing interior finishes. The adjusted cost estimate is outlined below.

Material	Quantity	Unit of Measure	Unit Cost	Location and Year Multiplier	Total
CONCRETE					
Ceiling	33.0	CY	\$376.00	1.26	\$15,614.60
Slab	127.8	CY	\$242.25	1.26	\$39,572.34
Footings	7.5	CY	\$246.50	1.26	\$2,348.97
CMU/aggregates	758.6	SF	\$16.00	1.26	\$15,516.89
METAL					
3 5/8" metal studs	6497.5	SF	\$4.42	1.26	\$32,780.84
1 5/8" metal studs	972.2	SF	\$4.17	1.26	\$4,627.31
6" metal studs	858.4	SF	\$5.24	1.26	\$5,133.94
Stairs	1.0	LS	\$25,000.00	1.26	\$28,536.05
Remainder/composite metals	1.0	LS	\$17,000.00	1.26	\$19,404.52
Hollow metal doors	19.0	EA	\$2,225.00	1.26	\$48,254.46
WOOD					
Existing sloped roof deck	1777.0	SF	\$2.86	1.26	\$5,800.97
Flat roof	355.9	SF	\$2.71	1.26	\$1,101.05
2nd floor	1624.8	SF	\$4.69	1.26	\$8,698.14
Stained/painted wood (doors and detailing)	1435.3	SF	\$3.25	1.26	\$5,324.59
Plywood	26405.7	SF	\$2.50	1.26	\$75,351.44
Wood doors	26.0	EA	\$350.00	1.26	\$10,387.12
Aluminum clad wood doors	8.0	EA	\$500.00	1.26	\$4,565.77
ENCLOSURE					
Rigid board insulation	42008.4	SF	\$2.05	1.26	\$98,297.82
Batt insulation	12073.3	SF	\$1.34	1.26	\$18,466.50
Moisture barrier	5334.9	SF	\$3.96	1.26	\$24,114.34
Existing brick	4227.9	SF	\$13.69	1.26	\$66,066.61
Stucco	1107.0	SF	\$8.50	1.26	\$10,740.40
Windows	2423.5	SF	\$70.00	1.26	\$193,635.95
Asphalt roofing	8884.9	SF	\$2.26	1.26	\$22,920.01

Material	Quantity	Unit of Measure	Unit Cost	Location and Year Multiplier	Total
CONCRETE					
Ceiling	33.0	CY	\$376.00	1.26	\$15,614.60
Slab	127.8	CY	\$242.25	1.26	\$39,572.34
Footings	7.5	CY	\$246.50	1.26	\$2,348.97
CMU/aggregates	758.6	SF	\$16.00	1.26	\$15,516.89
METAL					
3 5/8" metal studs	6497.5	SF	\$4.42	1.26	\$32,780.84
1 5/8" metal studs	972.2	SF	\$4.17	1.26	\$4,627.31
6" metal studs	858.4	SF	\$5.24	1.26	\$5,133.94
INTERIOR FINISHES					
Gypsum board	35050.2	SF	\$1.55	1.26	\$62,012.05
Plaster	728.1	SF	\$10.50	1.26	\$8,726.38
Acoustic paneling	4540.1	SF	\$3.50	1.26	\$18,137.91
Carpet	8360.8	SF	\$4.50	1.26	\$42,945.16
Carpet padding	6738.5	SF	\$1.25	1.26	\$9,614.51
Resilient flooring	1014.0	SF	\$6.50	1.26	\$7,523.24
Tile	4166.7	SF	\$14.50	1.26	\$68,962.68
PLUMBING					
Toilets	12.0	EA	\$500.00	1.26	\$6,848.65
Sinks	11.0	EA	\$250.00	1.26	\$3,138.97
LUMP SUMS					
Mechanical and plumbing	1.0	LS	\$420,000.00		\$423,000.00
Electrical	1.0	LS	\$520,000.00		\$527,900.00
Fire protection	1.0	LS	\$45,000.00		\$45,300.00
Site construction and demolition	1.0	LS	\$200,000.00		\$200,000.00
Furnishings	1.0	LS	\$350,000.00		\$375,000.00
Appliances	1.0	LS	\$90,000.00		\$90,000.00
Miscellaneous materials	1.0	LS	\$775,000.00		\$825,000.00

Material	Quantity	Unit of Measure	Unit Cost	Location and Year Multiplier	Total
CONCRETE					
Ceiling	33.0	CY	\$376.00	1.26	\$15,614.60
Slab	127.8	CY	\$242.25	1.26	\$39,572.34
Footings	7.5	CY	\$246.50	1.26	\$2,348.97
CMU/aggregates	758.6	SF	\$16.00	1.26	\$15,516.89
METAL					
3 5/8" metal studs	6497.5	SF	\$4.42	1.26	\$32,780.84
1 5/8" metal studs	972.2	SF	\$4.17	1.26	\$4,627.31
6" metal studs	858.4	SF	\$5.24	1.26	\$5,133.94
Silo	1.0	LS	\$90,000.00		\$100,000.00
General Conditions	1.0	LS	\$546,000.00		\$546,000.00
SUBTOTAL					\$4,117,370.21
DEDUCT - Existing materials					\$71,867.58
MATERIALS TOTAL					\$4,045,502.63
Subcontractor Default Insurance (1% SDI)					\$39,906.10
General Liability Insurance (1.25%)					\$49,882.63
Permits (0.9%)					\$359,154.93
Performance/Payment Bond (0.75%)					\$29,929.58
A/E Design and Reimbursables (6.6%)					\$263,380.28
D/B Contingency (6.0%)					\$239,436.62
OH/Profit (3.2%)					\$127,699.53
PROJECT TOTAL					\$7,113,751.38

Appendix E: Historic Preservation Financial Resources

Listed below are additional resources for local, state and federal historic preservation tax incentives and grants.

- [Federal Historic Preservation Tax Incentives program](#)
- [Novogradac's Historic Tax Credit Resources by state](#)
- [Minnesota's Historic Rehabilitation Tax Credit](#)
- [South Carolina's Abandoned Building Tax Credit](#)
- [Minnesota Historical Society's Minnesota Historical and Cultural Heritage Grants](#)
- [National Trust for Historic Preservation](#)
- [The Kinsman Foundation](#)