LIFE CYCLE ASSESSMENT FRAMEWORK FOR DEMOLITION AND DECONSTRUCTION OF BUILDINGS

by

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Abstract

Widespread structural abandonment can create an atmosphere of lowered confidence in a community, by decreasing property values, discouraging habitation, and driving away future investment opportunities. The process of demolition is a widely prevalent practice for the rehabilitation of abandoned properties by governmental agencies, such as county land banks. Despite its mechanized speed and efficiency, the process does not aim to be a sustainable solution to the problem of structural abandonment in the long run. Moreover, the process generates a large amount of debris, which causes waste management issues and heavily burdens the landfills. Deconstruction is an alternative strategy that proposes reusing, repurposing and recycling building material salvaged from abandoned properties, and thus, contributes to controlling the amount of waste that finally gets hauled into landfills. The process, being largely manual in nature and requiring skill-based training, also proves to be an avenue for local employment and means of community engagement.

This research aims to understand the various impacts of the processes of demolition and deconstruction from a lifecycle perspective across the dimensions of environment, economy, and society. This is done with the aid of a Life Cycle Sustainability Assessment (LCSA) framework, which effectively collates the loadings of 14 identified impact categories of demolition and deconstruction projects. Conventionally, Life Cycle Assessment (LCA) is a standardized technique that is used to examine potential environmental impacts associated with all the stages over the life of a product or a process - from raw material extraction through its final disposal. However, the LCSA methodology has the potential to integrate and bring together hybrid LCA approaches, input-output models, impact categories and characterization factors that measure the consequential effects of applying either approaches of demolition or deconstruction to address the problem of structural abandonment and removal of buildings in the U.S. The framework thereby entails careful development with a focus on the end-of-life phase of abandoned residential properties by incorporating the expertise and acumen of stakeholders in the industry, and reports the implications of its application in the real-world scenario using case studies, such that it can be utilized as a robust and valuable decision-support tool for policy-makers and stakeholders by comparing a relatively novel practice of deconstruction with traditional demolition in the long run.

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Domicology, the study of policies, practices, and consequences of structural abandonment, has played a large part in my graduate school experience, and I would like to extend my deepest gratitude towards the research facilities at Michigan State University and the Center for Community and Economic Development, without which I would never have been introduced to the critical appreciation of the field, in theory and in practice. This research report was made possible by the encouragement and generosity of several individuals, who in one way or another contributed to the acceleration of my efforts through the duration and completion of my work.

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Thank you.

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CHAPTER 1
1.0. INTRODUCTION

1.1. OVERVIEW

Ever since the dawn of human civilization, the definition of a space for shelter has been prone to constant change. Starting from vernacular huts built in the Neolithic Age, to the classical grandeur of the Renaissance and Middle Ages, to minimalistic tiny houses in what is described as the Fourth Industrial Revolution - through periods of tremendous growth and squalid decline - building construction has come a full circle today. Furthermore, with the rise of urban populations, building life spans have started to shrink as consumer requirements in terms of design, construction, services, and functions keep evolving. Such rapid economic development must allow for the expansion of the built environment at the same pace; older structures must make way for the new. However, this fast change in demographic and societal patterns also results in a growing concern about sustainability as well as the depletion of energy and natural resources for future generations.

At present, even though the construction industry is driven by the difficulty of meeting the demand for new buildings, rather than by the lack thereof, society grapples with the issue of deterioration of existing properties. Older buildings, often found in a state of abandonment or deemed inappropriate for continued use, face limited options as they reach the end of their life. These options are typically demolition or adaptive reuse. Moreover, with construction costs on the rise, society cannot afford to reconstruct the built environment with every generation (Petruzzelli, 2008). Establishing an alternative approach to cycling buildings and construction materials, such as deconstruction, which promotes the recycling and reuse of existing building materials and components, can thus prove to be beneficial in the long run.

This report aims to explore and discuss a sustainable solution for the problem of structural abandonment in the United States (U.S.) by developing a comparative life-cycle impacts framework, focused on the processes of deconstruction and demolition and their impacts across the environment, economy and society.

1.1.1. Structural Abandonment in the U.S.

Construction is frequently sought to be an indicator of the economy because of its significant contribution to gross domestic product (GDP) and total employment of a country. It also bolsters the manufacturing industry by creating a market for finished goods and products, and reflects characteristics of overall business cycles (Organization for Economic Cooperation and Development, 2001). Structural abandonment of buildings is hence viewed as a dismal aftermath of the decline of an economy, which could have been caused by a host of different reasons.

Historically, several cities that used to constitute the industrial heartland of the U.S. were subject to widespread economic distress during the mid-20th century. A variety of interrelated factors, namely the decentralization of economic activity that accompanied the foundering of the U.S. steel and coal sectors, globalization of traditionally domestic sectors, increased automation, and the transfer of manufacturing units to the south and the west, caused desolate and fragmented socio-economic conditions in these urban communities. Furthermore, the middle-class population was seen to migrate away from the city centers and towards the suburbs in cities including New York, Baltimore, Detroit, and Cleveland. In fact, during the period 1970 to 1980, it was found that 90 out of 153 large cities with greater than 100,000 people in the U.S. experienced population loss due to increased preference of low-density living (Bradbury et al., 1982).

Deindustrialization also drained cities' tax bases, and municipal costs eventually escalated as the working population left, which led to limited social and economic opportunities and isolation of poverty-stricken communities (Lamore et al., 2013). This pattern of 'walk-away' abandonment resulted in the disfigurement of the urban landscape that was particularly apparent in the Midwest. Popularly referred to as the ‘Rust Belt’ and primarily stationed around the Great Lakes, this region of the U.S. possesses a significant number of ghost towns, blighted communities, and vacant neighborhoods as a result of industrial ruination, loss of jobs in the heavy-industry sector, and depopulation. Other places with a high rate of abandonment include cities in the Northern Plains of Nebraska, Montana, North Dakota and South Dakota, which faced railroad abandonment, as highways became the popular mode of transport in the U.S after the 1950s.

The current extent of structural abandonment is also a major consequence of the Great Recession that occurred during the late 2000s and early 2010s. The period was marked by unemployment and loss of sources of income of a vast majority of the population, which induced decreasing home values and increasing levels of foreclosures and bankruptcies (Kingsley et al., 2009). The mortgage crisis of 2010 was also a contributing factor to the abandonment problem, wherein despite poor credit and a high probability of defaulting on their payments, homeowners were given easy access to mortgages, often in amounts that exceeded the market value of the house at the time the first payment was due. The demand for housing grew significantly over a short period of time, and set the tone for higher prices and mortgage payments that could not be paid off by the people affected by the recent recession, ultimately leading to more abandonment, housing vacancies, and blighted neighborhoods across the U.S. (Michigan State University and Center for Community and Economic Development, 2016).

Abandoned properties that went from being productively used to a state of disuse are not restricted to metropolitan centers, but also extend to outlying suburbs and rural areas. Moreover, abandonment and blight do not stay restricted to a particular type of building; residential, commercial, and industrial properties are all subject to structural abandonment, which ranges across buildings of differing sizes, designs and functions.

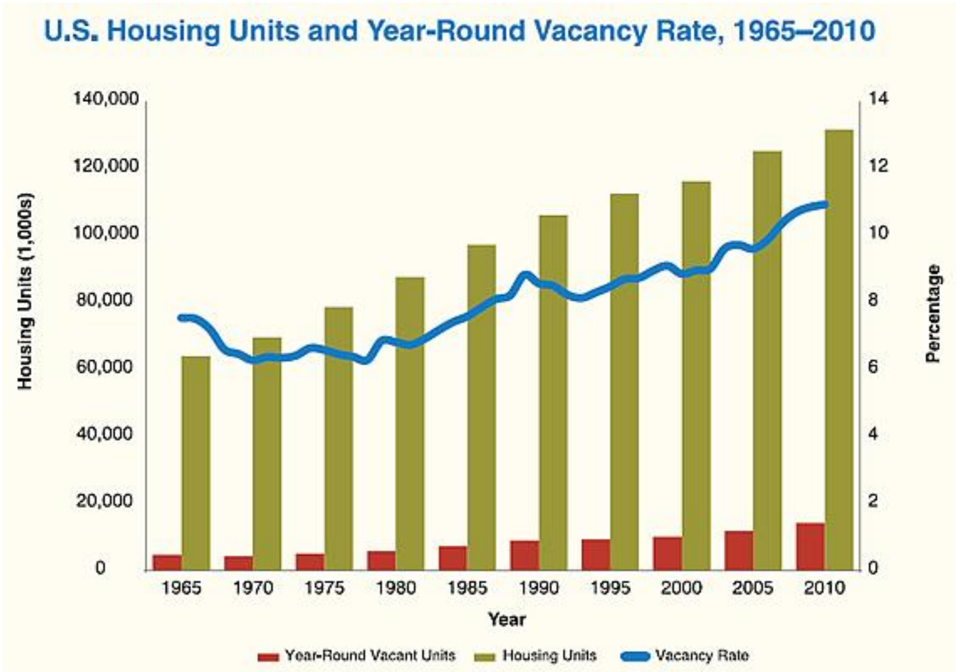
The Office of Policy Development and Research of the U.S. Department of Housing and Urban Development (HUD) states, “derelict houses, dormant factories and moribund strip malls are among the most visible outward signs of a community’s reversing fortunes”

(HUD, 2014). With the decline of local markets and commercial activities, cities eventually get littered with derelict storefronts and unoccupied retail spaces. Abandoned industrial properties are often left contaminated with hazardous wastes from their previously polluting operations, in scales as large as the automotive plants in Michigan, Ohio and Indiana, to smaller dry-cleaning and gas station establishments. These are termed as ‘brownfields,’ and there are approximately 500,000 such sites in the U.S. today (HUD, 2014). Studies have found that property values of sites within a 1.5-mile radius of a brownfield site are 10% lower than the value of similar properties that are located beyond the 1.5-mile radius (Paul, 2008; Lamore et al., 2013). Thus, more than just being an eyesore and posing an issue for public safety, abandoned industrial and commercial properties present serious environmental and socio-economic threat to surrounding, non-abandoned properties in a community as well (Lamore et al., 2013).

Residential abandonment does not have a universal definition, which makes it a difficult phenomenon to measure accurately. When considered in terms of rental and homeowner ‘vacancy’ rates, a private property may be vacant for a number of different reasons. For example, a vacation home might be vacant for the most part of a year, but a home for rent or sale might be vacant for a much shorter period of time (HUD, 2014). The U.S. Census Bureau uses an ‘Other Vacant’ category to calculate the volume of abandonment, which refers to properties that are unoccupied year round, not for sale, not for rent, and are not used as seasonal units, and are therefore considered to be abandoned (U.S. Census Bureau, 2012).

Figure 1.1 exhibits the growth in the national vacancy rate of residential housing units in the U.S. from 1965 to 2010, which increased from 7% of the total housing stock in the late 1970s to 11% of the total housing stock in 2010 (U.S. Census Bureau, 2012; HUD, 2014). The Joint Center for Housing Studies of Harvard University also reported a record high of 7.4 million vacant homes in 2012, following which the housing market in the U.S. showed signs of revival (Joint Center for Housing Studies, 2013).

Figure 1.1: Vacancy Rate of Housing Units in the U.S.



(Source: U.S. HUD, 2014; U.S. Census Bureau, 2012)

Most cities that were affected by decline, depopulation, and disinvestment exhibit characteristic symptoms of not having fared well, such as depletion of tax revenues, crumbling infrastructure, and dwindling property values. In turn, these predicaments give rise to private property abandonment, foreclosures, unemployment, poverty, vandalism, crime, urban decay, and blight, and pose an alarming threat to societal and economic welfare. Table 1.1 exhibits the salient effect of foreclosures on crime and unemployment in cities in Michigan, which was one of the states most affected by urban decline (HUD, 2008; U.S Census Bureau, 2008; Lamore et al., 2013).

Table 1.1: Effect of Foreclosures on Crime and Unemployment

City	Foreclosure Rates 2008	Crime Index per 100,000 inhabitants 2008	Unemployment Rate 16 year and older 2008
Detroit	16.0%	1,832	20.4%
Flint	12.8%	5,530	18.5%
Lansing	9.3%	2,938	9.6%
Grand Rapids	8.0%	3,050	9.4%
Ann Arbor	4.1%	1,241	6.0%

Source: (USA.com, 2008), (US Department of Housing and Urban Development, 2008), (United States Census Bureau, 2008)

Studies have also found that deteriorated neighborhood conditions such as dilapidated housing, defaced buildings, and unkempt streets lower the quality of life of the local residents, and result in increasing dissatisfaction and decreasing desirability of the neighborhood (Dahmann, 1985). The 'broken windows' theory presented by James Q. Wilson and George L. Kelling in 1982 supports this notion by stating that 'broken windows' (i.e., abandonment and vandalism in the physical environment) lead to more 'windows being broken' and ultimately result in social disorder (Wilson and Kelling, 1989).

Furthermore, the problem of abandonment does not stay limited to eroding the fabric of communities, but creates severe implications for the execution of urban renewal initiatives as well. For revitalization to take place, old and dilapidated cityscapes that stand in the way of new construction must be cleared out. The U.S. HUD and the U.S. Department of Treasury have consistently funded programs for community revitalization and blight prevention by using demolition to achieve these goals (MSU CCED, 2016). The Pollution Prevention Resources Exchange estimates that the U.S. demolishes 245,000 residential and 44,000 commercial structures each year (Guy and Gibeau, 2003). The full cost of demolishing an average residential property can be approximated to be anywhere from $4,800 to $12,585, depending upon the size, archetype, and location of the building (U.S. Government Accountability Office, 2011; Genesee County Land Bank, 2015; Zahir et al., 2016; MSU and CCED, 2016). Specialized abatement of hazardous and toxic material such as lead and asbestos from the abandoned properties adds to these costs.

Moreover, according to the US. Census Bureau, there were an estimated 691,792 vacant housing units in Michigan, out of a total housing stock of 4.5 million units in 2015 (U.S. Census Bureau, 2015). Of these vacant units, 237,107 are in the 'Other Vacant' category, which implies that approximately 6% of the total number of housing units is considered abandoned. Based on demolition cost measures and data from the U.S. Census Bureau, the removal of all of the currently estimated abandoned residential properties in Michigan could cost approximately $2.5 billion. With more than 7.4 million vacant properties in the country, the costs of removal are estimated at $78 billion (JCHS, 2013). Federal, state and local governments across the U.S. face this enormous financial burden today, in addition to the direct revenue loss and societal dissatisfaction associated with structural abandonment.

1.1.2. Demolition

Demolition, using heavy mechanical equipment, has been the conventional method of removal and disposal of buildings once they reach the end of their serviceable life (Zahir et al., 2016). The process is quick, uncomplicated, and relatively inexpensive, but creates a substantial amount of rubble and debris. The Environmental Protection Agency (EPA) estimates that 136 million tons of building-related Construction and Demolition (C&D) waste is generated in the U.S every year, of which only 20-40% is recycled (EPA, 2010). The rest is disposed in landfills without proper segregation and treatment. In 2014, the amount of C&D waste generated increased to 534 million tons as a result of greater per capita levels of resource consumption corresponding with continued development (EPA, 2014).

Further, approximately 92% of the C&D waste that goes into landfills is considered to come from renovation and demolition practices (Guy and Gibeau, 2003). This leads not only to landfill depletion, but also to surface and groundwater contamination and uncontrolled emissions into the air. Harmful gases such as carbon dioxide, hydrogen sulfide, and methane also get released, which create smog and contribute to global climate change. Apart from the waste generation, heavy equipment such as hydraulic excavators and bulldozers, which are used to demolish structures, also create emissions in the form of particulate matter (PM), hydrocarbons (HC), nitrogen oxide (NO_x), oxides of sulfur (SO_x), and carbon monoxide (CO). Demolition techniques thus adversely affect the environment, and pose a threat to the health and safety of communities nearby.

Adding to these concerns is the fact that many municipalities do not have regulations set in place for addressing C&D waste disposal and recycling, even though it is an ongoing process. With waste getting continuously generated and dumped, many of the landfills in the U.S. are soon reaching their maximum holding capacity (MSU CCED, 2016). For example, in a state like Michigan that has comparatively lower landfill tipping fees, several counties are running out of landfill space for C&D waste and municipal solid waste (MSW). In 2014, the Michigan Department of Environmental Quality (DEQ) stated that Michigan's landfills have lesser than 28 years of remaining disposal capacity (Anders, 2014; MSU and CCED, 2016). Again, due to the dearth of appropriate recycling and reuse of salvaged C&D material from demolished buildings, raw material extraction and virgin mining of new construction material become necessary, and in turn cause harm to the environment in the form of fossil fuel depletion, soil erosion, desertification, habitat alteration etc.

Consequently, demolition is said to change assets into liabilities by turning buildings into demolition debris, and hence not meeting long-term sustainability goals when confronting the problem of structural abandonment (Leigh and Patterson, 2006). In order to overcome these disadvantages of demolition, the process of deconstruction is introduced wherein the building removal practices encourage the reuse and recycling of building materials, and do not contribute to the exhaustion of landfill space, energy and other resources.

1.1.3. Deconstruction

Deconstruction is an alternative strategy used to remove abandoned buildings, which proposes to reduce the harmful and wasteful impacts of demolition on the environment.

Often considered as ‘construction in reverse,’ the process involves selective dismantling, disassembly, recovery, and removal of building materials from a structure in order to make maximum use of recycled materials (HUD, 2000). Recycling proves its viability by reducing manufacturing costs for new products and promoting the judicious use of what already exists. In this regard, reuse is always the most preferred outcome because reemploying materials recovered from C&D sites in the same or related capacity of their original application requires the consumption of lesser energy and raw materials than any other viable waste management option (Guy and Gibeau, 2003; United States Green Building Council, 2016). Deconstruction thus reduces the need for extraction of raw materials for new construction, conserves the energy and natural resources used in the manufacturing of new building material, prevents environmental pollution by diverting waste, and increases the longevity of landfills.

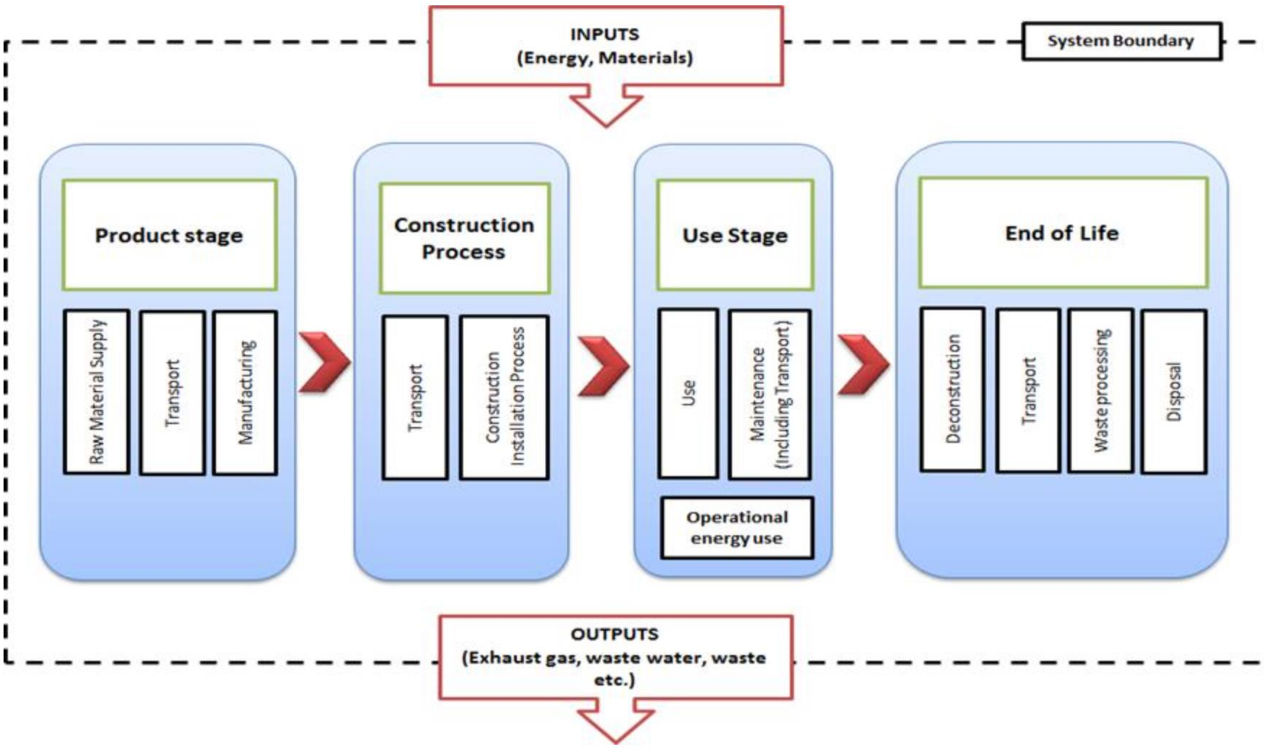
Furthermore, careful dismantling, disassembly, and recovery of building materials such as wood, brick, concrete, and drywall from a structure require a highly skilled and labor-intensive procedure. Deconstruction has the powerful potential to support workforce training, create new jobs, foster small businesses, and promote historic preservation and local markets for recycled C&D material, and thereby encourage the growth of economic opportunities in disadvantaged and blighted communities (Leigh and Patterson, 2006). By creating a sense of self-reliance in such communities, social benefits such as better community-building capacity, improved quality of life and overall neighborhood satisfaction can also be brought about. In addition to promoting the reuse and recycling of salvaged building materials from abandoned properties, extending the useful life of the building materials, and protecting the natural environment, deconstruction introduces a new dimension to sustainable development and urban revitalization by factoring in impacts across the economy and society as well.

The practice of deconstruction is considered to be 'green' as it aims to harvest constituent building materials and components and give them a new life, when the building itself has reached the end of its useful life. Despite requiring more time and labor to be employed as compared to demolition, deconstruction ensures that the salvaged materials are at least recycled to take the form of valuable inputs for other materials, resulting in their longer lifespans. For example, concrete blocks can be crushed and reused as road base and asphalt shingles can be ground and incorporated into the hot-mix asphalt manufacturing process (EPA, 2008). However, in practice, deconstruction is perceived to be more expensive, difficult to apply across the unique characteristics of buildings, and more complex in terms of stakeholders' decisions and planning efforts. As a result, demolition is often preferred over deconstruction by many owners and contractors (Zahir et al., 2016). Furthermore, not all buildings are fit to be deconstructed. Buildings constructed after 1950 are generally less suitable for salvage recovery, as they do not contain the volume of high quality structural and architectural building material as buildings constructed prior to 1950 did (Zahir et al., 2016). In order to adopt this improved practice and promote sustainability in the long run, it thus becomes necessary to implement a 'cradle-to-grave' Life-Cycle Assessment (LCA) that can assess and identify the benefits of deconstruction across the environment, economy and society, over the entirety of the process.

1.1.4. Life-Cycle Assessment and Sustainable Life-Cycle Assessment

Conventionally, an LCA consists of a standardized technique that is used to examine potential environmental impacts associated with all the stages over the life of a product or a process - from raw material extraction through building materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling (Singh et al., 2011). In the construction sector, previous studies have often quantified the input and output 'loadings' (emissions to air, water and land) through upstream stages, such as material manufacturing and on-site construction, to assess their environmental effects (Treloar et al., 2000; Sharrard et al., 2007; Bilec et al., 2010; Hossaini et al., 2015). Figure 1.2 exhibits the general methodology followed while conducting a process-based LCA of a building by focusing on the different processes the building is subject to over its life stages (FoamBuild, 2016; USGBC, 2016).

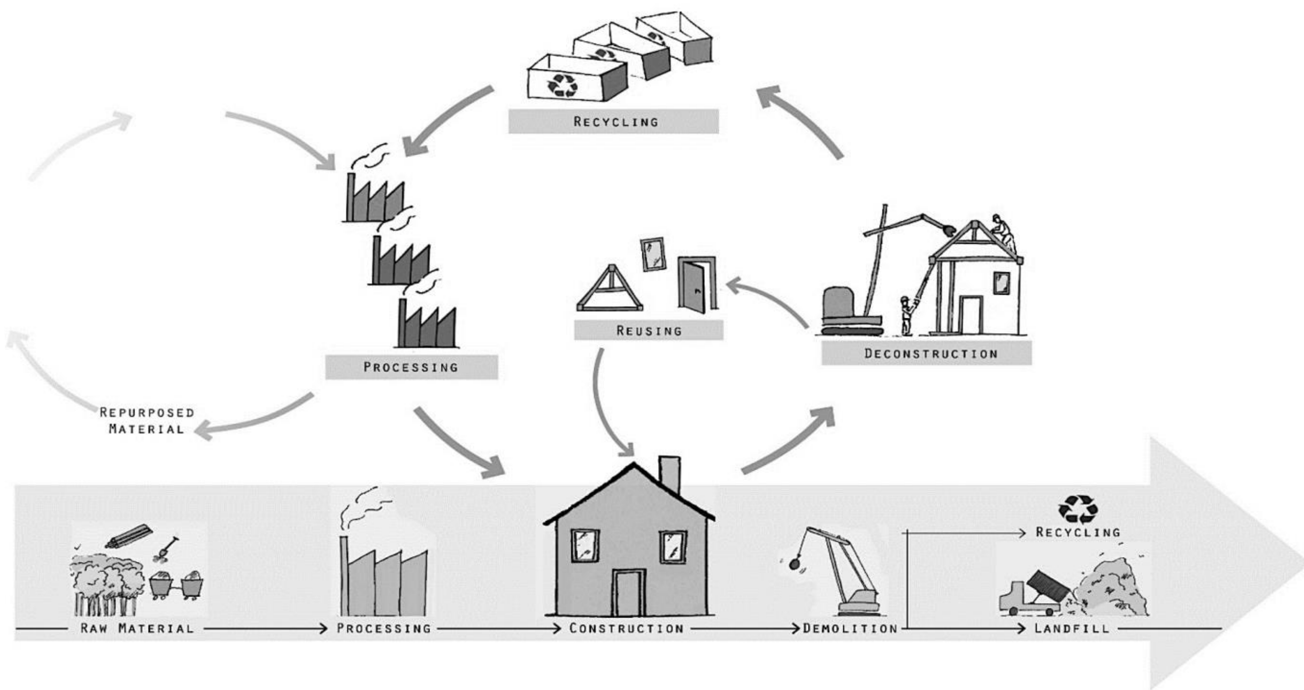
Figure 1.2: Process-based LCA for a building



(Source: FoamBuild, 2016; USGBC, 2016)

Demolition and deconstruction processes, like other mechanical processes, have a life cycle. Thus, there is a crucial requirement to effectively collate their impacts on the environment by means of an LCA, prior to relying on them to reduce the problems of blight and structural abandonment. Figure 1.3 illustrates how deconstruction closes the loop of material and resource use with reuse and recycling, as compared to the linear options presented by demolition (Lamore, 2016).

Figure 1.3: Deconstruction and Demolition in Building Life Cycle



(Source: Lamore, 2016)

In this context, it is worth mentioning the parameters and principles that expound the concept of sustainability. The Brundtland Report, released by the United Nations World Commission on Environment and Development, defines 'sustainable development' as the process that strives to meet the needs of the present without compromising on the ability of future generations to meet their own needs. The report proceeds to expand upon the three underlying dimensions that describe the complex scheme of sustainability - environment, economy and society (Brundtland Commission, 1987). Despite the high degree of uncertainty involved with the other variables, researchers working with LCA have realized that it is not enough to analyze the effect of the product or process on the environment alone (United Nations Environment Program, 2009; Singh et al., 2011). In the recent past, many LCA models have tried to assimilate this multi-criteria definition of sustainability by incorporating economic and ecological models with social theories in order to address dynamic systems, in the form of a sustainable LCA, known as the Life

Cycle Sustainability Assessment framework (LCSA) (Hunkeler and Rebitzer, 2005; Zamagni, 2012; Hossaini et al., 2015).

An LCSA is a transdisciplinary framework that acknowledges the impacts of the product or the process on the environment, economy as well as society by encompassing a system-wide analysis to understand the positive and negative outcomes across its lifecycle. Hence, with regard to an end-of-life or downstream phase, an LCSA model has the potential to integrate and bring together hybrid LCA approaches, input-output models, impact categories and characterization factors that measure the consequential effects of applying a demolition or deconstruction process to address the problem of structural abandonment and removal of buildings in the U.S. (Singh et al., 2011; Zamagni, 2012; Hossaini et al., 2015).

LCSA frameworks are still evolving and facing challenges in the construction sector due to the variety of decisions that need to be made with regard to their adoption, and the changing interests of the involved decision-makers (UNEP, 2009). The flexibility of the tool to be able to accommodate the wishes of different types of stakeholders such as architects, demolition contractors, urban planners, property developers, realtors, new buyers and old residents, is a prerequisite to it becoming standard industry practice (Singh et al., 2011). Here, an LCSA of demolition and deconstruction processes thereby entails careful design and development, such that it can be utilized as a robust and valuable decision-support tool for policy-makers and stakeholders by comparing a relatively novel practice with the traditional one (Urie and Dagg, 2004).

1.2. NEED STATEMENT AND RESEARCH QUESTION

Widespread structural abandonment can unfortunately create an atmosphere of lowered confidence in a community. It can bring about a decrease in property values of surrounding areas, discourage habitation, drive away future investment opportunities, and ultimately lead to more structural abandonment (Downs, 2010). In order to logically implement regeneration and renewal in communities that have already been subject to abandonment, existing vacant and abandoned sites must first be eliminated. In the past, demolition has been the conventional technique that is used to facilitate this clearing away, and despite its mechanized speed and efficiency, the technique does not aim to be a sustainable solution to the problem of structural abandonment in the long run. It generates a significant amount of waste in the form of C&D debris and places a large burden on landfills.

Deconstruction is an alternative strategy that proposes to reduce the harmful and wasteful impacts of demolition. By reusing, repurposing, and recycling building material salvaged from abandoned properties, the process contributes to controlling the amount of waste that finally gets hauled into landfills. Moreover, it also has the potential to foster employment and entrepreneurial opportunities, and instill a sense of identity and belongingness towards the neighborhood. However, when posed with the question of redevelopment and revitalization, it is critical to be able to balance out the environmental, economic and social interests of the community (Leigh and Patterson, 2006).

With the fast pace of urbanization and growth in the construction industry, solving the looming problem of structural abandonment requires an informed decision to be made. Although the benefits of deconstruction over demolition are well known, there is still a vital uncertainty associated with the adoption of the more sustainable technique. This research aims to understand both processes from a life cycle perspective, quantify and evaluate their different aspects that impact the environment, economy, and society by means of developing an LCSA framework, and consequently create a decision-support tool for future selection of demolition and deconstruction techniques.

1.3. RESEARCH GOALS AND OBJECTIVES

As discussed previously, this report seeks to find a sustainable solution to the problem of widespread abandonment and blight in American communities by contrasting the practice of deconstruction with demolition. An LCSA framework is created to identify and provide measures for the various impact categories of both demolition and deconstruction processes across facets of the environment, economy and society. To pursue the focus of the study, this report considers the following objectives and methods:

Objective 1: Analyze the practices of demolition and deconstruction.

- Literature Review: The entire processes of demolition and deconstruction are to be comprehensively compiled and studied by reviewing relevant works of literature, such as published journal articles, research papers, reports, and existing case studies.

Objective 2: Review the implementation of process-based and hybrid LCA models in the construction industry, and understand the LCSA of a process.

- Literature Review: Suitable process-based LCA models corresponding to the building construction process are to be obtained and reviewed in order to develop an impact assessment framework for demolition and deconstruction processes. The methodology of implementing an LCSA for a process is also to be studied by means of understanding present-day approaches that consider impacts over the environment, economy and society.
- Information Analysis: Using information collected from Objective 1, demolition and deconstruction processes are to be identified and analyzed for pertinent environmental, economic, and social impact categories, and their associated input and output loadings.

Objective 3: Create the LCSA framework.

- Information Analysis: The impact categories of demolition and deconstruction from the review of literature are to be amalgamated and illustrated into a comparative, transdisciplinary LCSA framework following an analytical, hierarchical order.

- Industry Survey and Interviews: The relative importance of each category across the environment, economy, and society for both demolition and deconstruction are to be indicated by utilizing the Multi-Criteria Decision Analysis (MCDA) and Analytic Hierarchical Process (AHP) with inputs from primary stakeholders and experts in the industry. This will help the framework function as a decision-support tool to help assess the advantages and disadvantages relating to the adoption of either process in a complete manner.

Objective 4: Test the LCSA framework.

- Case Study Analysis: By applying the LCSA framework to a case study, the overall effects of both demolition and deconstruction are to be appraised. This will exemplify and evaluate the more sustainable process to adopt in a real-world scenario.

1.4. SCOPE AND LIMITATIONS

Since the absence of universal definitions of vacancy and abandonment complicates efforts to determine the number of abandoned properties nationally, the scope of this report is limited to residential property abandonment and demolition and deconstruction processes in the distressed urban communities of Michigan.

The proposed LCSA will be process-based and serve the purpose of analyzing the extent of environmental, economic, and social impacts across the processes of demolition and deconstruction, by staying restricted to the building dismantling and building disposal phases only. The report will also attempt to determine the loadings for the valuation and measurement of impacts across various categories of the environment, economy and society.

Moreover, the ramifications as a result of the end-of-life stage operations of a building will remain confined to C&D waste generation and landfilling issues. The report will *not* include the following aspects:

- Analysis of the end-of-life impacts associated with the recovered building products and components. This happens to be within the context of a product-based LCSA of the salvaged materials and relates to their reuse and repurposing, and material and energy flows in their recycling/reprocessing activities.
- Considerations of what occurs down the C&D waste stream after demolition and deconstruction have been carried out - the supply and value chains and market dynamics for salvaged materials, for instance.

1.5. CONCLUSION

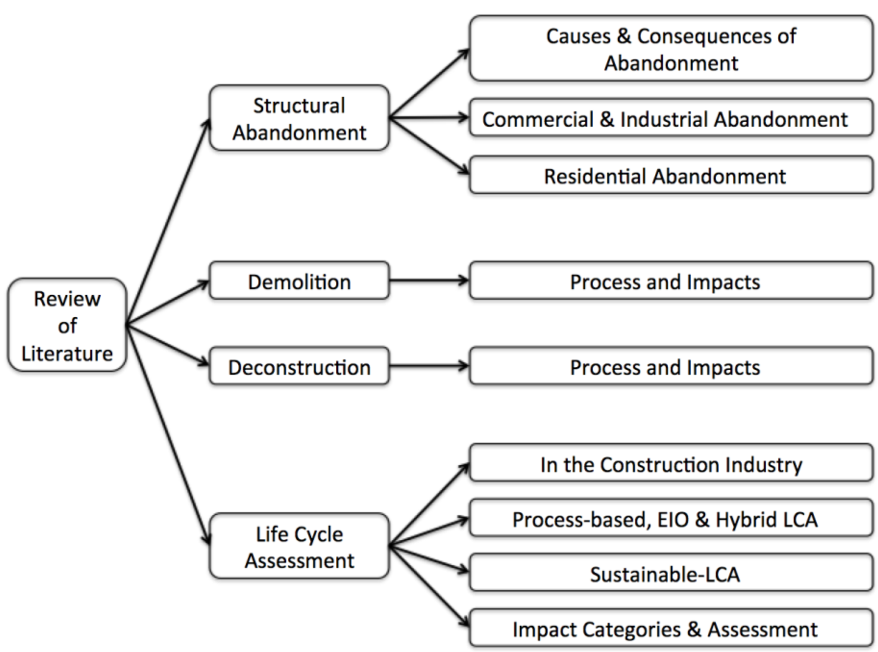
This chapter gives an overview of the widespread problem of structural abandonment in the U.S., its numerous causes and consequences, and the pressing need of a sustainable solution. An assessment of the current conditions that influence the selection of demolition and deconstruction processes is undertaken, and the merits and demerits associated with them are evaluated. Moreover, to validate the selection of either demolition or deconstruction, the dynamic of an LCSA framework is proposed, that will help identify various impact categories of the aforementioned processes across the environment, economy and society. The study thus aims to serve as a holistic decision-making tool for possible redevelopment and urban renewal initiatives in the future.

CHAPTER 2
2.0. REVIEW OF LITERATURE

2.1. OVERVIEW

This chapter entails an extensive study of literature sources to provide an overview of the three broad topics that have been considered for the research. First, the problem of structural abandonment in the U.S. is presented, based upon the different typologies and conditions observed in the commercial, industrial and residential sectors. Second, the various approaches and practices employed in demolition and deconstruction processes are analyzed to identify their potential impacts across the environment, economy and society. Lastly, a pertinent review of Life Cycle Assessment (LCA) models utilized in the construction industry is done, taking into consideration the significance of sustainability over the end-of-life phase of buildings, by assessing the impacts corresponding to the proposed methods used to address their disposal. Figure 2.1 represents an understanding of the structure of this chapter.

Figure 2.1: Outline of Review of Literature



2.2. STRUCTURAL ABANDONMENT IN THE U.S.

Structural abandonment of properties and urban blight are complex and dynamic phenomena, that usually bring about a myriad of harmful impacts on the landscape and the life cycle of the neighborhoods and communities they pervade. Vacancy and abandonment, however, are not happenstance. They are the result of a series of powerful institutional decisions, uneven distribution of city services, consequences of deindustrialization, suburban investments, depopulation, and in the recent past, the widespread mortgage foreclosure crisis.

2.2.1. Causes and Consequences of Abandonment

The Vacant Properties Research Network (VPRN), a project of the Metropolitan Institute at Virginia Tech, states that historically, 'blight' was often perceived as an “unsanitary and offensive pathogen that could spread across cities like disease” (VPRN, 2015). In addition to displaying issues related to public health and moral well-being, American cities affected by urban decline and structural abandonment in the mid-20th century were found to be characterized by mass disinvestment, stalled economic growth, poverty, unemployment, and poor housing infrastructure.

2.2.1.1. Deindustrialization

A major factor that caused this squalid state was the devastating redundancy of the once-powerful industrial and manufacturing sector in the Northeast and Midwest. Marked by abundant infrastructure and proximity to the Great Lakes, this region was previously known as the 'Industrial Heartland' of the U.S. in the late-19th century, and was home to the auto, steel, rubber, agricultural machinery, and consumer goods industries (High, 2003). This led to the development of great manufacturing cities such as Chicago, Buffalo, Detroit, Milwaukee, Gary, Pittsburgh, and Cleveland among others, in the legendary industrial 'boom' of the early-20th century. However, in the 1960s, manufacturing activity relocated from the traditional 'Industrial Belt' towards the southern and western United States, and shifted out of larger metropolitan areas to smaller metropolitan and rural areas (Beeson, 1986).

This occurred because of the amalgamation of a host of circumstances that contributed to the transformation of the landscape of the American industry. Labor costs in the Southeast were cheaper, and hence, more attractive than the skill-based high wages prevalent in the North. Moreover, increased automation in steel and coal industrial processes resulted in a decreasing need of labor in manufacturing steel products, and a spike in layoffs and loss of jobs in the sector. Around the same time, American businesses also experienced a rise in globalization due to the liberalization of foreign trade policies (Beeson, 1986).

Furthermore, during the period 1959 to 1978, manufacturing employment rates in standard Metropolitan Statistical Areas (MSAs) drastically fell by 8% as compared with a national growth rate of 23% (Beeson, 1986). By the year 1982, 12 million Americans, almost 10.8% of the national workforce, were unemployed. Michigan and Ohio were ravaged by recession due to the decline of the auto industry, with official unemployment rates going up to 17.2% and 14.2% respectively (High, 2003). In fact, between 1969 and 1996, manufacturing employment in the industrial states decreased by 32.9% and resulted in severe depopulation and dislocations across its once-booming metropolises (Kahn, 1999). Over a period of time, these areas began to be typically characterized by declining productivity, old and aging capital stock, and deteriorating infrastructure due to outdated transportation and communication technologies. The region spanning from Milwaukee and Chicago in the west to Buffalo and Pittsburg in the east was coined as the 'Rust Belt', and was said to represent the spatial distribution of the decline of the heavy industry in the U.S.

2.2.1.2. Suburbanization

The ‘White Flight’ phenomenon also plagued American cities and caused them to fall prey to disrepair and desolation in the late 1960s and early 1970s. Middle-class white people migrated from cities like New York City, Baltimore, Detroit, and Cleveland and moved towards the suburban regions, as many black Americans and European immigrants migrated to the metropolitan urban areas. More than 445,000 whites and 358,000 blacks who were born in the southern states of Alabama, Arkansas, Mississippi, Georgia and the Carolinas were found to be residing in Michigan through 1970, due to the concentration of manufacturing employment in the region (McDonald, 2014).

Thus, although many of the metropolitan urban areas (which included the suburbs) showed overall substantial population growth, city centers, in contrast, reflected population decline. Detroit showcases a prime example of this trend of suburbanization spread across the northeastern region of the U.S. From 1950 to 1970, the black population in the metropolitan area more than doubled from 358,000 to 757,000, and the population of black residents in the city increased from 16.2% to 43.7%; by 1990, this had risen to 81.1% (McDonald, 2014). As neighborhoods came to be segregated according to social class and color, white populations left to escape the influx of minorities in the city center, and issues such as environmental racism became prevalent. The white population number in the central city had dropped from 851,000 in 1970 to 252,000 in 1990 (McDonald, 2014).

The construction of the freeways and the Interstate Highway System between 1955 and 1970 also encouraged the rise of suburbs by facilitating convenient transportation between offices and homes. A fiscal disparity between the cities and their suburbs emerged as the city of Detroit lost a majority of its white middle-class taxpayers, leading to an inhospitable cityscape in the 1970s that was characterized by depopulation, unemployment, and poverty. Poor socioeconomic conditions and racial segregation also led to abandoned neighborhoods that attracted violent youth and street gangs, and contributed to crime.

2.2.1.3. Foreclosure Crisis

The 1990s marked an era of urban rebirth and political resurgence to uplift and revitalize the decayed state of city downtowns. In an attempt to eradicate poor neighborhoods and substandard properties, reformers in the late-20th century resorted to clearance programs that used federal grants to strengthen zoning regulations, and building, fire, and health codes. However, new housing stock was not pursued elsewhere, resulting in a great shortage of housing for the low- and moderate-income population, and residents argued for revitalization without the displacement of their neighborhoods (VPRN, 2015).

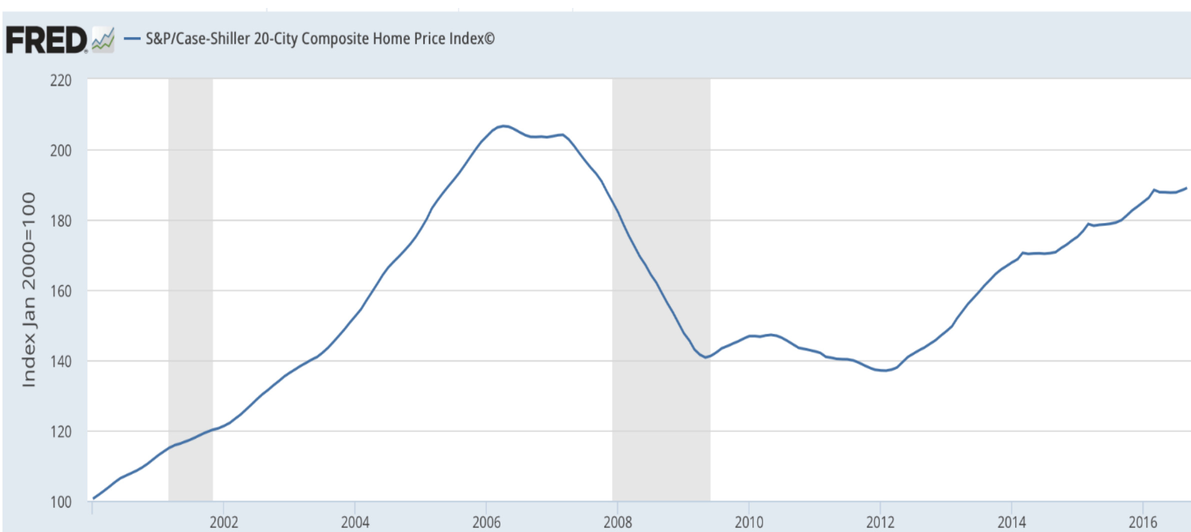
Local governments also chartered property acquisitions through 'eminent domain' for economic redevelopment in communities. The legal clause gave the government the power to transfer the title of the private property to itself and to exercise ownership over the taking for public use, with the payment of a just compensation to the original owner (Benson, 2008). However, eminent domain was not always applied solely to vacant and structurally deficient buildings, or those that posed a risk on public health and safety. This resulted in extensive debates over the controversial legal and political nature of using the clause to address abandonment and blight (VPRN, 2015).

Despite posing a few social concerns for neighborhoods at a micro-scale, urban renewal programs considered blighted cities to offer a greater positive opportunity in creating better communities with revitalized housing conditions and a better quality of life at a macro-scale (VPRN, 2015). The early 2000s saw housing prices rise in an unprecedented manner, with a favorable turn of the American economy, decades after the deindustrialization period. Accompanying this, low-income families were allowed easier access to subprime loans and adjustable-rate mortgages with irrationally low interest rates resulting in the creation of the U.S. housing market bubble.

Traditionally, residential mortgages had a fixed rate of interest for 15 to 30 years, with a down payment of 10-20%, and were made to a borrower with a steady income, and a good credit score (U.S. Government Publishing Office, 2011). Poor regulatory and risk management foresight in making homeownership affordable to the low- and moderate-income populations, however, caused unpreparedness for the destructive projections of the bubble. Moreover, lenders offered and approved loans to high-risk borrowers, without performing required background checks and mortgage underwriting standards that enormously increased the probability of mortgage default and fraud (GPO, 2011).

In 2004, the homeownership rate in the U.S. peaked at an all-time high of 69.2% (U.S. Census Bureau, 2007). Soon after, the housing bubble collapsed and home prices underwent a steep downward spiral – by 2009, prices had fallen approximately 30% on average from their peak in 2006 (Federal Reserve Bank of St. Louis, 2016). Figure 2.2 illustrates Standard & Poor's (S&P) home price index trend in the U.S. across a composite of 20 cities (MSAs) over the period 2000 to 2016. The period from 2006 to 2009 shows the drop in the price index from 206.65 to 140.80.

Figure 2.2: Home Price Index 2000-2016



(Source: Federal Reserve Bank of St. Louis - S&P/Case-Shiller Index, 2016)

Homeowners could not refinance their loans as the interest rates went up, and resulted in defaulting on their mortgage payments. A financial catastrophe was inevitable in 2008, as several major financial firms in the U.S. filed for bankruptcy owing to the mortgage delinquencies (GPO, 2011; MSU CCED, 2017). The negative impact of foreclosure proceedings that lenders followed at the aftermath of the mortgage crisis went beyond affecting just the homeowners – high rates of foreclosures transformed the landscape of neighborhoods and cities as a whole.

Almost always causing its residents to move, high foreclosure rates in cities often lead to widespread dislocations, housing instability, unemployment, and structural abandonment and vacancies (Lamore et al., 2013). Abandonment and vacancy are not the same – a property might be unoccupied causing it to be vacant, but still be maintained for future resale, lease, or other occupancy (VPRN, 2015). However, when a vacant building is no longer maintained, it transitions into abandonment, and can turn into a nuisance for the neighborhood and pose threats to environmental safety and public health by violating code requirements, being structurally unsound, or creating the risk of fire hazards.

Derelict foreclosed clusters frequently include houses that have been broken into and vandalized, and characteristically depict an increase in the number of thefts. According to the Broken Windows Theory, vacant and foreclosed properties with boarded windows and doors and unkempt lawns can create a haven for criminal activity in communities, ultimately leading to social disorder (Wilson and Kelling, 1989). In fact, it was observed that vacancy was the strongest indicator among other socioeconomic and demographic patterns for predicting crime, and longer periods of vacancy of properties only had a greater effect on crime rates in a neighborhood (VPRN, 2015). In Chicago, a 1% increase in the foreclosure rate was found to increase the number of violent crimes by 2.33% in the same ‘tract’, which is the housing equivalent of a neighborhood (Kingsley et al., 2009).

As an extension of the housing crisis, foreclosures also cause a decline in the sales and market values of properties within close proximity. Property values in low-poverty metropolitan neighborhoods were found to decrease by approximately $7,000, or anywhere between 4.2-7.5% (VPRN, 2015). Based on sales data from over 140 zip codes in 13 states, it was found that property values within 300-feet of foreclosed homes decreased by 1.3%, while property values for homes within a one-eighth mile (660-feet) radius dropped by 0.6%. As a result of the subprime loan crisis through the end of 2009, 2.2 million foreclosures were estimated to suffer an average price decline of $5,780 per home, resulting in a $235 billion loss nationally (Kingsley et al., 2009).

2.2.2. Commercial and Industrial Abandonment

With the advent of suburbanization in the metropolitan regions of the U.S. there was a pronounced shift of habitation, property investment, and employment to the outskirts of industrial cities in the mid-20th century. The availability of more land also resulted in the comparatively low-density spatial distribution of these satellite car-dependent communities. This was accompanied by the formation of the suburban sprawl and the construction of new commercial and light industrial structures in the form of retail strips, mixed-use centers, shopping malls, and manufacturing plants that were in close proximity to the residential neighborhoods.

However, with deindustrialization and the economic recession, many of these retail spaces were directly affected by the widespread loss of population and income. ‘Power centers,’ characterized by open-air shopping spaces with big-box retail stores that anchor smaller retailers nearby, were subject to ‘Big-Box blight’ and abandoned because of the imbalance between the retail supply and consumer demand and per capita income, especially between 1996 and 2005 (MSU CCED, 2017). The large size and design of these structures made repurposing them difficult as well. According to a New York Times report, more than two dozen shopping malls have been closed in the past four years, and more than 60 malls face the same consequence today (Wu, 2015).

The U.S. Environmental Protection Agency (EPA) defines 'brownfields' as real property, the redevelopment or reuse of which may be complicated by the presence of potential hazardous substances or pollutants (Brownfield Action, 1999). These brownfields are most commonly found in the form of abandoned industrial or commercial facilities that are now functionally obsolete and blighted, such as an abandoned factory in a town's former industrial section, or a closed commercial building or warehouse in a suburban setting (Jones and Welsh, 2010). Brownfields, however, can be located anywhere and can be quite small – dry cleaning establishments and gas stations, for instance. According to the EPA, there are presently over 450,000 brownfields in the United States, but this number only includes sites for which an Environmental Site Assessment (ESA) has been conducted (Brownfield Action, 1999).

During the industrial boom in the U.S., the automotive sector flourished with 447 automaker plants in operation across the country in the 1970s. However, following the decline of the economy and the automotive plant closings, only 180 were found to remain in operation through 2011 (Brugeman et al., 2011). Nearly 65% of these closed automotive plant brownfields are concentrated in the midwestern states of Michigan, Ohio, and Indiana. Further, 128 closed facilities have been repurposed to cater to industrial uses, as well as logistics and warehousing for auto-related sectors. Despite these numbers, research shows that the scale of industrial and commercial abandonment continues to grow owing to the lack of funding to address the removal and repurposing of these unique and large structures (Lamore et al., 2013).

Brownfields redevelopment can represent advantages on many fronts (Brownfield Action, 1999). Fiscal impacts include generating new sources of local revenue derived from previously unproductive land and lowering requirements for investment in new infrastructure to accommodate growth. On the socioeconomic side, there are employment opportunities, leveraged investments, expansion of tax bases, and revitalized neighborhoods. The EPA Brownfields program has created 48,238 jobs and $11.3 billion in new investments as of 2008 (Paul, 2008). Moreover, brownfield redevelopment, when compared to greenfield development, saves land from the negative externalities associated sprawl, reduces air emissions and greenhouse gases, improves water quality through reduced runoff, and generally accommodates growth in an environmentally responsible fashion. The International Economic Development Council (IEDC) has reported that brownfields-to-greenspace remediation projects have had positive effects on surrounding property values of up to 126% (Paul, 2008).

Revitalization has thus become an important issue for federal, state and local governments, and real estate developers, banking and insurance companies alike. Despite the many positive gains that it can offer, however, many abandoned and contaminated brownfields and other commercial sites sit idle and unused due to the high and uncertain costs associated with the cleanup and ESAs.

2.2.3. Residential Abandonment

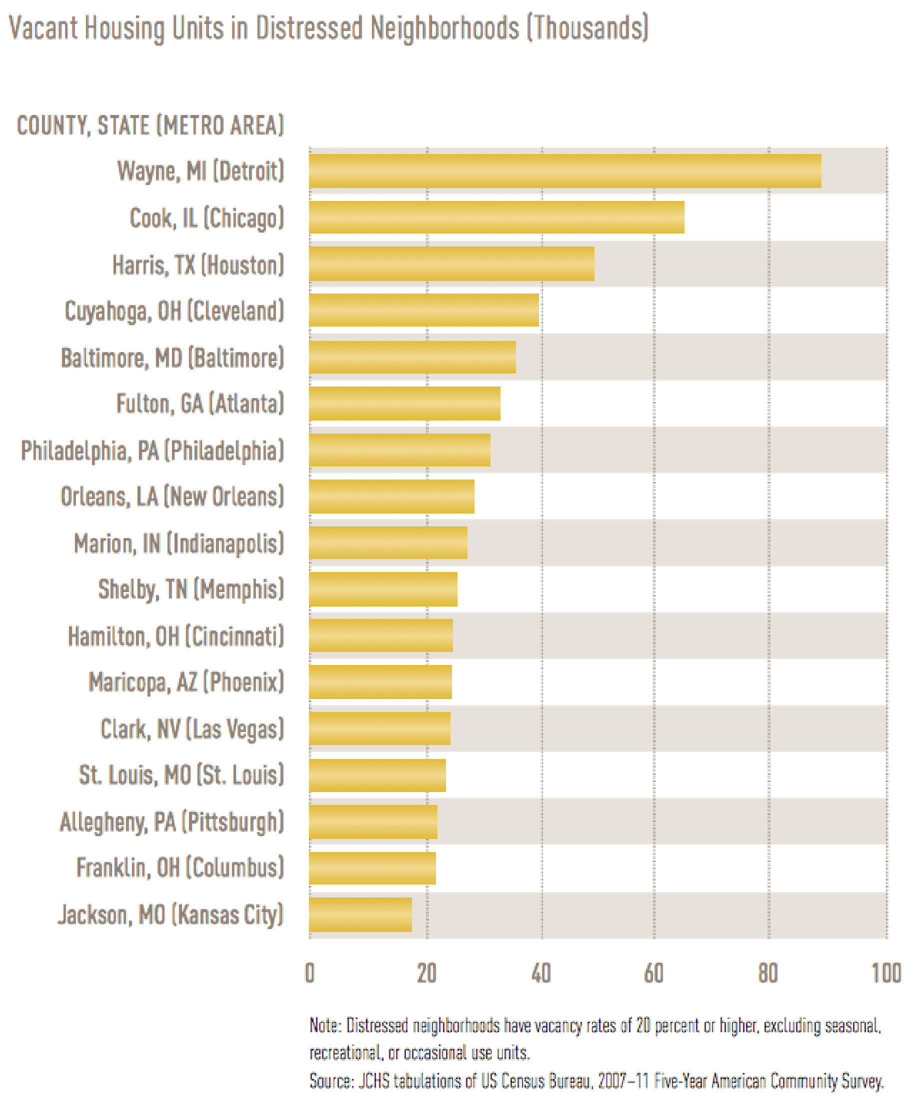
After being subject to deindustrialization and the subsequent economic recessions, the residential sector in the U.S. still faces a number of housing challenges – the greatest of which is the problem of blighted communities with deteriorating housing conditions. According to data from the U.S. Census Bureau, the total number of vacant units present nationwide can be approximated to be upwards of 7.4 million (Joint Center for Housing Studies, 2013; U.S. Census Bureau, 2015).

Through the downturn of the housing market from 2007 to 2011, 17 U.S. counties had distinctly more than 50 very high-vacancy neighborhoods with an average vacancy rate of approximately 26% - more than triple the U.S. total vacancy rate (JCHS, 2013). Although distressed communities exist in every state except Vermont today, they are found to be heavily concentrated in the central counties of relatively few metropolitan regions. In fact, more than half of these troubled areas are located in just 50 counties across the U.S. (JCHS, 2013).

Figure 2.3 depicts the 17 counties with the greatest number of distressed neighborhoods and their respective vacancy rates through the 2007-2011 period. The highest concentrations are in Wayne County, within the Detroit MSA (89,000 units) and Cook

County, within the Chicago MSA (65,000 units), where more than 200 neighborhoods have very high vacancy rates (JCHS, 2013). Many other counties with the highest concentrations of vacant units are in metropolitan areas where household growth has been modest for many years, including Cleveland, Baltimore, and Philadelphia. Even so, concentrations are found to be high in areas such as Houston, Atlanta, Phoenix, and Las Vegas, which developed at a fast pace in the early 2000s but were severely affected by the consequences of the housing bubble crisis after 2007 (JCHS, 2013).

Figure 2.3: Vacant Housing Units in Distressed Neighborhoods



(Source: Joint Center for Housing Studies, 2013)

Abandonment and blight do not affect all neighborhoods equally, and predominantly impact areas where politically and socially marginalized populations live. Coalitions of state governments, non-profit organizations, and community residents are thus undertaking strategic planning and remediation initiatives to address structural abandonment and tax-delinquent properties locally. In Michigan, quasi-public land banks and other agencies such as the Center of Community Progress are advocating policy changes and providing technical assistance workshops. Detroit has put in place its Blight Removal Task Force that hopes to revitalize more than 80,000 vacant and dilapidated lots, 50% of which require demolition. Flint has proposed five-year benchmarks with its Blight Elimination Framework Element in order to reclaim 20,000 derelict properties in the city (VPRN, 2015).

Vacant and abandoned housing is often sought to be a fundamental indicator of social and neighborhood distress, serving to depress local property values, encourage the spread of crime, and strain municipal tax bases by imposing higher service costs while reducing property revenues. Surprisingly, policies to address property vacancies and consequent abandonment have been largely reactive and not proactive in nature till date, in spite of the distinct and predictable patterns associated with economic development and decline. In order to confront and resolve the oversupply of vacant residential, commercial and industrial structures corresponding with market demand and the current population, the place-specific relationship between abandonment and the solution of demolishing buildings must be paid more attention to before making a decision for the future.

2.3. DEMOLITION

According to the National Association of Home Builders (NAHB), the size of an average home in the United States increased nearly 45%, from 1,500 square feet to over 2,200 square feet between 1970 and 2002, while the number of people living in each home decreased from an average of 3.2 people to 2.6 people (U.S. Environmental Protection Agency, 2008). This meant expansion of the built environment and clearing away of older structures to allow for new and bigger structures by demolishing buildings and hauling a significant amount of their constituent materials to landfills as they reached the end of their useful life.

Demolition is a multifaceted engineered task that involves structural dismantlement, implosion, specialized rigging, salvage, recycling and reuse, and hazardous material handling (Diven and Shaurette, 2010). The type of demolition and tasks carried out in the process often depend upon the nature of construction and the size of the structure that is to be demolished. For example, high-rise industrial structures, such as steel mills and chemical plants with chimneys and towers, are usually demolished using heavy equipment such as hydraulic excavators, cranes and explosives, whereas, interior demolitions carried out during remodeling or upgrading of existing buildings may involve labor-intensive, selective dismantling techniques only (Diven and Shaurette, 2010).

Further, the initial preparation and planning of a demolition project considers other factors in order to adhere to various regulatory requirements, environmental standards, and contracting specifications. These include safety issues, site planning and access, protection of adjacent structures, sequence of work and scheduling, unforeseen conditions, and disposal, recycling and reuse of material after demolition (Tatiya, 2016; Zahir et al., 2016). Until the 1950s, buildings that reached the end of their lives due to functional obsolescence were dismantled by hand. However, due to the advancement of construction technology, mechanical demolition is preferred over manual demolition today (Pun et al., 2005). It provides the quickest method of removing a facility, and finds widespread use with redevelopment projects in the residential demolition sector that have strict time and budget constraints.

2.3.1. Process and Potential Impacts

2.3.1.1. Site Survey

The first step taken prior to planning and executing a demolition project is conducting a site survey to examine the building and its surroundings. The site is evaluated by means of its overall condition, the structural system and the type of construction materials used in the building, utility locations, access roads, adjacent properties, etc. The sensitivity of the neighborhood in which the site is situated is also taken into consideration, with respect to the potential impacts of demolition being carried out there, such as noise, dust, vibration, and obstruction in traffic patterns. An existing plan of the layout of the site and the building is documented, and a subsequent demolition plan is prepared based on the nature of findings of the site survey. Local municipality permits for demolition according to specific building type, work hours, hauling, and utility disconnection are also taken into consideration prior to commencement of the project (Diven and Taylor, 2006; Diven and Shaurette, 2010).

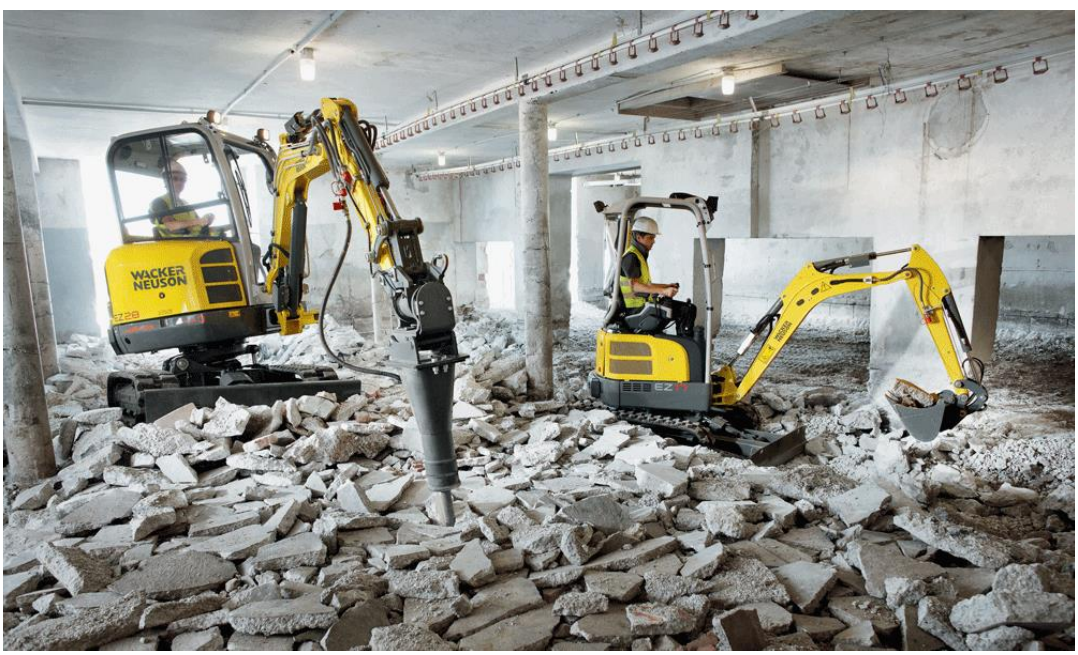
2.3.1.2. Safety and Jobsite Security

A variety of federal, state, and local standards also apply to demolition projects that determine the means and methods used in the demolition work, and need to be specifically adhered to during its course. Safety features such as OSHA compliance, fire protection, equipment safety, and worker training that ensure a safe working environment for the protection of the public and site personnel are mandatory on the jobsite. The general contractor is typically in charge of the continuous supervision that entails these regulations and requirements. Jobsite security is also given emphasis in a demolition project, and measures such as fencing and scaffolding, screened enclosures, demarcated pedestrian walkways, signage, and temporary lighting are devised to protect the workers and the public from potential danger (Diven and Taylor, 2006; Diven and Shaurette, 2010).

2.3.1.3. Equipment Use

Different types of equipment and attachments are used by contractors, depending upon the type of demolition work being executed and the size of the structures being demolished on the project. Mechanical demolitions typically employ heavy equipment in the form of crawler excavators with grapple, bucket and thumb, pulverizer, or hydraulic hammer attachments. Currently, with the advancement of technology, remote-controlled mini-excavators fitted with shears, grapples, concrete crackers, etc. are used for specialized demolition work on sites where load restrictions or unsafe conditions (radioactive environments) do not allow for workers to operate heavy equipment. Hand tools and manual demolition equipment such as jackhammers, and steel cutting torches, and hydraulic shears are also used in small-scale demolition procedures (Diven and Shaurette, 2010). Figures 2.4 and 2.5 depict the use of different types of demolition equipment on site.

Figure 2.4: Mini-Excavators with Concrete Pulvrizer attachment



(Source: http://meconstructionnews.com/9708/construction-machinery-why-small-is-beautiful)

Figure 2.5: Worker cutting brick wall with Hydraulic Shears

(Source: http://www.directindustry.com/prod/darda-gmbh/product-65781-909223.html)

2.3.1.4. Environmental and Social Regulations

Demolition project planning requires strict compliance with general construction site regulations to avoid exacerbating dangerous conditions, which can have a potentially harmful impact on the environment. Dust is a common result of building demolition and its constituent activities such as concrete breaking and debris hauling. Regulations are adopted on the jobsite to minimize and manage fugitive dust emissions and control air pollution. National Emissions Standards for Hazardous Air Pollution (NESHAP) is one such standard set by the EPA which governs the maximum degree of emission reduction achievable. Toxic air pollutants such as particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), sulfur oxides (SOx), volatile organic compounds (VOCs), etc. also originate from the exhaust of the diesel-powered equipment and machines employed in demolition work, and the vehicles used to haul debris to landfills (Diven and Taylor, 2006; EPA, 2008).

Noise and vibration are another nuisance factor associated with demolition projects. The use of mechanical equipment such as excavators, pneumatic breakers, and generators, the erection of temporary scaffoldings, and the loading and transportation of debris on and off the jobsite can affect the workers as well as the local community in the vicinity of the site. Local municipalities often restrict the number of hours in the day that demolition work can be executed to prevent any prolonged disturbances (EPA, 2008). Moreover, demolition sites over one acre in size are required by the EPA to administer the National Pollution Discharge Elimination System (NPDES), to devise and implement a plan to prevent surface water pollution, subsurface groundwater contamination, and pollutants conveyed by rainwater leaving the site (Diven and Shaurette, 2010).

2.3.1.5. Hazardous Material Handling

The presence of hazardous materials and contamination on site requires specialized handling and management prior to the commencement of the demolition work. Demolition contractors typically address the removal of toxic and corrosive materials such as Asbestos Containing Materials (ACM), Polychlorinated Biphenyls (PCBs), Lead Based Paints (LBPs), Petroleum Oil Lubricants (POLs), and Chlorofluorocarbons (CFCs) in brownfield and domestic sites. OSHA and individual state safety regulations may also mandate a careful planning process, including surveys, notifications and permits, and workforce training, that dictates the abatement of hazardous materials (EPA, 2004; Diven and Shaurette, 2010). More often than not, these stringent regulations and fees have a significant impact on the overall project cost.

2.3.1.6. Debris and Waste Management

Mechanical demolition normally results in a pile of mixed debris on site, due to the use of powerful equipment such as bulldozers and hydraulic excavators. This debris is hauled to the landfill directly, often without prior abatement of hazardous contaminants and proper segregation of demolished materials. Recycling and reuse of demolition debris are thus less likely to occur. Failing to optimize the use of these building materials by landfilling results in the wastage of resources, as their residual lifecycle expectancy is not being fully exploited. This simultaneously causes the landfills to fill up and create a deficit of disposal facilities, which is far from being a sustainable consequence to the practice of revitalization of the environment (Diven and Shaurette, 2010).

Further, given tight budget and time constraints, the technique employed in demolition projects and the use of equipment and labor resources is often driven by economics (Pun et al., 2005). Over the past several years, the costs of basic waste collection and recycling services have been dramatically increasing. In fact, the greatest costs incurred throughout the waste management process are associated with the process of discarding waste into landfills (MSU CCED, 2017).

The practice of selective demolition is preferred as it facilitates the recycling of building materials that can be stripped and removed from the structure, before the demolition work is executed. The goal is to reuse the recovered materials, minimize the burden on municipal landfills and public filling areas by reducing overall waste generation, and thus, benefit the environment (Pun et al., 2005). In general, household items such as furniture, plumbing fixtures, electrical appliances, etc., metal components such as window frames, pipes, etc., timber components such as doors, wooden floors, staircases, etc., and other building materials such as floor and ceiling tiles, asphaltic materials, ceramic products, etc. should be removed first. Most of these salvaged materials may be sold or recycled depending on the circumstances of the job and the market value of the products to be recycled, allowing savings from waste disposal and landfilling charges and reducing demolition project costs (Diven and Taylor, 2006; Diven & Shaurette, 2010).

2.4. DECONSTRUCTION

Deconstruction is the systematic and selective disassembly of buildings to enable the reuse and recycling of building components and construction materials that can be salvaged before the building is demolished (EPA, 2004). These salvageable materials include bricks, concrete, steel, wood, and architectural elements and fixtures, among others. As compared to demolition, which is mostly associated with tearing down buildings into rubble as soon as possible, deconstruction is an idealized method from the perspective of valuable material reuse.

Bradley Guy, a research pioneer in the field of building deconstruction and president of the Building Materials Reuse Association (BMRA) defines deconstruction as “a process of building disassembly in order to recover the maximum amount of materials for their highest and best reuse. Re-use is the preferred outcome because it requires less energy, raw materials, and pollution than recycling does in order to continue the life of the material. As a consequence of deconstruction, there are also many opportunities for recycling other materials along the way" (Guy et al., 2003; EPA, 2008).

2.4.1. Process and Potential Impacts

2.4.1.1. Planning

Projects that involve deconstruction work often require careful planning to determine the sequence of dismantling various building materials, ensuring a safe environment at the jobsite, and maintaining the quality and integrity of salvaged material for recycling and reuse. The foremost step consists of a visit to the site of the building that is to be deconstructed in order to survey the types and condition of salvageable building materials. An inventory of materials is recorded, the structural design is studied, and potential hazards during the dismantling of the building are identified.

Using the information collected onsite, a comprehensive work schedule is created which also enlists the tools and equipment, labor requirements, safety and training procedures etc. In addition to this, a site plan needs to be illustrated, marking the locations of operations, site constraints, and circulation and storage of inventory. A well-defined organizational plan is also a key element of successful deconstruction project with specific operations being assigned to competent and skilled managers (Guy et al., 2003).

2.4.1.2. Types of Deconstruction and Equipment Use

Deconstruction enterprises are found to vary from project to project, often in the form of partnerships between federal, state, and local governments, and non-profit and for-profit organizations to allow for sharing of resources (Leigh and Patterson, 2006). In any of these capacities however, deconstruction is of two distinct types – structural and non-structural (EPA, 2008). Non-structural deconstruction is also known as 'soft-stripping' and involves the removal of building components that do not affect the structural integrity of the building. Most demolition projects already include some activities that salvage HVAC equipment, cabinetry and finish flooring, plumbing fixtures, fireplace mantles etc. prior to destructive work, considering minimal effect on the project schedule (EPA, 2008).

However, structural deconstruction involves a more thorough procedure of removing and salvaging integral building components such as framing, masonry, and roof systems, and requires comparatively more time, labor and equipment. The salvaged materials are also larger in size and volume, and entail additional transportation costs to secondary markets and higher material handling costs (EPA, 2008).

Figure 2.6: Workers performing Deconstruction of a House

(Source: https://www.huduser.gov/portal/pdredge/pdr_edge_featd_article_092313.html)

Further, different materials necessitate the use of specific types of equipment in order to be deconstructed. For example, cast-in-place concrete needs to be crushed using crushers and pulverizers to be able to be reused in its original form. Steel rebar can be extracted from the reinforced concrete during the crushing process by using heavy-duty magnets. Brick masonry, on the other hand, needs meticulous cleaning by hand to remove the mortar while maintaining the highest possible quality of the recovered material. In this regard, automation and mechanization of demolition and deconstruction tools and techniques is becoming an increasingly important direction of future development, to uphold the call for safer work environments and faster project schedules (Endicott et al., 2005).

2.4.1.3. Material Management

Salvaged materials from deconstruction projects face three options after they have been recovered. They can be judiciously reused in their extant form for their intended purpose, such as doorframes, and lighting/plumbing fixtures. They can also be repurposed and recycled, in the same form for another purpose. For example, spent gypsum ceiling tiles can be used as raw materials in the manufacturing of new gypsum tiles, thereby replacing the virgin gypsum that would otherwise need to be mined for the manufacturing process. Concrete blocks can be crushed to form aggregate material for new concrete, or used as backfill for utilities (MSU CCED, 2017). Figure 2.7 depicts workers carefully salvaging a window frame from an abandoned house to reuse or repurpose as a design element.

Other materials that cannot be reused or recycled are usually disposed in landfills as construction and demolition (C&D) debris. Deconstruction projects thus necessitate efficient material handling on site, and include different types of cleaning, sorting and stacking procedures with the aim of trying to reduce waste (Guy et al., 2003; Endicott et al., 2005).

Figure 2.7: Manual Deconstruction of Window Frame for Reuse

(Source: http://seekerofthelostarts.com/after-the-earthquake-whole-house-reuse-christchurch-new-zealand)

In this context, it is imperative to mention that although deconstruction and building material recovery affords environmental, economic and social benefits to society, concerns regarding public health and safety exist. Potentially harmful and hazardous materials that might have circulated through the construction and occupancy phases of the building, such as lead, asbestos, mercury, PCBs, etc. in paint and older building materials, need to be handled carefully and abated prior to introducing the salvage into reuse and recycling processes.

Moreover, despite their lower cost, using salvaged building components for their intended structural applications does not necessarily meet building code requirements, nor is it often practical in the long-run. For example, an old single-pane window fitted into the exterior facade of a building would not provide an energy-efficient thermal solution. It would be better suited to fulfill an interior requirement, such as a transom for the penetration of light in hallways (EPA, 2016). Reclaimed lumber is a good instance to exemplify the quality that building materials need to have in order to possess high resale value in secondary markets. Lumber needs to be de-nailed, treated, and kiln-dried before it can be reused as certified flooring, siding or other wood products (MSU CCED, 2017).

2.4.1.4. Historic Preservation and Permits

Many old buildings slated for deconstruction contain traditional materials and artistic elements that hold cultural significance for the community and might need to be preserved. These items include moldings and mantels, carved stonework, brick and terracotta features, and stained glass windows (EPA, 2008). Local municipalities, historical societies, and historic preservation organizations should be contacted to understand the proper guidelines that need to be followed to protect and shelter these valuable building materials.

Deconstruction permits that state the formal notification of intent are similar to the permits required for demolition work. They need to be obtained and approved from the local governing bodies during the planning stage of the project. Moreover, all utilities present on site need to be disconnected prior to the commencement of the work.

2.4.1.5. Reduction of Emissions and Waste Debris

By reducing the need to extract and process raw materials through upstream processes and then transport them over long distances, deconstruction conserves natural resources, saves energy, and reduces greenhouse gas emissions. The process of manufacturing new construction materials also causes different types of pollution, and can lead to global implications such as climate change, water source and fossil fuel depletion, habitat alteration, etc. that deconstruction helps prevent by promoting the efficient use and reuse of salvaged building materials (MSU CCED, 2017).

Further, deconstruction diverts wastes from landfills, and mitigates the environmental impact that would have been caused by demolition waste disposal (EPA, 2008). In fact, studies have found that deconstruction can reduce construction site waste up to 70% (EPA, 2008). It reduces the need for landfilling of C&D debris from downstream processes, and generates savings from the budget earmarked for debris disposal in demolition projects.

Deconstruction is often regarded as a labor-intensive process, wherein to ensure the quality of dismantled building materials, a large proportion of tasks need to be accomplished manually. Consequentially, labor costs contribute to a significant proportion of the total project cost when employing deconstruction techniques. Conversely, less involvement of machinery also results in creating a smaller impact on the environment by reducing the fuel and energy use, and amount of potential fugitive emissions and pollutants (Pun et al., 2005).

2.4.1.6. Economic Benefits and Community Revitalization

Since deconstruction requires more manpower than demolition, it is a powerful tool for economic development and job creation. Typically, a deconstruction site will require between 12 and 24 skilled workers, whereas a demolition site only requires two to three workers (MSU CCED, 2017). Labor is needed for every aspect, including supervision and coordinating team efforts, mechanically removing building materials, and processing and sorting materials for reuse or disposal (Zahir at al., 2016). Processing the dismantling of building materials by hand also ensures that the salvage is of better quality and able to be resold at a higher price. In the process, workers on deconstruction projects also gain transferable skills for maintenance, renovation, and restoration of buildings, and hazardous material handling and waste management.

In addition to workforce development, deconstruction supports smaller material resale and salvage businesses, and helps them generate revenue with local sales. Lesser C&D debris also imply avoided transportation and disposal costs. Moreover, property owners can also gain tax deductions by donating the value of the deconstructed building and its salvaged materials to non-profit organizations (Leigh and Patterson, 2006; EPA, 2008).

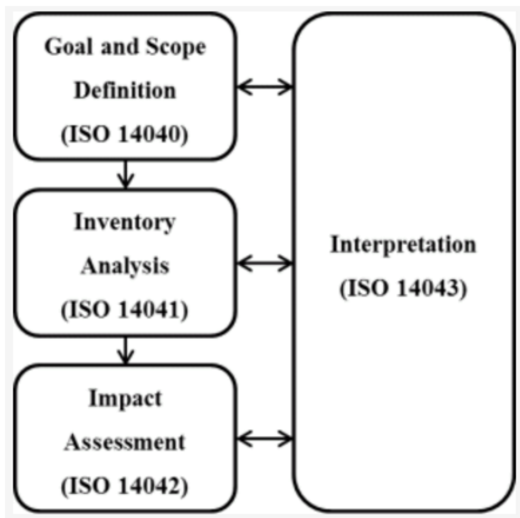
Further, deconstruction projects incorporate the participation of residents in neighborhood revitalization programs as volunteers to help offset labor costs, while salvaged materials offer low cost building and furnishing options in their local market. Governments also find the opportunity to use deconstruction as a means to educate the community by creating awareness about their history and sustainable development for the future (EPA, 2008).

2.5. LIFE CYCLE ASSESSMENT

According to the ISO 14040, a series of international standards that address environmental management, Life Cycle Assessment (LCA) is a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product or service system throughout its lifecycle" (American Institute of Architects, 2010). The lifecycle of a product or service system refers to the consecutive, interlinked stages of its life, starting from the extraction and processing of raw materials, manufacturing, distribution, use and maintenance of the product or service, to its final disposal. In place since the 1960s, LCAs originally addressed energy use and environmental outcomes due to the limited availability of natural resources for the manufacturing of automobiles, chemicals, and electronics, among other products, and accounted for the consequences of these uses (AIA, 2010). They served as a valuable tool for policymakers and patrons in the industrial sector to compare and assess the impact of goods and services, and take holistic and informed decisions related to product design, strategic planning, marketing, and process improvement (Guinee et al., 2011).

According to ISO 14044, the methodological framework for LCA consists of four phases as shown in Figure 2.8 (AIA, 2010; Singh et al., 2011). Widely used across many fields, the LCA framework first defines the goal and scope of the study by identifying its purpose, boundaries and functional unit of analysis. Next, it examines and analyzes the material and energy flows for each stage of the life cycle of the product or service and establishes an inventory of data. The impact assessment step classifies, aggregates and characterizes various midpoint and endpoint environmental impacts based on the inventory of data collected. This step also incorporates weighting and normalization methodologies to assess the relative significance of these midpoint and endpoint impacts. The final step interprets the results of the LCA, and assists by recommending the selection of environmentally preferable products and process improvements.

Figure 2.8: LCA Framework (ISO 14044)



(Source: AIA, 2010; Singh et al., 2011)

Several different LCA methodologies use the underlying basis of the ISO general framework. Organizations and tool developers that plan to implement an LCA choose to employ industry-specific or region-specific Life Cycle Inventory (LCI) databases to account for elementary flows, inputs, and outputs of material and energy which correspond to their model and scope of study. Life Cycle Costing (LCC) is another decision-support tool that takes financial benefits, costs and revenue, initial capital investments, economic comparisons, etc. into consideration instead of relying solely on environmental effects. Conversely, Life Cycle Energy Analysis (LCEA) is a form of LCA that measures only energy as an environmental impact and caters to energy-efficient products and systems. Life Cycle Management (LCM) is an associated framework that compiles LCA procedures in an integrated manner, to serve as a decision-support tool and address environmental, economic, technological and social concerns (AIA, 2010; Halog and Manik, 2011).

In this context, it is pertinent to mention that the general LCA framework typically supports process-based environmental impact analyses, which tend to be data-intensive and involve multiple interdependent inputs and outputs and, in turn, complicate boundary definitions and make the LCA susceptible to truncation errors. Economic Input-Output (EIO) and Environmentally Extended Input-Output (EEIO) LCA models addressed such issues by using economy-dependent input-output matrices to keep track of the material and energy flows. However, high levels of aggregation and nation-wide averages used in the input-output matrices often negate product-specific or comparative LCAs within the same industry and region. This led to the development of hybrid LCA methods that accommodated product and process information as well as their input-output categories, and maximized the advantages of both process-based and EIO LCAs (Sharrard et al., 2008; Singh et al., 2011). The evolution and characteristics of these LCA models are discussed later in the chapter.

2.5.1. LCA in the Construction Industry

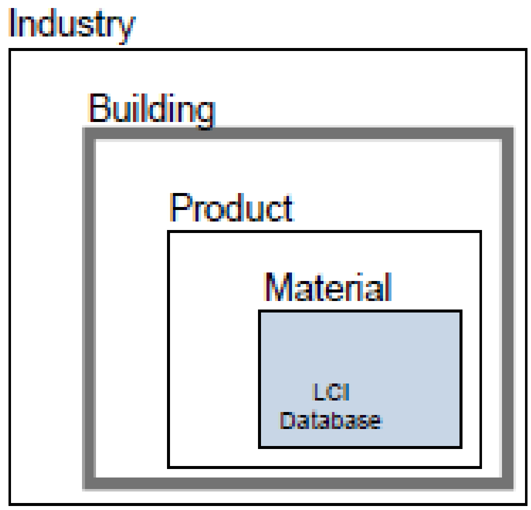
From a global perspective, civil works and building construction have been found to consume 60% of the raw materials extracted from the Earth's lithosphere, and contribute significantly to the global depletion of natural resources, clean air, and water (Dong et al., 2005; Bribian et al., 2011). Therefore, studies have found it essential to quantify and analyze the impacts of environmental metrics such as energy requirements and material flows utilizing LCA frameworks, for the construction industry to grow and perform in a sustainable manner. For example, when concrete, a building material that releases a significant CO_2 emissions during its manufacturing process, is reused as an aggregate or filler material in new infrastructure, the emissions considerably reduce over its whole lifecycle by corresponding to its second life as a recycled product. Through the years, research has also duly emphasized upon the realms of repair, renewal, retrofit, adaptive reuse, and recycling associated with building materials (Dong et al., 2005; Bribian et al., 2011; Hassan et al., 2016; MSU CCED, 2017).

The applications of LCA have broadened and have found use across various commercial, industrial and factory settings in recent times – the construction industry being one of them. This path of progress initiated primarily because of the formalization of LCA standards in the ISO 14040 series, and the launch of the Life Cycle Initiative by United Nations Environment Programme (UNEP), and the Society of Environmental Toxicology and Chemistry (SETAC) in 2002, as industrial ecologists and engineers sought to reduce the environmental burden of manufacturing processes and streamline them (Singh et al., 2011; Guinee et al., 2011).

However, LCA principles and guidelines suited to industrial products and processes cannot be directly borrowed from for use with regard to the construction (and deconstruction) of buildings. Every building project differs from the likes of thousands of identical products found in industrial manufacturing systems, and it thus becomes tedious to define a specific functional unit or boundary of analysis for each one of them. LCA methodologies in the construction industry pose a necessity to be optimized and take into consideration the fundamental attributes and unique character of every building design and the complexity of structural components and systems, in addition to the spatial and functional needs of occupants (Guinee et al., 2011).

The LCA methodology, as it presently relates to the construction industry, operates at one of four levels: Material, Product, Building, or Industry, as depicted in Figure 2.9 below (AIA, 2010).

Figure 2.9: Four Levels of LCA in the Construction Industry



(Source: AIA, 2010)

Each larger level builds from the level below - starting from the Material kernel LCA, which guides the basic material and product selection process in building projects, and expanding to the top. Functioning at a much greater scope, the Industry kernel seeks to minimize environmental footprint and meet the purpose of planning and regulatory requirements through iterative design and construction processes.

Moreover, while conducting an LCA, it is important to deliberate upon the stage of life that the product or the process is going through. Each stage consists of several activities, which have apposite inputs and outputs associated with the scope of the study. Understanding this notion and allocating the boundaries, functional units, and impact categories of the LCA framework will subsequently result in providing an accurate, complete and transparent analysis (Guinee et al., 2010; AIA, 2010; EPA, 2016). With whole buildings being regarded as the product, the four important lifecycle stages are shown in Figure 2.10, and their commonly accompanying impact categories are elaborated below (AIA, 2010).

Figure 2.10: Life Cycle Stages of a Building

(Source: AIA, 2010)

Material Manufacturing Stage

This includes the energy consumption and resource use during the extraction of raw materials from the earth, upstream manufacturing and packaging processes for building material and assemblies, and downstream distribution of final building products in the market.

Construction Stage

This includes energy consumption and resource use of all activities associated with the on-site construction project, such as mobilization of material and equipment to site, use of tools and equipment during construction, site work, fabrication, and temporary services and utilities.

Use and Maintenance Stage

This includes the operation and use phases of the building that correspond to energy consumption, water use, and environmental waste generation. It also accounts for the repair and replacement of building components, assemblies and systems, and incorporates the transportation and equipment use for these maintenance activities.

End of Life Stage

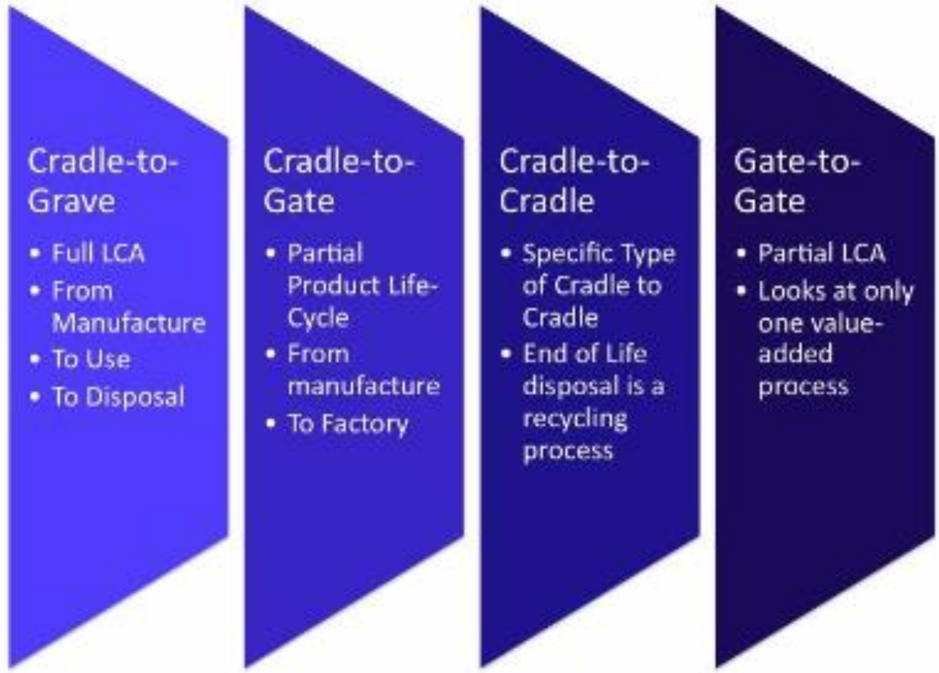
This includes the energy consumed and environmental waste produced due to building demolition, equipment use, and disposal of materials in landfills. Other activities that contribute to the impacts are the transportation of waste building materials, and recycling and reuse of salvaged building materials from an environmental and economic standpoint.

2.5.2. Methodologies of Life Cycle Assessment

2.5.2.1. Process-based Life Cycle Assessment

As discussed earlier, there are usually one of two primary methodologies of conducting LCAs depending upon the nature, scope and purpose of the study – each with its own set of strengths and limitations, differing only on the basis of the nature of questions they intend to answer (Guinee et al., 2011). The first is a Process-based LCA, which determines the overall impact of a product by analyzing the known inputs and outputs for each step of its production. Here, inputs include all the material and energy resources that are assimilated in the process, while outputs refer to the release of emissions into the environment and the amount of waste generation (Bilec et al., 2010; AIA, 2010). In the construction industry, LCA methods implemented for selection of building materials and improvement of construction techniques are typically process-based (Bilec et al., 2010).
Figure 2.11 depicts the four variants of a process-based LCA, namely Cradle-to-Grave, Cradle-to-Gate, Cradle-to-Cradle, and Gate-to-Gate models that are differentiated by their boundary definitions. Each model offers an assessment of the impacts that the whole building, or individual building product, is subject to over different stages of its lifecycle (AIA, 2010). For example, evaluating the environmental consequences of the demolition of a residential property would entail a gate-to-gate approach that centers on a partial LCA, i.e. the impact of one process over the end-of-life stage of the building.

Figure 2.11: Variants of Process-Based LCA Methods



(Source: AIA, 2010)

Cradle-to-Grave Model

This is considered to be a linear, one-way LCA process, wherein a building material is extracted from the 'cradle' and eventually disposed of as waste in the 'grave,' such as post-consumer vinyl flooring, carpets, glass, etc. These materials last only through the lifecycle of the product, and are directly discarded at landfills or incinerated thereafter.

Cradle-to-Gate Model

This is the LCA of a product through its partial lifecycle of upstream and downstream processes, i.e., from resource extraction to the factory 'gate' where it gets transported to the consumer. For example, reviewing the cradle-to-gate industrial process for manufacture of structural lumber would be helpful in understanding the environmental impacts associated with deforestation.

Cradle-to-Cradle Model

This is considered to be a relatively new LCA concept, which presents an alternative design strategy, and assumes that a material will be reclaimed and reused at the end of its functional life for the same purpose or a new use. Structural lumber, salvaged and repurposed into design elements, furniture, etc., would be an example of this model.

Gate-to-Gate Model

This is another partial LCA that looks at only one value-adding process over the entire production and supply chain of a product. For example, the industrial treatment of reclaimed structural lumber to manufacture into certified products such as wood flooring, siding, etc. for reuse and resale, would be a gate-to-gate consideration.

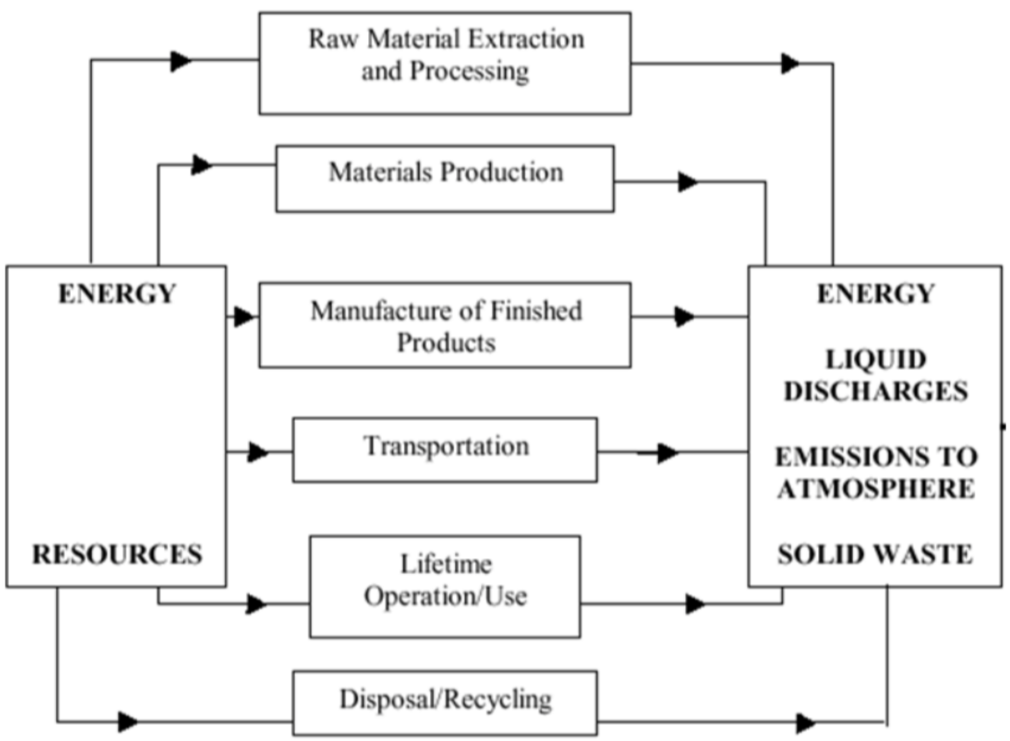
2.5.2.2. Input-Output Life Cycle Assessment

The second broad method of conducting an LCA is by using the Economic Input-Output (EIO) framework, which estimates the material and energy resources required for, and the environmental emissions resulting from, activtities in a certain economy, geographic location, industry or service sector (AIA, 2010). Unlike process-based LCA models, EIO LCA models propose a more realistic approach to determine the impacts of a product or process by incorporating the factor of interdepedence among constituent activities and sub-activities. This provides a more holistic view of the real-world scenario, but is often faced with the possibility of scarce, incomplete, inaccurate or divergent data for analysis (Guinee et al., 2011).

There are several reasons for these limitations. First, the EIO LCA model is based on aggregation of data, often considering 'averages' for industry-specific data, which makes assessment of individual products and processes difficult. Second, most of the data is based on American standards, making the study of international variables uncertain. Further, not every impact over the lifecycle of a product or a process can be quantified in terms of energy or resource use, thus causing the economy-centered EIO LCA to remain incomplete (Bilec et al., 2006).

Figure 2.12 depicts a diagram of the flows and inventory for various inputs and outputs over the lifecycle of typical building materials used in construction, such as lumber, concrete, and steel. (AIA, 2010). An LCA model suited to accommodate all of these layers requires the need to employ the facilities of both process-based and EIO LCA models and overcome the framework deficiencies presented by them (Hossaini et al., 2015).

Figure 2.12: Inventory of Inputs and Outputs for LCA of Building Materials



(Source: AIA, 2010)

2.5.2.3 Hybrid Life Cycle Assessment

As construction is defined by a multitude of processes and involves the blending of material and resource inputs, as well as interaction with project costs, schedules, quality, and safety, it is pragmatic to be flexible while implementing LCAs and decrease reliance on standardized models. Moreover, the best available inventory and information might not be inclusive and consistent, nor in conjunction with the specifications of the project (Bilec et al., 2010). A hybrid LCA framework is an efficient means of addressing these complexities. It follows a top-down approach and combines the benefits of a large EIO boundary with process-level inputs and outputs, and thus provides for more comprehensive and informed decision-making (Sharrard et al., 2008; Singh et al., 2011).

2.5.3. Sustainable Life Cycle Assessment

The focus of the current LCA methodologies in the construction industry as discussed previously has been on building materials and products, and evaluating the environmental effects of material selection, material manufacturing, building energy use, and indoor environmental quality (IEQ) (Sharrard et al., 2008; Bribian et al., 2011). Other complex analyses incorporate the quantification of the impact of land use, air emissions, water discharges, energy use, and waste generation during the occupancy-phase operations and maintenance of buildings (Bilec et al., 2010; EPA, 2016). For example, energy rating systems such as Leadership in Energy and Environmental Design (LEED) and Energy-Star are laudable when it comes to providing a specific list of do's and don'ts to be applied during the design process. However, they do not provide much guidance while getting feedback about how well a design is working, leading to a gap in understanding the full spectrum of possible sources of environmental impacts from the life cycle of the built environment (AIA, 2010).

Other studies relevant to pre-occupancy construction phase include LCA models that encompass energy consumption by on-site activities, equipment utilization, and the transportation of materials and resources (Bilec et al., 2010). The Athena Impact Estimator 4.0, a whole-building LCA software that gives snapshots of the environmental footprint of buildings and serves as an influential decision-support tool during the schematic design phase of a project, adds to the aforementioned impact categories by including the aspects of labor, construction service sectors, temporary site facilities, and equipment manufacturing (Bilec et al., 2010; AIA, 2010).

Nevertheless, it can be inferred that not much research has been done on the post-occupancy and end-of-life phases of buildings. LCA practitioners are often faced with the difficulty of selecting the appropriate scope or boundary of the analysis, and relevant sources of data for lifecycle inventories, software, and impact assessment methods and metrics (Bilec et al., 2010). Moreover, studies on construction and demolition processes of residential homes have indicated negligible impacts in contrast to use-phase, with findings suggesting that the operation of buildings accounts for almost 91% of the total life-cycle energy consumption over an average 50-year lifespan (Sharrard et al., 2008; Singh et al, 2011).

In order to truly understand the effects of a process such as demolition or deconstruction on a building, remaining limited to specifically environmental or economic criteria is not enough. A sustainable hybrid LCA framework may be more appropriate to consider as it combines the principles of both I-O and process-based LCA modeling approaches, and delves into the multiple dimensions of sustainability to address the issue of structural abandonment.

2.5.3.1. Sustainable Development

Sustainability is a global concept that seeks to balance environmental, economic and social interests over time (Leigh and Patterson, 2006; Zamagni, 2012). As defined in the Brundtland Report of the United Nations World Commission on Environment and Development, “sustainable development is the process that strives to meet the needs of the present without compromising on the ability of future generations to meet their own needs" (Brundtland Commission, 1987). An integrated, transformative, multi-impact decision-making perspective, demonstrating relationships between supply chain processes, is thus essential for policy interventions to occur at multiple stages over the lifespan of buildings (Zamagni, 2012). This can also cater to the interconnectivity between contractors, businesses, and governments trying to achieve common goals and reach a sustainable solution for the problem of structural abandonment in the construction industry.

2.5.3.2. Three Pillars of Sustainability

As mentioned above, the three-pillar approach to sustainable development – Planet, People, and Prosperity (or Profit) – has been prioritized unevenly, and received differing degrees of attention over the years (Shin et al., 2015). Having its origins from the advocacy of the green movement of the 1960s, the sustainability assessment debates were dominated by environmental issues, including natural resource consumption, emissions and greenhouse gas accounting, carbon and water footprinting, etc. This led to the initial development of the traditional process-based and EIO-LCA methods, and subsequent hybrid LCA methods to produce better LCA results (Halog and Manik, 2011). Further, tools such as the LCC and lean practices enabled better economic assessments to focus on the improvement of financial capability by reducing the negative impacts of products and processes (Shin et al., 2015).

In this context, it can be said that social considerations are seemingly treated as an 'afterthought' in sustainability, by remaining limited to account for the politics and implications of LCA with tools such as Corporate Social Responsibility (CSR) and Social Life Cycle Assessment (SLCA), instead of playing the role of a third and equally integral pillar of sustainable assessment frameworks (Shin et al., 2015). Moreover, despite several attempts being made to evaluate the social implications of building sectors on stakeholders such as building occupants, workers, and local communities, the SLCA methodology still lacks a broad consensus on adequate indicators and hence, a standardized procedure (Halog and Manik, 2011).

Furthermore, social indicators measure the degree to which cultural values and societal goals are achieved, which in terms of performance metrics, are not easily quantifiable and subject to swifter changes across different time scales, countries, and interest groups (Halog and Manik, 2011; Shin et al., 2015). Some critical indicators that are included in SLCA frameworks are health and safety, employment opportunities, workforce education and training, quality of working conditions, knowledge management, and social acceptance and dialogue (Halog and Manik, 2011).

The progress in the field of sustainable development has been concurrent with the integration of dynamic ecological and economic models, and the inclusion of non-linear social theories in LCA methodology (Zamagni, 2012). It is this integration that has helped address the complexity, uncertainty, and urgency characteristically presented by the questions of sustainability, be it climate change or urban revitalization. Conversely, this has also heightened the facets of multi-disciplinary variables, multi-spatial time scales, challenges of poor information and data availability, etc. over the lifecycles of products and processes, along with the introduction of a range of local, national and global stakeholders, and their interactions (Zamagni, 2012).

2.5.3.3. Life Cycle Sustainability Assessment

The Life Cycle Sustainability Assessment (LCSA) framework aims to bring in a wider perspective than the traditional LCA framework by evaluating not only the natural environmental impacts of a product or process, but also integrating associated socioeconomic factors into the equation (Zamagni, 2012). In the construction industry, the LCSA approach provides a technical basis for assessing the environmental, economic, and social metrics related to design, construction, operation, and disposal of built assets and infrastructure systems, and thereby covers the three pillars of sustainability in the assessment framework (Hunkeler and Rebitzer, 2005; Hossaini et al., 2015).

The LCSA equation intends to capture the overall sustainability of solutions to lifecycle-based questions related to building products and processes by assessing the three main categories: environmental protection, economic optimization, and social acceptability (Hossaini et al., 2015). For a product or process, this is formalized as:

$$\text{LCSA} = \text{LCA} + \text{LCC} + \text{SLCA}$$

Where, the LCA reviews the hybrid input-output analyses of environmental criteria; the LCC studies the costs and economic impacts of acquisition, manufacturing, operation or disposal options; and the SLCA evaluates the interactions and experiences of different users and stakeholders (Hunkeler and Rebitzer, 2005; Halog and Manik, 2011; Zamagni, 2012; Hossaini et al., 2015).

Despite being more holistic in its approach by considering impacts across the environment, economy, and society, the LCSA framework presents several concerning factors with regard to its accuracy and completeness. First, the data collection for inventory analysis over the lifecycle of products and processes can become an exhaustive and daunting task. This is especially relevant in the case of building assemblies, which will require aggregated LCAs and LCCs associated with building materials, design and construction processes, etc. (AIA, 2010). For example, the LCSA framework for deconstruction or demolition of a house will not only consider the LCA of the process itself, but also, the LCAs of salvaged building material, waste and debris generated, equipment and labor utilized, and the like. Moreover, in order to maintain data quality, these comprehensive LCA databases will need industry-wide consistency.

Further, different input loadings have different functional units of measurement associated with them, and it is not possible to objectively quantify every impact in a real-world scenario. Typically, weighting and benchmarking of impact categories are sought to offer a basis for comparing the products or processes under consideration in decision-making processes. However, the weighting system might vary across multiple stages of the lifecycle, and also be subject to generalizations by the limited set of authorities, stakeholders, occupants, and users involved. Even though perspectives and judgments can contribute significantly in case a more directed response to the specified scope of the

LCA is required, the approximated assessments can render the results of the LCSA to be subjective and questionable (AIA, 2010). It is this uncertainty, an inevitable and inherent characteristic of sustainability assessments, that needs to be accommodated and managed in the long run (Zamagni, 2012).

In conclusion, it can be said that the LCSA framework is a highly sophisticated decision-support tool, with a broadened ability to assess and integrate impacts of products and processes over their lifecycles (Guinee et al., 2011; Zamagni, 2012). Still in its nascent stages of development, the methodology of the LCSA framework remains conceptual and open to the inclusion of normative strategies, software, and other mechanisms of application. Further, the multiple criteria and indicators involved in the traditional LCA metrics need to be reconciled into a few vital variables that can dictate the veracity of the LCSA framework. This is critical to the optimal performance of a resilient and robust sustainability assessment system.

2.6. CONCLUSION

This chapter lays the foundation for the problem, the process and the proposal to achieve the objectives of the research. First, the history and background of structural abandonment is presented which stipulates the nature of the receiving end of demolition and deconstruction processes. Further, the typical techniques and relevant regulations involved in the execution of demolition and deconstruction work are described in detail. Lastly, the proposal of a sustainable LCA (LCSA) framework is discussed to understand and find a solution for the real-world scenario at hand – the adoption of the more suitable disposal process at the end of the useful life of a building. The methodology for creating the LCSA framework, as well as identifying potential impact categories of demolition and deconstruction across the environment, economy and society, is addressed in the next chapter.

CHAPTER 3
3.0. LIFE CYCLE SUSTAINABILITY ASSESSMENT FRAMEWORK

3.1. OVERVIEW

This chapter reviews the methodology of developing a Life Cycle Sustainability Assessment (LCSA) framework in order to solve the challenges pertaining to structural abandonment in the U.S., focused on the processes of deconstruction and demolition and their impacts across the environment, economy and society.

As discussed in the previous chapter, demolition is widely regarded as a quick and effective process with moderately low costs. However, there are concerns with regard to the environmental impacts of this building removal method, primarily due to the burden it places on landfills (EPA, 2008; Diven and Shaurette, 2010; Zahir et al., 2016; MSU CCED, 2017). Similarly, although deconstruction may be a socially, environmentally, and sometimes economically beneficial approach for the removal of buildings, not all buildings are good candidates to be deconstructed due to issues such as project complexity and completion time. Furthermore, for deconstruction to progress and be popular, the building materials recovered from the deconstruction process need to foster a comprehensive value chain of production, supply, logistics and consumption of building materials from salvage of demolition waste. More often than not, industry perception and risks such as heavy upfront investment and immaturity in salvage material reuse markets deter contractors from deploying deconstruction in building removal projects (Pun et al., 2005; EPA, 2008).

Despite it being prudent to take a cost-benefit ratio into consideration while deciding upon the better alternative between demolition and deconstruction to address structural abandonment, it is not enough to account the justification in terms of dollar value only (Pun et al., 2005; EPA, 2008). An integrated and transdisciplinary sustainability assessment framework is essential to understand the multiple parameters and factors that come into play in the construction and demolition (C&D) industry. In order to support and strengthen the case for the more sustainable approach at the end-of-life stage of a building, strategic and informed decisions need to be made to adopt greener and leaner initiatives for societal development and to be able to anticipate future changes and adapt better – one such all-encompassing decision-support tool is developed below.

3.2. DEFINING THE BOUNDARY OF THE LIFE CYCLE ASSESSMENT FRAMEWORK

In order to create a comparative framework that incorporates a holistic overview of how sustainable either demolition or deconstruction processes prove to be in addressing structural abandonment and blight, the current geographic scope and condition of the problem must first be established. The absence of a universal definition of abandonment in the U.S. has created gaps in data sources, and identifying the exact number of affected properties and communities nationally is difficult. Thus, for the purpose of this research, the focus will remain limited to data based on the demolition and deconstruction of abandoned residential property in Michigan.

In this regard, it is also pertinent to mention the nature of the abandoned residential properties found in Michigan. Through review of data from the U.S. Census Bureau 5-year estimates, the typical residential archetype was the detached, single-family home, 1,500 sq. ft. in size and built prior to 1950 (MSU CCED, 2017). Most of these homes also exhibited moderate to severe problems characteristic of abandoned properties, including moisture damage and dilapidated interiors. However, building materials such as structural and non-structural wood, asphaltic roof shingles, drywall, and vinyl flooring, were found to be in salvageable condition, and therefore, suitable for deconstruction activities (MSU CCED, 2017).

Furthermore, the Life Cycle Assessment (LCA) of the impact categories of demolition and deconstruction across the environment, economy, and society will remain confined to the end-of-life stage of the building (i.e. from the end of its functional use to its final disposal). This will include the impacts of on-site operations executed during demolition and deconstruction, transportation of workers and equipment to the site, C&D waste generation, and disposal issues. The LCA boundary will also include the transportation of waste materials to landfills, and the transportation of salvaged materials to secondary recycling centers. However, associated product-based lifecycles such as the downstream facets of cascade recycling of salvaged materials and the value chain dynamics of secondary reuse markets will *not* be included. Figures 3.1 and Figure 3.2 depict the sequence of activities that are usually representative of demolition and deconstruction projects and fall within the boundary of the scope of this study.

Figure 3.1: Sequence of Demolition Project

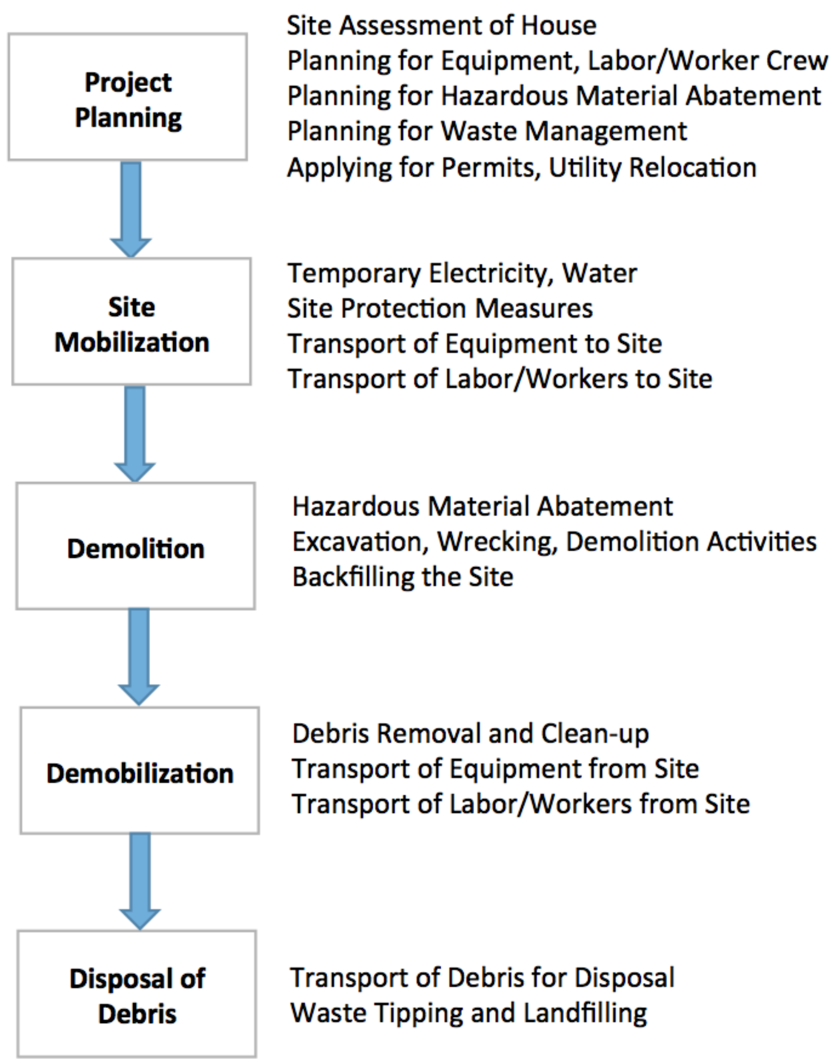
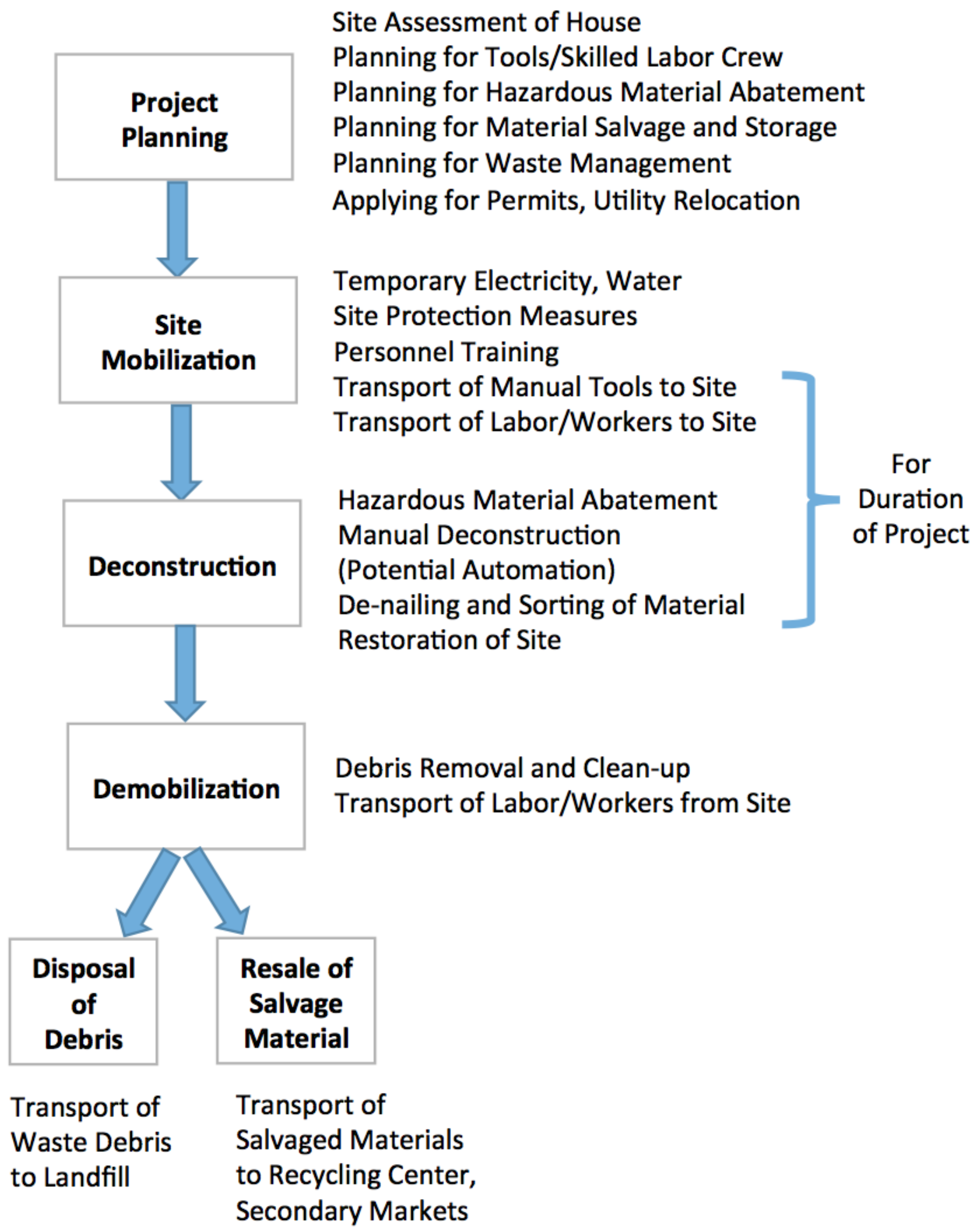


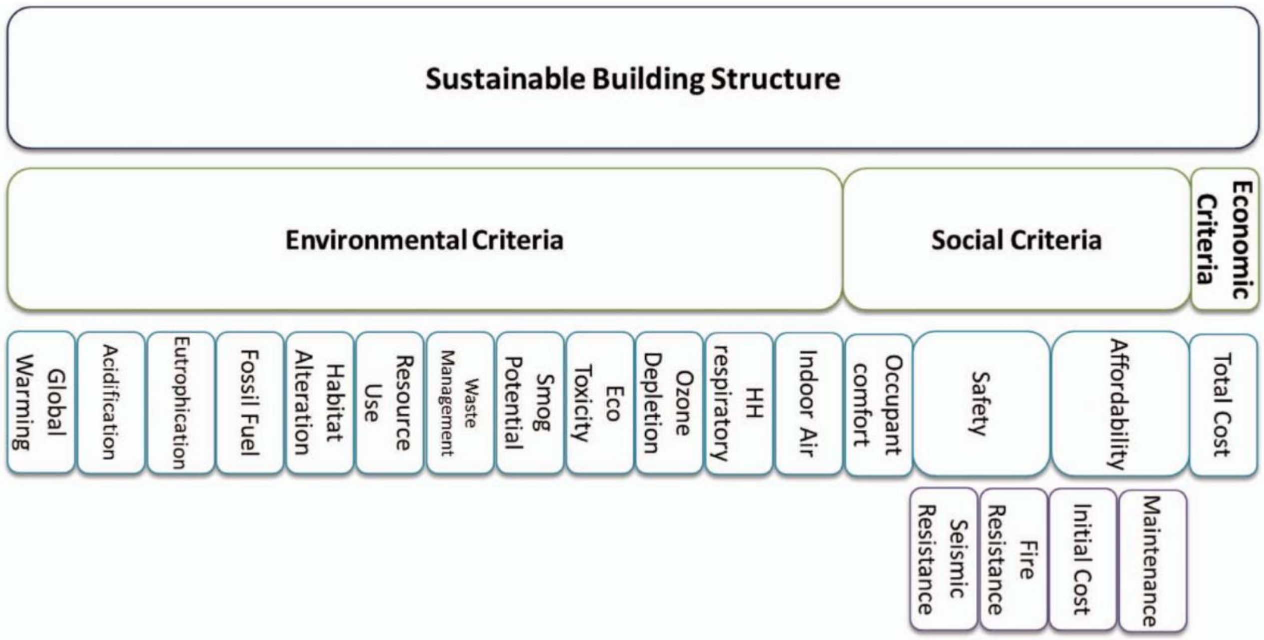
Figure 3.2: Sequence of Deconstruction Project



3.3. Impact Categories of Demolition vs. Deconstruction

The LCSA framework is underscored by the axiom that all phases in the lifecycle of a product or a process can cause environmental and socioeconomic consequences (Zamagni, 2012; Hossaini et al., 2015). Figure 3.3 depicts the typical impact categories taken into consideration across the disciplines of environment, society, and economy, while implementing a sustainability assessment of a building (Hossaini et al., 2015). These categories are found to be common to all the phases of the lifecycle of a building, including raw material extraction and processing of building materials, transportation and installation onsite, operation and maintenance, and ultimately end-of-life recycling and waste management.

Figure 3.3: Impact Categories in Sustainability Assessment for New Construction



(Source: Hossaini et al., 2015)

To remain within the confines of the boundary of this research, only selected environmental, economic, and social categories pertaining to the end-of-life, abandoned, and blighted state of buildings are considered for the LCSA framework. Further, the processes of demolition and deconstruction of an abandoned building have a number of impacts associated with them as reviewed in Chapter 2. These are compiled into the LCSA criteria and discussed below.

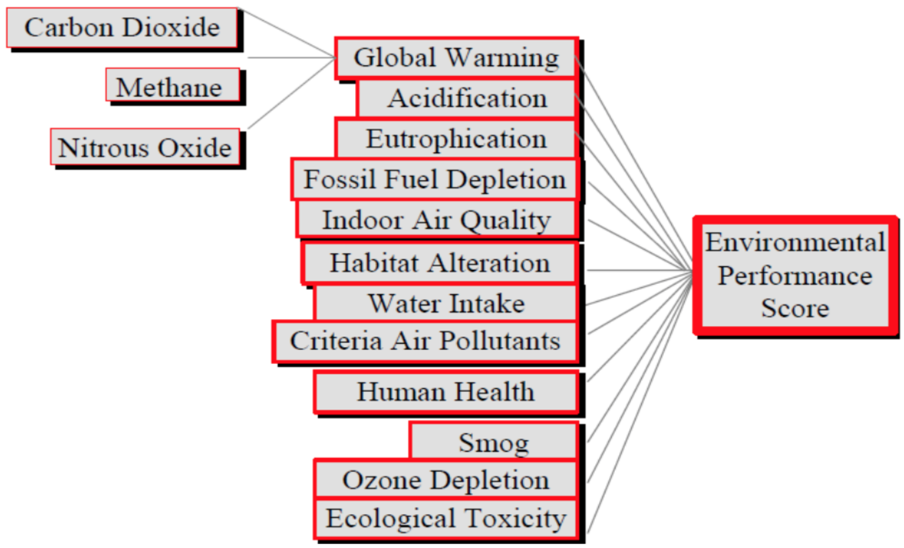
3.3.1. Environmental Impacts

Several studies across the disciplines of environmental sciences, engineering, architecture, planning, and construction management have attested to the promise of deconstruction in reducing the overall environmental impact that is often associated with demolition (Guy and Gibeau, 2003; Leigh and Patterson, 2006; Denhart, 2010; Zahir et al., 2016; MSU CCED, 2017). Environmental loadings are typically evaluated in terms of their functional units, and then normalized according to nationally recognized standards established by agencies such as Environmental Protection Agency (EPA), Occupational Safety and Heath Administration (OSHA) and National Institutes of Health (NIH) (Stranddorf et al., 2005; AIA, 2010).

Figure 3.4 illustrates the potential environmental impact categories used by the Building for Environmental and Economic Sustainability (BEES) software to measure environmental performance of buildings for the construction of new buildings (AIA. 2010). As an example, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (NO_x) emissions are shown to add to the Global Warming Potential (GWP) of the building. Again, these emissions can be classified to emerge from different phases over the entire lifecycle, such as from gaseous fumes of vehicles used to mobilize materials and equipment onsite during the construction of the building.

For the purpose of this study, five relevant environmental impact categories have been identified based on the operations that entail demolition and deconstruction processes. These include 1) generation of waste; 2) air, 3) water, and 4) soil pollution; and 5) depletion of non-renewable energy resources.

Figure 3.4: BEES Model for Environmental Impact Categories



(Source: AIA, 2010)

3.3.1.1. Landfilling of Debris

The current practice of demolition of abandoned buildings typically consists of turning them into rubble; recovery of building material is incorporated into the demolition work only when economically feasible (Zahir et al, 2016). Waste materials and debris generated from C&D activities constitute the largest by mass fraction of solid wastes in urban areas (Achillas et al., 2013). In fact, the National Association of Home Builders (NAHB) Research Center estimated that “If 25 percent of the buildings demolished every year were deconstructed, approximately 20 million tons of debris could be diverted from landfills” (Denhart, 2010).

As the majority of solid waste is landfilled in the U.S., there are rising concerns about the landfills nearing or reaching their capacity. In the Great Lakes region, it has been found that companies in other states and Canada preferred transporting solid waste to Michigan landfills as opposed to dumping in their own due to the state’s comparatively low landfill costs (approximately $46 per ton of waste) (MSU CCED, 2017). The environmental impacts of landfilling include soil and water contamination, air pollution as a result of odors, smog and release of harmful gases, aesthetic degradation, and landscape blight (Achillas et al., 2013; Nathanson, 2016). Further, Asbestos Containing Material (ACM), Lead-Based Paints (LBPs), and other toxic stains and adhesives that are commonly found in abandoned buildings can also cause contamination and need to be disposed in compliance with federal regulations (EPA, 2017).

3.3.1.2. Air Pollution

Air pollution caused by demolition operations is often the result of heavy use of machinery, and the wrecking of the building. Equipment like excavators, loaders, forklifts, etc. are powered by diesel, which burns more carbon into the air than other fuels (Ajufoh and Ogwuche, 2016). The exhaust fumes from equipment, transportation vehicles, and generators emit smoke, diesel soot, and other criteria air pollutants directly into the atmosphere, thereby compromising the overall quality of ambient air near the site.

Demolition operations also result in a large amount of C&D waste generated that are hauled from the site in trucks and disposed in landfills, which in turn, adds to the use of transportation vehicles and the associated release of air emissions. Further, landfill biodegradation can release toxic gases, the most serious of which is methane. Methane (CH_4) is a poisonous gas, more potent that carbon dioxide (CO_2), that is naturally produced during the decay of organic matter and decomposition of solid waste material (Nathanson, 2016).

Another major concern about demolition is the large amount of dust that is produced as a result of dismantling and breaking down the structure. In addition, old paint found in abandoned homes (built before 1978) can create toxic lead dust that can remain present long after the work activities have been completed, and can then be blown into other homes in the neighborhood, parks, playgrounds and public places. A study conducted in Maryland found that dust fall during demolition is six times the allowed EPA standard for lead in paint, dust, and soil (MSU CCED, 2017). ACM, found in old flooring, siding, roofing and wall systems, also presents a similar environmental hazard.

3.3.1.3. Water Pollution

Wet demolition is a helpful technique where the building and the site are repeatedly wetted with water to suppress the emission of dust into the air (Zahir et al., 2016). However, this increases the level of water consumption on site, and can result in flooding and storm water runoff when not executed efficiently (Ajufoh and Ogwuche, 2016). Further, contaminated leachate that generates in landfills as a result of decomposition of demolition waste, can percolate and seep into groundwater or nearby surface water sources, and cause water pollution and consequently jeopardize public health (Nathanson, 2016). In comparison, deconstruction has minimal impacts onsite by virtue of its manual and labor-intensive nature, which reduces the overall generation and disposal of waste.

Figure 3.5: Wet Demolition for Dust Control

(Source: https://www.epa.gov/sites/production/files/styles/large/public/2014-06/dust-control-fema-cropped.jpg)

3.3.1.4. Soil Pollution

The excavation of structural foundations can result in site disturbance and also expose the site to soil erosion. Moreover, as discussed above, landfilling of the C&D debris such as wood and metal objects, concrete and drywall rubble, and asphalt that are generated through the processes of demolition and deconstruction, can pose a significant threat to environmental quality (Nathanson, 2016). In this case, the soil permeability of the landfill and other soil disposal sites usually proves to be important with regard to soil pollution. Greater permeability leads to higher risks of pollution (Nathanson, 2016). Open dumps can also become breeding grounds for disease-carrying rats, mosquitos, and flies, and emanate unpleasant odors, wind-blown debris, and other such nuisances for surrounding areas.

3.3.1.5. Energy Use and Fuel Consumption

Fossil fuel depletion is another environmental impact category frequently found in LCA studies of the built environment. This impact category is typically reported in mega joules (MJ) and is calculated as a functional unit associated with the total operational energy use and fuel consumption over the entire execution of demolition and deconstruction activities (AIA, 2010). Specifically, this category includes on-site electricity use and gasoline and diesel consumption by generators, mechanical equipment and tools, transportation vehicles plying to landfills, recycling centers, etc., and transportation of labor to site (Sharrard et al., 2007). Demolition activities usually employ heavy machinery and equipment for faster operations on site, where as deconstruction activities involve more manual work and take a longer duration to complete (Zahir et al., 2016). Factoring in this time duration of energy and fuel consumption that each approach requires potentially creates a comparable energy footprint for both demolition and deconstruction.

3.3.2. Economic Impacts

A host of factors influence the demolition and deconstruction costs of a project. Depending on the scope of work, the costs can vary greatly and be controlled by the size of the building, location and weather considerations, schedule and time limitations, mechanical equipment and crew availability, existing site and utility conditions, salvage conditions, local government and municipal regulations, hazardous material inspections, etc. (Diven and Shaurette, 2010; Zahir et al., 2016; MSU CCED, 2017). However, it has been found that structural removal and debris disposal costs can be as high as 80 to 90 percent of the total project costs (Zahir et al., 2016).

In Michigan, land banks and other such governmental entities are ultimately responsible for demolition of abandoned properties and revitalization of the local community. Thus, costs of addressing abandonment and blight are often borne by taxpayers of the municipality in which the demolition and deconstruction take place, and it becomes imperative to understand and monitor economic impacts in the selection of the process used to address the issues of abandonment and blight. (MSU CCED, 2017).

Further, even though there are some federal grants and funding sources set in place for the elimination of abandoned residential properties, the allocated money is required to be used for the holistic purpose of community revitalization and not in direct support of demolition and deconstruction costs (MSU CCED, 2017). The Neighborhood Stabilization Program (NSP) by the U.S. Department of Housing and Urban Development (HUD) and the Hardest Hit Fund (HHF) by the U.S. Department of Treasury are some examples of federal programs developed to rehabilitate vacant and foreclosed homes.

According to Guy and McLendon (2003), typically the net costs of demolition and deconstruction can be calculated as:

Net Demolition Costs = (Demolition + Disposal) – (Contract Price)

Net Deconstruction Costs = (Deconstruction + Disposal + Processing) – (Contract Price + Salvage Value)

However, for qualifying to stay within the scope of this study, the economic and cost impacts of only demolition and deconstruction operations on site, and landfill disposal methods are elaborated upon.

3.3.2.1. Energy and Fuel Costs

Demolition equipment, trucks, and other vehicles account for the energy and fuel consumption on site in terms of electricity, diesel fuel, and gasoline usage. However, a wide variability in usage patterns due to project type, age and maintenance condition of the equipment, operator and driver styles etc. can directly impact project costs (Athena Sustainable Materials Institute, 1997). Deconstruction, on the other hand, utilizes minimal equipment for the operations, relying largely on a skilled labor force. However, the transportation of the workforce to the site everyday for the entire duration of the project also accounts for vehicular usage. Further, the distance between the site, landfills and material recycling centers, for hauling and tipping costs also need to be taken into account (MSU CCED, 2017).

3.3.2.2. Equipment and Labor Rates

The number of workers and amount of equipment on the demolition or deconstruction project is dependent on the productivity, and often determined by the optimum scheduling of the activities on site (ASMI, 1997). However, as the funders of the demolition or deconstruction activity impose accelerated timelines for the project, the required rates of productivity and performance are usually high (MSU CCED, 2017). It should be noted that though deconstruction is found to be more cost-effective than demolition in terms of net costs when considering reduced landfill disposal costs because of the salvage value of recovered building materials, the work also requires skilled labor to salvage more material with the least damage over a much longer project schedule (Zahir et al., 2016).

Moreover, due to the noisy nature of demolition, the work is carried out with time restrictions or during certain hours in the day, and often results in overtime rates that add to project costs. Renting of specialized machinery and vehicles is also another factor to be taken into consideration.

3.3.2.3. Hazardous Material Abatement

The recovery, sorting and separation, processing, and disposal of building materials and debris in demolition and deconstruction can be a lengthy, tedious and expensive process. Further, as asbestos and lead are commonly found in homes built in the mid-20th century, a hazardous material abatement process is a necessary component of rehabilitation projects (EPA, 2014). These costs can range from $1,000-$42,500 depending on the size of the project, with an average cost of $9,514 per project (MSU CCED, 2017). Overall, the impact of hazardous material abatement in terms of costs remains constant across both processes.

3.3.2.4. Value of Salvage Materials

As iterated earlier, opportunities for the reuse and repurposing of building materials are typically minimal in the demolition industry and recycling of C&D waste is carried out only when feasible (Zahir et al, 2016). This results in majority of the demolished debris being landfilled, adding to waste transportation and disposal costs. Conversely, deconstruction prioritizes the recovery of building materials, with the primary objective being to maximize their value in a secondary market (MSU CCED, 2017). In fact, the amount of recyclable material in the structure and its salvage value helps to reduce the overall cost of the project.

3.3.2.5. Tax Exemptions

Many deconstruction operations are run by for-profit and non-profit organizations, which offer a tax-deductible donation benefit to clients in their deconstruction bids and cost estimates. Table 3.1 shows the cost comparison between deconstruction and demolition work with salvage and tax deductions for a typical 2,500 sq. ft. home by Piece by Piece Deconstruction, a for-profit organization based in Massachusetts and New York (Zahir, 2015). The net cost for deconstruction is calculated to be lower than that for demolition, but many professional appraisers believe that the allowances are not realistic and can be affected by factors such as age, condition, quality and design of the property (Zahir et al., 2016).

Table 3.1: Cost Comparison of Deconstruction and Demolition

Cost items	Deconstruction	Demolition
Labor cost	$16,875	$10,000
Disposal cost	$1,667	$6,250
Total cost	**$18,542**	**$16,250**
Salvage value	$7,500	$0
Tax savings	**$2,625**	**$0**
Final cost	**$15,917**	**$16,250**
Salvage value is based on used building materials selling for 1/3 of their new price – the industry average. Factors such as age, condition and design obviously affects the value of salvaged materials. Tax savings are based on an owner tax bracket of 35%.		

(Source: http://www.piecebypiecedecon.com/costs.html)

3.3.3. Social Impacts

Social impacts measure the degree to which societal goals are achieved at local, national or global levels, and the benefits are not easily quantifiable. This is because they are weighted differently by different interest groups and in different countries and regions, and their evaluation is subject to swifter changes over time depending on cultural, technological, or economic change (Halog and Manik, 2011). Even though there are several indicators that can be associated with social sustainability assessment over the lifecycle of a process, only the ones pertinent to the demolition and deconstruction in the C&D industry are compiled and discussed below.

3.3.3.1. Public Health

Demolition and deconstruction are inherently hazardous processes, as the typical work environment can become potentially dangerous due to the presence of contaminants such as asbestos, lead, particulates, etc. that can leech into the air, water, soil and persons near the site. Demolition dust containing air-borne cement particles and silica can cause 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 and Kumar, 2016; Bandopadhyay, 2016).

In this context, the Disability Adjusted Life Year (DALY), established by the World Health Organization (WHO), can be used to measure the aggregated human health impact that is expressed in terms of cumulative number of years lost due to ill health, disability, or early death (Arvidsson et al., 2016). The metric is calculated as a combination of years of life lost (YLL) due to premature mortality, and years of life lost due to disability (YLD) when living with a disease or its consequences. DALY can be incorporated into different environmental and social LCAs; however, varying social and cultural preferences can dictate the weighting and loading of impact categories (Arvidsson et al., 2016).

3.3.3.2. Jobsite Safety

At the most basic level, it can be said that safety and sustainability concurrently focus on the same objective - the wellbeing of human resources. Thus, while selecting a demolition and deconstruction contractor, a culture of safety should always be prioritized keeping in mind the quality of the project. As mentioned above, the level of noise on site, and occupational exposure to contaminants and hazardous materials can pose a serious concern to worker health in both demolition and deconstruction projects. However, several other factors also lay emphasis on stringent safety measures on site, including the hazards that arise on all construction sites. Poor worker training, unskilled and inefficient operation of equipment and tools, sloppy housekeeping and site logistics, overstaffing and congestion due to short project schedules, etc. can lead to decreased productivity and a greater possibility of accidents occurring on site (ASMI, 1997).

3.3.3.3. Noise

Even though logistical considerations and project planning are given due importance in demolition operations, activities such as jackhammering, sawing, crushing, and running equipment engines generate noise and vibration on site and can create noise pollution, affect the health of workers, and disturb the peace of the surrounding neighborhood (Zahir, 2015; Ajufoh and Ogwuche, 2016). On the other hand, deconstruction work consists of sawing, shearing, and selective dismantling of building materials, structural elements, wall sections, etc. that result in lower cumulative noise levels both on and off site.

3.3.3.4. Job Creation and Community Involvement

As discussed in Chapter 2, deconstruction encompasses largely manual processes in order to retain the structural integrity and quality of building materials salvaged from abandoned homes that are identified for demolition. This creates a need for skilled and trained local workers employed in the revitalization of their community, thereby encouraging the growth of economic opportunities, but more importantly, instilling a sense of belongingness and boosting morale in distressed neighborhoods affected by abandonment and blight (EPA, 2008; MSU CCED, 2017). Even though demolition operations require labor in the form of equipment operators and site supervisors, the dependence is primarily on machinery and does not showcase potential social benefits as deconstruction does (Zahir et al., 2016).

3.3.4. Summary of Impact Categories

In summary, Figure 3.6 and Figure 3.7 illustrate the identified environmental, economic, and social impacts of demolition and deconstruction through their respective sequence of operations on projects. Here, it is also pertinent to mention that the overall level of impacts for both the processes primarily depends on the duration of the project. For example, due to the largely manual nature of deconstruction projects, the costs for employment of skilled workers and their transportation to the site until completion of the work might have a much greater impact when compared to the costs for the rental of demolition equipment and energy and fuel costs for demolition projects.

In order to address the objective of the study and create the LCSA framework, it is necessary to understand how the different impact categories across the criteria of the environment, economy and society apply to both demolition and deconstruction approaches. This is done by utilizing a two-step method: 1) Based on the qualitative understanding of the level of impact of each category; and 2) Based on the loading and measurement of impact of each category.

Figure 3.6: Impacts Across Demolition Project

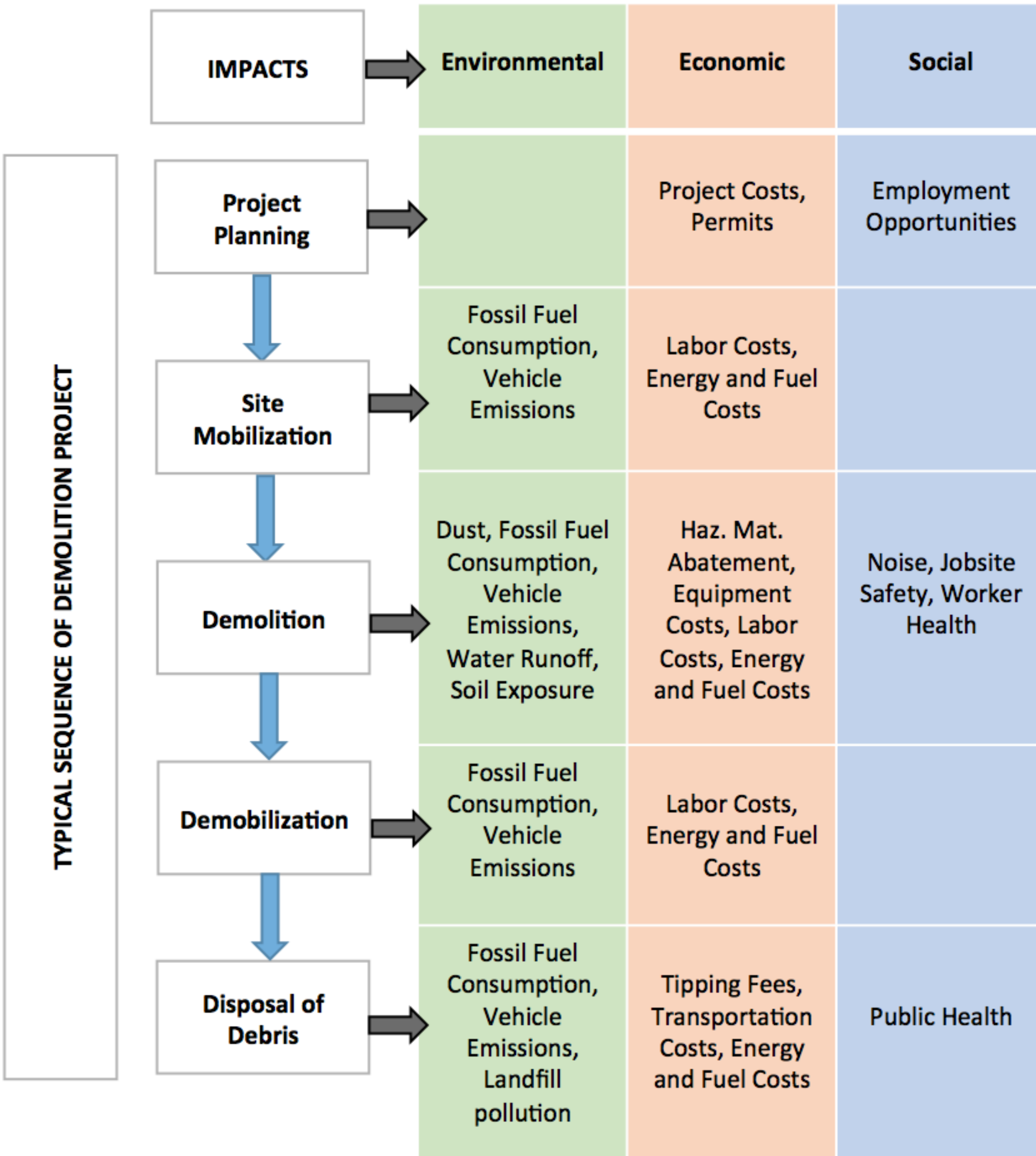
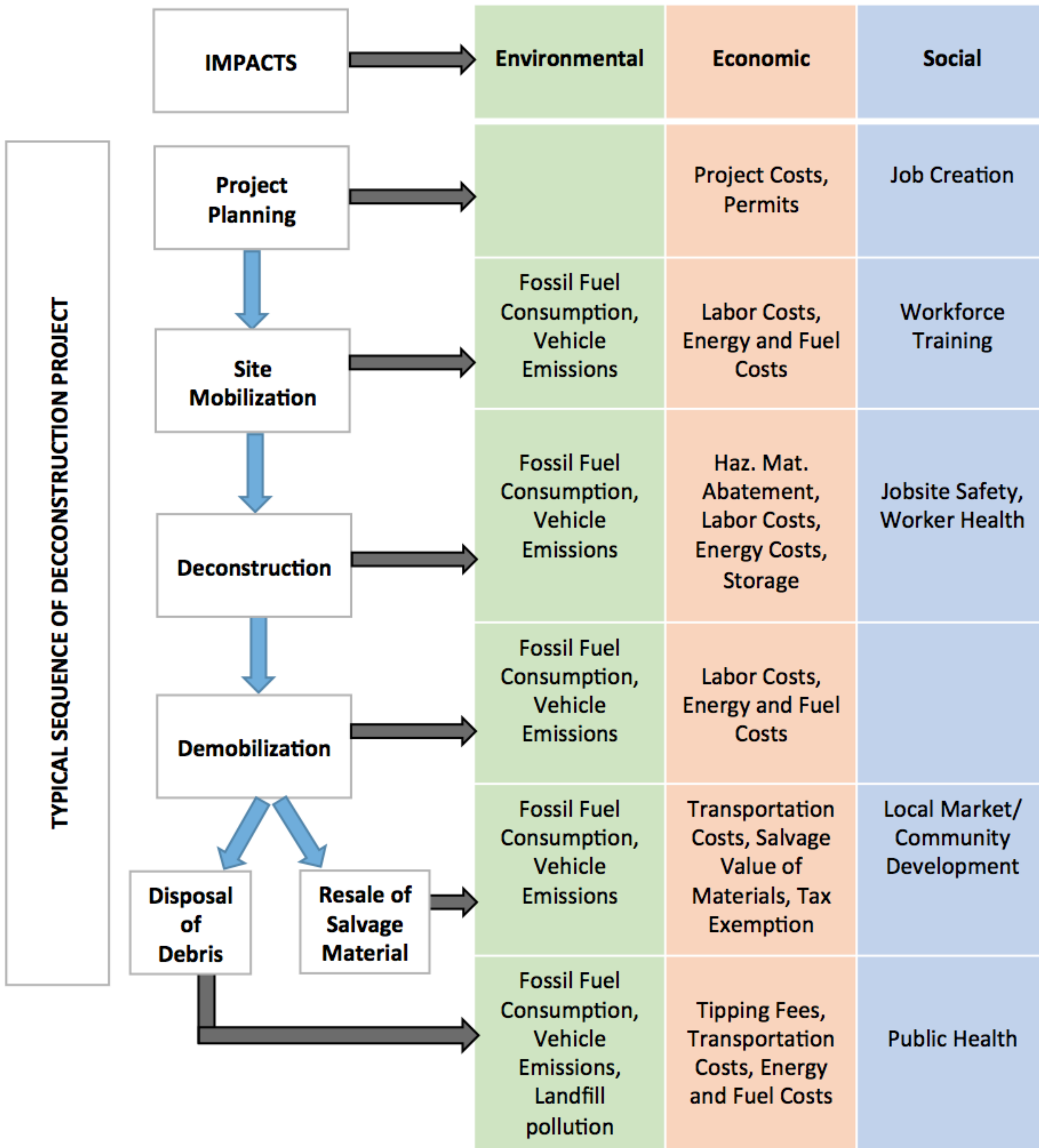


Figure 3.7: Impacts Across Deconstruction Project



3.3.4.1. Level of Impacts

Table 3.2 summarizes the inferences for the 14 identified impact categories on the basis of subjective measures of heavy (bad), moderate, or light (good) levels of impact, corresponding to the extent of their consequences as discussed in the above sections and derived from various sources of literature.

Table 3.2: Relative Comparison of Impact Categories Across Demolition and Deconstruction Activities

IMPACT CATEGORY		**LEVEL OF IMPACT**	
		DEMOLITION	**DECONSTRUCTION**
ENVIRONMENTAL			
Landfilling of Debris		**Heavy** impact due to disposal of waste generated in the process	**Light** impact due to salvage of materials and conservation of resources
Pollution	Air	**Heavy** impact due to dust, emissions from equipment and trucks, landfilling	**Light** impact due to more manual work, less mechanical wrecking, salvage of materials
	Water		
	Soil		
Energy Use and Fuel Consumption		**Heavy** impact due to use of equipment and machinery on-site, hauling waste to landfills	**Moderate** impact due to more use of manual labor, but transportation of labor to site
ECONOMIC			
Energy and Fuel Costs		**Heavy** impact due to use of equipment on site and trucks to landfills	**Heavy** to **Moderate** impact due to transportation of labor to site, and salvaged materials to recycling centers

Equipment and Labor Rates	**Moderate** impact due to shorter duration of operations on site	**Heavy** impact due to high level of skilled labor, and workforce training
Value of Salvaged Materials	**Heavy** impact due to no recovery and recycling of building materials	**Light** impact due to high quality recovery and segregation of building materials
Hazardous Material Abatement	**Heavy** impact due to the presence of asbestos and lead in abandoned homes	**Heavy** impact due to the presence of asbestos and lead in abandoned homes
Tax Exemption	**Heavy** impact due to no recovery and recycling of building materials	**Light** impact due to recycling and resale of salvaged materials
SOCIAL		
Public Health	**Heavy** impact due to hazardous nature of operations	**Moderate** impact due to emphasis on manual labor and workforce training, but risk of exposure
Jobsite Safety	**Heavy** impact due to hazardous nature of operations	**Moderate** impact due to emphasis on manual labor and workforce training, but risk of exposure
Noise	**Heavy** impact due to use of equipment and machinery on-site	**Light** impact due to more use of manual labor and small tools
Job Creation and Community Involvement	**Moderate** impact due to more use of equipment and machinery on site	**Light** impact due to manual operations, secondary markets and growth of economy

3.3.4.2. Loading of Impacts

According to the ISO 14042, LCA methodology includes several mandatory steps from inventory analysis to the interpretation of data (Stranddorf et al., 2005). The first step involves the 'classification' of data, where the impact categories are defined and the exchanges, inputs, loadings, etc. from the inventory are assigned to the impact category according to their contribution. The second step involves the 'characterization' of data, where the loadings are converted to common units and aggregated within each impact category to calculate a numerical result for the category. Further, where relevant, global and regional normalization references, weighting factors, and sensitivity analyses need to be taken into account to acknowledge the inherent uncertainties in the data, reflect relative importance of impact categories, and facilitate comparisons (Stranddorf et al., 2005).

For the purpose of this study, only the various types of loadings associated with each classified impact category for the proposed LCSA framework are reviewed. Table 3.3 summarizes these different loadings associated with of each of the 14 impact categories across the environmental, economic, and social consequences of demolition and deconstruction. The environmental criteria follow typical LCA measures such as Global Warming Potential (GWP), Acidification, Eco-toxicity, etc. (Stranddorf et al., 2005). The economic criteria are proposed to be measured in cost dollars ($), while the social criteria have different measures depending upon the varying nature of the impact, as reviewed in literature sources (Arvidsson et al., 2016; Azarmi and Kumar, 2016; Ajufoh and Ogwuche, 2016).

Moreover, all the categories are assessed in metric (SI) units of measurement for ease of normalization of data. For future scope of research, a unified and functional unit of measurement, such as a sustainability index, can potentially be incorporated into the LCSA framework for better accuracy of the comparative analysis of demolition and deconstruction.

Table 3.3: Loadings of Impact Categories Across Demolition and Deconstruction Activities

IMPACT CATEGORY		LOADING	MEASUREMENT
		DEMOLITION AND DECONSTRUCTION	
ENVIRONMENTAL			
Landfilling of Debris		Volume of Debris sent to Landfills	Tons or Kilograms (kg)
Pollution	Air	Volume of Emissions from Equipment	Global Warming Potential (Per kg CO_2 - equivalents) Acidification (Per kg SO_2 – equivalents) Ozone Depletion (Per kg CFC - equivalents) Nutrient Enrichment (Per kg NO_x – equivalents)
		Volume of Emissions from Transportation Vehicles	
		Volume of Emissions from Landfills	
	Water	Volume of Leachate in Landfills	Eco-toxicity (Per Cubic Meter of Water) Human Toxicity (Per Cubic Meter of Water)
		Volume of Storm Water Run-off from Site	
	Soil	Volume of Contaminants in Demolition and Deconstruction Debris	Nutrient Enrichment (Per kg NO_x – equivalents) Eco-toxicity (Per Cubic Meter of Soil) Human Toxicity (Per Cubic Meter of Soil)
		Soil Degradation on Site	

Energy Use and Fuel Consumption	Electricity Use on Site	Global Warming Potential (Per kg CO_2 - equivalents)
	Fuel Use by Equipment	
	Fuel Use by Vehicles	
ECONOMIC		
Energy and Fuel Costs	Electricity Use on Site	In Dollars
	Fuel Use by Equipment	
	Fuel Use by Vehicles	
Equipment and Labor Rates	Equipment Rental	In Dollars
	Prevailing Wages for Workers	
Value of Salvaged Materials	Volume of Building Materials Diverted from Landfills	In Dollars
Hazardous Material Abatement	Removal of Asbestos, Lead	In Dollars
	Hazardous Material Management Plan	
Tax Exemption	Appraisal of Salvaged Material Donation	In Dollars
SOCIAL		
Public Health	Air Quality and Lead Dust Fall	Permissible Exposure Limit (PEL) Per Cubic Meter of Air
	Worker Exposure	DALY
Jobsite Safety	Injury and Contaminant Exposure Rates	Job Hazard Analysis (JHA) Jobsite Safety Analysis (JSA)

Noise	Noise Creation on Site	In Decibels (dB)
Job Creation and Community Involvement	Number of Jobs Created	Qualitative Interpretation of Data from Stakeholder Perspective
	Workforce Training	
	Fair Working Conditions and Salary	
	Growth of Local Economy	
	Community Engagement	

3.4. CREATING THE SUSTAINABILITY FRAMEWORK

In the construction industry, the extent of the work and associated impacts of the demolition and deconstruction activities that are identified in the earlier sections are recognized to be dependent on the various characteristics of the abandoned building. These will also most likely differ across every project. Comprehensive LCAs thus require a substantial inventory of scientifically proven data to be collected. Further, as discussed in Chapter 2, the LCSA equation captures the three pillars of sustainability by incorporating the environmental LCA, Life Cycle Costing (LCC) assessment, and Social Life Cycle Assessment (SLCA) into one holistic framework. Hence, comparing the significance of the results relative to each other proves to be a tedious and difficult task as the basis of assessment and the units for each impact category are different (Gloria et al., 2007). Property developers, demolition contractors and other medium-to-small-sized enterprises usually do not have the resources or the expertise to devote to the project to carry out a complete and systematic LCA for every residence that is to be demolished or deconstructed.

This research aims to create a decision-support tool by incorporating the various impact categories and loadings associated with end-of-life approaches of demolition and deconstruction into an LCSA framework. In order to exemplify the application of the proposed framework in a real-world scenario, the methodology first adopts the review of two case studies of rehabilitation of abandoned residential property, executed by the

Ingham County Land Bank in Lansing, Michigan. Next, the impact categories across the three dimensions of environment, economy, and society are also assessed from the perspective of stakeholders, by means of a Multi-Criteria Decision Analysis (MCDA) method. This results in the development of a hierarchical structure for a comparative matrix that can be utilized to assess the overall lifecycle impacts of demolition and deconstruction, and subsequently throw light upon the selection of the better solution in future research.

3.4.1. Scenario Development

In LCA, a scenario is defined as “a description of a possible future situation relevant for specific LCA applications, based on specific assumptions about the future, and when relevant, also including the presentation of the development from the present to the future” (Pesonen et al., 2000). Typically, scenario development is a joint approach that includes compiling an inventory of relevant inputs and outputs, links between the impacts and operations of the process, and combining and cultivating this objective information with the intuitive knowledge of decision-makers. This study considers the real-world context of selecting either demolition or deconstruction process at the end-of-life phase of a residential building, which is defined by its condition of structural abandonment. The scenarios are presented in the format of two case studies, based in Lansing, Michigan.

<u>*Scenario 1*</u>:

This is designed on the basis of selection of the conventional method of demolition, using equipment and mechanical tools on site. The abandoned residential property studied for the development of this scenario is 524 Baker Street, Lansing. The demolition was executed quickly over 1 day, with the help of 4 workers by using an excavator. The building materials were not salvaged and reduced to demolition debris, which were later hauled to the landfill in trucks and disposed. Figure 3.8 depicts the state of the house prior to its demolition, and Table 3.4 compiles the details of the project after completion.

Figure 3.8: Demolition Project Scenario – 524 Baker Street

(Source: Ingham County Land Bank, 2016)

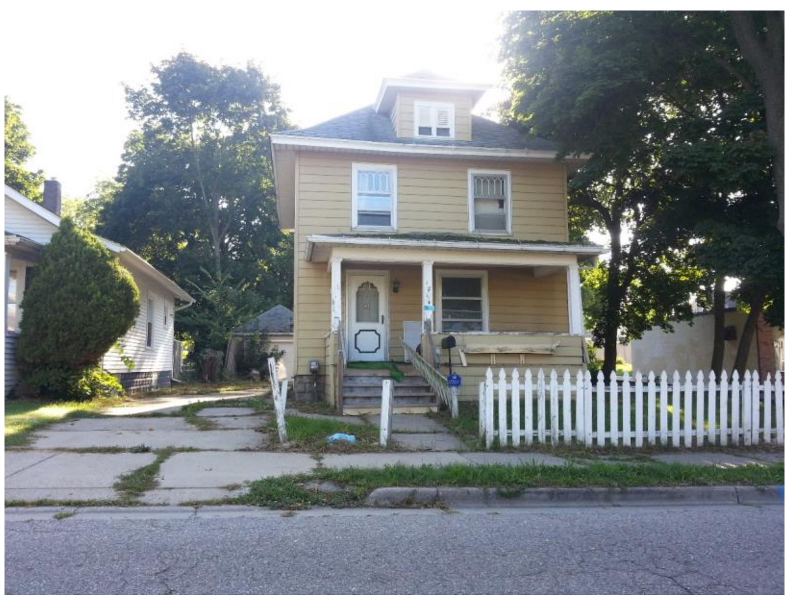
Table 3.4: Demolition Project Details – 524 Baker Street

Scenario 1	524 Baker Street, Lansing	
Total Size	1,100 sq. ft.	
Cost	Hazardous Material Abatement	$7,985
	Demolition and Debris Removal	$5,950
	Debris to Landfill	$1,440 (120 yd. X $12/yd.)
	Soil Backfill and Restoration of Site	$1,350
Labor	4 persons (1 Excavator Operator, 1 Ground Person, 2 Truck Drivers)	
Total Time	40 hours 32 hours (4 persons X 8 hours each) for Demolition 8 hours (2 persons X 4 hours each) for Restoration	

Scenario 2:

This is designed on the basis of selection of the selective method of deconstruction, which involves manual dismantling and sorting of building materials. The abandoned residential property studied for the development of this scenario is 1214 Massachusetts Avenue, Lansing. The project took a longer time to execute, and required a larger and highly skilled labor force, as compared to Scenario 1. The process of hazardous material abatement itself took around 2 weeks to complete. However, most of the house was gutted and torn down during the abatement process, which led to faster deconstruction operations when compared to the number of hours that would be usually expected for a 1200 sq. ft. house. Most of the material, depending on its quality and condition, was salvaged and de-nailed by the deconstruction contractor, and sent to recycling facilities for reuse or resale. However, the rest of the debris was landfilled. Figure 3.9 depicts the state of the house prior to its deconstruction, and Table 3.5 compiles the details of the project after completion.

Figure 3.9: Deconstruction Project Scenario – 1214 Massachusetts Avenue



(Source: Ingham County Land Bank, 2016)

Table 3.5: Deconstruction Project Details – 1214 Massachusetts Avenue

Scenario 2	1214 Massachusetts Avenue, Lansing	
Total Size	1,232 sq. ft.	
Cost	Hazardous Material Abatement	$7,100
	Deconstruction	$24,600
	Debris to Landfill	$660 (55 yd. X $12/yd.)
	Value of Salvage Materials	$4,500
Labor	6 persons (5 workers, 1 Denailer) Deconstruction Contractor sells all the salvaged material	
Total Time	260 hours 134 hours (5 workers X 3-4 days each) for Deconstruction 126 (1 Denailer X 15 days) for Denailing	

In the sections to follow, Scenarios 1 and 2, which are comparable in their size, condition of structural abandonment, geographic location and archetype, intent of rehabilitation, and stakeholders involved in the process of demolition and deconstruction, are utilized as the basis of assessment of the impact categories for either process in the proposed LCSA framework.

3.4.2. Identifying the Stakeholders

The next aspect in developing the LCSA framework is the integration of the knowledge and opinions of the multiple stakeholders associated with the demolition and deconstruction of abandoned residential properties. These stakeholders often have their own interests in the direction of the respective environmental, economic, and social criteria for adopting a sustainable process. This, in turn, contributes to advancing initiatives regarding demolition and deconstruction practices and policies, and reducing the harmful impacts associated with abandonment and blight in the long run.

In the context of rehabilitation of distressed communities in Michigan, the major stakeholders and key participants in the process are identified as the following:

- Land Bank Authorities
- Demolition and Deconstruction Contractors
- Members of Neighborhood/Community who are directly affected
- Secondary Salvage Material Markets, Reuse and Recycling Centers
- Policy Makers, Planners, Local Government

In order to stay within the chosen scope of this report to demonstrate the function of the weighting scheme, only the perspective of the primary stakeholder, i.e. the county land banks that facilitate the rehabilitation of abandoned homes, are taken into consideration. These entities are directly involved in and affected by the dynamics of the demolition and deconstruction sectors in Michigan.

Other major industry stakeholders include: the demolition or deconstruction contractors who execute the work on site, and members of the neighborhood in which the demolition or deconstruction takes place. Their opinions and preferences could potentially be regarded and integrated into a more comprehensive LCSA framework in future research.

3.4.3. Impact Assessment

Weights have been defined as the ‘nexus’ between the quantitative results of LCA and the value-based, subjective choices of stakeholders (Gloria et al., 2007). A simple, flexible and transparent impact assessment methodology using a weighting scheme is thus sought to support the LCSA framework, by drawing from prior knowledge, history, experiences and preferences of decision-makers in the industry.

For the purpose of this study, the primary stakeholder, i.e. the Ingham County Land Bank, evaluated the impacts of demolition and deconstruction processes across the environment, economy, and society, by utilizing Scenarios 1 and 2 developed earlier in Section 3.4.1. Here, the Land Bank assigned each impact category with a qualitative value depending on the extent of their consequences in a real-world scenario, similar in fashion to the impact inferences summarized in Table 3.2 with respect to literature sources. Further, in order to keep the evaluation simple, they were asked to determine which scenario had a 'high/bad' or 'low/good' impact upon execution and completion of the project. A 'medium' value represented a relatively equal or neutral performance associated with the impact category. The responses are compiled in Table 3.6, and discussed in more detail in the following chapter.

Table 3.6: Ingham County Land Bank Scenario Assessment

IMPACT CATEGORY		**LEVEL OF IMPACT**	
		DEMOLITION	**DECONSTRUCTION**
ENVIRONMENTAL			
Landfilling of Debris (Volume of debris)		**High**	**Low**
Pollution	Air (Emissions, fumes, dust)	**High**	**Low**
	Water (Runoff)	**Medium**	**Low**
	Soil (Erosion due to exposure)	**High**	**High**
Energy Use and Fuel Consumption (Electricity, Fuel)		**Medium**	**Medium**
ECONOMIC			
Energy and Fuel Costs		**Medium**	**Medium**

Equipment and Labor Rates	**Medium**	**Medium**
Value of Salvaged Materials	**High**	**Low**
Hazardous Material Abatement	**High**	**Low**
Tax Exemption	**Medium**	**Medium**
SOCIAL		
Public Health	**High**	**High**
Jobsite Safety	**Low**	**Low**
Noise	**High**	**High**
Job Creation and Community Involvement	**Low**	**Low**

3.4.3.1. Multi-Criteria Decision Analysis

The MCDA method is typically used in scenarios featuring high uncertainty and unknown variables, different forms of data and information, multiple interests, and conflicting perspectives (Halog and Manik, 2011). According to Pacheco-Torgal et al. (2013), an MCDA model contains three basic components:

- A set of decision options or scenarios that need to be ranked or scored
- A set of criteria for each option, typically measured in different units, and
- A set of performance measures, which are the raw scores for each option against each criterion

In the case of an LCSA, the incorporation of the MCDA model into the framework involves determining a performance measure for each impact category of demolition and deconstruction scenarios, across environmental, economic and social criteria. The different variables of the MCDA model for the LCSA are depicted in Table 3.7.

Table 3.7: MCDA model for the LCSA

DECISION OPTIONS	Scenario 1: Demolition		Scenario 2: Deconstruction
CRITERIA	Environmental	Economic	Social
IMPACT CATEGORIES (SUB-CRITERIA)	Landfilling of Debris	Energy and Fuel Costs	Public Health
	Energy Use and Fuel Consumption	Equipment and Labor Rates	Jobsite Safety
	Air Pollution	Value of Salvaged Materials	Noise
	Water Pollution	Hazardous Material Abatement	Job Creation and Community Involvement
	Soil Pollution	Tax Exemption	

In simple MCDA problems, all the criteria are expressed in terms of the same unit (Pacheco-Torgal et al., 2013). However, in real-world scenarios, when it becomes difficult to express the measures of conflicting criteria or if the pertinent data becomes subjective in nature, the Analytic Hierarchy Process (AHP) can offer great assistance in finding an answer to the problem of how the different criteria measure against each other (Triantaphyllou and Mann, 1995).

3.4.3.2. Analytic Hierarchy Process

The AHP was developed in 1980 by Saaty and it is still widely used today. The term ‘analytic’ indicates that the problem is broken down into its constitutive elements, while the term ‘hierarchy’ indicates that a hierarchy of the constitutive elements is listed in relation to the main goal. This process is conducted in two phases to help develop priorities for the alternative decision options based on the decision-makers' judgments (Saaty, 2008; Achillas et al., 2013; Tatiya, 2016).

In the first phase, the criteria and the sub-criteria are defined using literature based reviews, knowledge and experience of experts in the field, etc. after analyzing the needs of the proposed goal. This is done in Table 3.2 and Table 3.3, by reflecting on the various criteria and sub-criteria of the proposed LCSA framework in Section 3.3.4. In the second phase, also known as the evaluation phase, a pair-wise comparison establishes the relative importance of each criterion against the other criteria to be able to create a hierarchical structure to base the decision on (Saaty, 2008; Achillas et al., 2013).

Table 3.8 illustrates a reference scale that is commonly used to indicate the importance or dominance of one criterion over another in a pair-wise fashion when dealing with qualitative and subjective data (Triantaphyllou and Mann, 1995; Saaty, 2008; Tatiya, 2016). The values 1, 3, 5, 7, and 9 represent the intensity of importance of one criterion when compared to another. The values 2, 4, 6, and 8 may be assigned when a compromise needs to be made in deciding the priority of one criterion over another. The reciprocal of the value assigned to the first criterion is respectively assigned to the criterion in the transpose position (Saaty, 2008).

Table 3.8: Fundamental Scale for Pair-Wise Comparison of Criteria

INTENSITY OF IMPORTANCE	**EXPLANATION**
1	Equal Importance (Both criteria contribute equally to decision)
3	Moderate Importance (One criterion slightly favored over the other)
5	Strong Importance (One criterion strongly favored over the other)

7	Very Strong Importance (One criterion very strongly favored over the other)
9	Extreme Importance (One criterion is favored over the other with highest possible order of affirmation)
Reciprocals of above 0	If Activity *i* has one of the above non-zero numbers assigned to it when compared with Activity *j*, then *j* is assigned the reciprocal value of the number when compared with *i*

(Source: Saaty, 2008; Tatiya, 2016)

In order to understand the scale and its application, Saaty (2008) has explained a simple example of relative consumption of drinks in the U.S. Based on the opinion of the interviewee, a number is assigned to the various drinks that are consumed in reference to the scale provided in Table 3.8. Figure 3.10 illustrates the judgment of the interviewee with regard to the consumption of drinks, such as coffee, wine, tea, beer, etc. (Saaty, 2008; Tatiya, 2016). For instance, if the interviewee feels strongly that coffee is consumed more than wine, they assign the number 9 in the 'Coffee/Wine' position in the AHP table. Following this judgment, the number 1/9 is assigned to the 'Wine/Coffee' position in the table. On the other hand, if the interviewee is of the opinion that milk consumption is almost equal to tea consumption, the number 3 is assigned to the 'Milk/Tea' position in the table. Again, the reciprocal of this, i.e. the number 1/3 is assigned to the transpose 'Tea/Milk' position in the AHP table.

Figure 3.10: AHP for Relative Consumption of Drinks in the U.S.

Which drink is consumed more in the USA?							
An example of examination using judgements							
Drink consumption in US	*Coffee*	*Wine*	*Tea*	*Beer*	*Sodas*	*Milk*	*Water*
Coffee	1	9	5	2	1	1	1/2
Wine	1/9	1	1/3	1/9	1/9	1/9	1/9
Tea	1/5	2	1	1/3	1/4	1/3	1/9
Beer	1/2	9	3	1	1/2	1	1/3
Soda	1	9	4	2	1	2	1/2
Milk	1	9	3	1	1/2	1	1/3
Water	2	9	9	3	2	3	1

(Source: Saaty, 2008; Tatiya 2016)

This scheme is elaborated upon with respect to the LCSA framework in Table 3.9 which depicts a pair-wise comparison matrix for all the 14 sub-criteria for the MCDA model determined earlier in Table 3.7, i.e. the impact categories involved in the processes of demolition and deconstruction of abandoned property. The relative weight for each impact category is calculated by dividing the sum of each individual row (X) with the total sum of all the rows (Y). The aim of determining the importance of each impact category relative to each other is addressed here, in order to develop a hierarchical order of impacts for the LCSA.

Table 3.9: AHP Table of Impact Categories for LCSA Framework

	LANDFILLING OF DEBRIS	ENERGY USE AND FUEL CONSUMPTION	AIR POLLUTION	WATER POLLUTION	SOIL POLLUTION	ENERGY AND FUEL COSTS	EQUIPMENT AND LABOR RATES	VALUE OF SALVAGE MATERIALS	HAZARDOUS MATERIAL ABATEMENT	TAX EXEMPTIONS	PUBLIC HEALTH	JOBSITE SAFETY	NOISE	JOB CREATION AND COMMUNITY INVOLVEMENT	Sum of each Row (X)	Relative Weight (X/Y)
LANDFILLING OF DEBRIS	1															
ENERGY USE AND FUEL CONSUMPTION		1														
AIR POLLUTION			1													
WATER POLLUTION				1												
SOIL POLLUTION					1											
ENERGY AND FUEL COSTS						1										
EQUIPMENT AND LABOR RATES							1									
VALUE OF SALVAGE MATERIALS								1								
HAZARDOUS MATERIAL ABATEMENT									1							
TAX EXEMPTIONS										1						
PUBLIC HEALTH											1					
JOBSITE SAFETY												1				
NOISE													1			
JOB CREATION AND COMMUNITY INVOLVEMENT														1		
															Total Sum (Y)	

Table 3.10: Ingham County Land Bank AHP Table for LCSA Framework

	LANDFILLING OF DEBRIS	ENERGY USE AND FUEL CONSUMPTION	AIR POLLUTION	WATER POLLUTION	SOIL POLLUTION	ENERGY AND FUEL COSTS	EQUIPMENT AND LABOR RATES	VALUE OF SALVAGE MATERIALS	HAZARDOUS MATERIAL ABATEMENT	TAX EXEMPTIONS	PUBLIC HEALTH	JOBSITE SAFETY	NOISE	JOB CREATION AND COMMUNITY INVOLVEMENT	Sum of each Row (X)	Relative Weight (X/Y)
LANDFILLING OF DEBRIS	1	9	9	9	9	7	7	1	1	9	5	1	7	1	76.00	0.1291
ENERGY USE AND FUEL CONSUMPTION	1/9	1	5	5	3	1/3	1/3	1/3	1/9	9	1/7	1/9	7	1/9	31.59	0.0537
AIR POLLUTION	1/9	1/5	1	1	1	1/3	1/7	1/9	1/9	1	1	1/7	7	1/7	13.30	0.0226
WATER POLLUTION	1/9	1/5	1	1	1	1/3	1/7	1/9	1/9	1	1	1/9	7	1/7	13.26	0.0225
SOIL POLLUTION	1/9	1/3	1	1	1	1/3	1/7	1/9	1/9	1	1	1/9	7	1/9	13.37	0.0227
ENERGY AND FUEL COSTS	1/7	3	3	3	3	1	1/7	1/3	1/7	1	1/7	1/9	7	1/9	22.13	0.0376
EQUIPMENT AND LABOR RATES	1/7	3	7	7	7	7	1	3	1/7	9	1/7	1/9	7	1/9	51.65	0.0878
VALUE OF SALVAGE MATERIALS	1	3	9	9	9	3	1/3	1	1/9	9	1/7	1/9	7	1/7	51.84	0.0881
HAZARDOUS MATERIAL ABATEMENT	1	9	9	9	9	7	7	9	1	9	1	1	7	1/5	79.20	0.1346
TAX EXEMPTIONS	1/9	1/9	1	1	1	1	1/9	1/9	1/9	1	1/9	1/9	1/3	1/9	6.22	0.0106
PUBLIC HEALTH	1/5	7	1	1	1	7	7	7	1	9	1	1	9	1	53.20	0.0904
JOBSITE SAFETY	1	9	7	9	9	9	9	9	1	9	1	1	9	5	88.00	0.1495
NOISE	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	1/7	3	1/9	1/9	1	1/9	5.62	0.0095
JOB CREATION AND COMMUNITY INVOLVEMENT	1	9	7	7	9	9	9	7	5	9	1	1/5	9	1	83.20	0.1414
														Total Sum (Y)	588.57	

Using the methodology presented above, the Ingham County Land Bank in Lansing, Michigan was interviewed and asked to assist in their professional capacity as a primary stakeholder in the demolition and deconstruction of abandoned residential property in Michigan. Their hierarchical assessment of the 14 impact categories considered for the LCSA framework are summarized in Table 3.10 and the inferences are discussed in the following chapter.

3.5. CONCLUSION

This chapter presents the outline for the development of the LCSA framework. The impact categories of demolition and deconstruction, their loadings, and means of assessment across all three sustainability criteria of the environment, economy, and society are reviewed in detail. Moreover, the methodology of creating the framework is defined and analyzed in terms of the proposed scenarios, stakeholders, weighting schemes, and calculations. The results and findings of the framework with the calculations are presented in the following chapter.

CHAPTER 4

4.0. FINDINGS, SUMMARY AND CONCLUSION

4.1. OVERVIEW

The goal of this research was to study and analyze the various lifecycle impacts of the processes of demolition and deconstruction across the environment, economy, and society, to be able to create a robust, operational decision-support tool using the Life Cycle Assessment (LCA) methodology. The comparative LCA framework could then be utilized to select a sustainable solution to address the complex problem of structural abandonment and blight in distressed communities in the U.S.

In the previous chapters, the underlying dynamics of residential structural abandonment in Michigan, the functional characteristics and impacts of demolition and deconstruction operations, the nature of major stakeholders in the industry, and the proposed methodology to create the Life Cycle Sustainable Assessment (LCSA) framework was presented. This chapter brings together the findings of the exercises undertaken in Chapter 3, and paves the path forward by identifying the limitations in the research and scope of future work.

4.2. FINDINGS OF IMPACT ASSESSMENT

As discussed in Chapter 3, the proposed LCSA framework integrates 14 different impact categories across the environmental, economic, and social facets of demolition and deconstruction processes. These impact categories are assessed in two ways. First, the application of the LCSA criteria in a real-world scenario is addressed by considering two case studies of demolition and deconstruction projects in Lansing, Michigan. The Ingham County Land Bank, identified as the primary stakeholder in the rehabilitation of abandoned residential property in Lansing, was asked to evaluate the level of performance of demolition and deconstruction against each impact category. The results were compiled in Table 3.6, and are elaborated upon in Section 4.2.1 below. Second, the relative importance of each impact category against the other impact categories was determined by utilizing the Analytic Hierarchy Process

(AHP), as depicted in Table 3.9. Again, the Land Bank was asked to assist the study and execute the pair-wise comparison and relative weighting procedure. These findings are discussed in Section 4.2.2 below.

4.2.1. Scenario Assessment and Level of Impact

Based on the development of the 2 scenarios in the previous chapter, the Ingham County Land Bank assessed the performance of demolition and deconstruction against the 14 identified impact categories of the LCSA framework. This performance evaluation was justified considering the comparable characteristics of Scenarios 1 and 2, such as the size of the house, age and archetype, employed contractor, etc. The qualitative values were assigned following whether the impacts were 'high/good', 'low/bad', or effectively 'medium/equal' over the lifecycle of the demolition and deconstruction projects. Table 4.1 compares the responses of the Land Bank with the inferences derived from literature sources for each identified impact category of demolition and deconstruction from Chapter 3, and presents the final logical conclusions. This is done to establish a more holistic review of which process would be the better option, as determined by previous research as well as in its application in the real world.

Table 4.1: Scenario Assessment for LCSA Framework

IMPACT CATEGORY	**LEVEL OF IMPACT**			
	DEMOLITION		**DECONSTRUCTION**	
	LIT REVIEW	**LAND BANK**	**LIT REVIEW**	**LAND BANK**
ENVIRONMENTAL				
Landfilling of Debris	**Heavy** impact due to disposal of waste generated in the process	**High** Impact	**Light** impact due to salvage of materials and conservation of resources	**Low** Impact

<table>
<tr><td colspan="2">Inference</td><td colspan="4">Deconstruction is better than Demolition as lesser volume of debris are landfilled</td></tr>
<tr><td rowspan="3">Pollution</td><td>Air</td><td rowspan="3">Heavy impact due to dust, emissions from equipment and trucks, landfilling</td><td>High Impact</td><td rowspan="3">Light impact due to more manual work, less mechanical wrecking, salvage of materials</td><td>Low Impact</td></tr>
<tr><td>Water</td><td>Medium Impact</td><td>Low Impact</td></tr>
<tr><td>Soil</td><td>High Impact</td><td>High Impact</td></tr>
<tr><td colspan="2">Inference</td><td colspan="4">Deconstruction is slightly better than Demolition as lesser equipment/vehicles, wet demolition techniques are employed; landfilling and soil degradation issues remain equal</td></tr>
<tr><td colspan="2">Energy Use and Fuel Consumption</td><td>Heavy impact due to use of equipment, transport vehicles</td><td>Medium Impact</td><td>Moderate impact due to transport of labor to site, material to recycling centers</td><td>Medium Impact</td></tr>
<tr><td colspan="2">Inference</td><td colspan="4">Deconstruction and Demolition have equal impacts; use of heavy equipment in Demolition is similar to use of transport vehicles over the longer duration of Deconstruction projects</td></tr>
<tr><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td colspan="2">ECONOMIC</td><td colspan="4"></td></tr>
<tr><td colspan="2">Energy and Fuel Costs</td><td>Heavy impact due to use of equipment on site and trucks to landfills</td><td>Medium Impact</td><td>Heavy to Moderate impact due to transport of labor to site, salvaged materials to recycling centers</td><td>Medium Impact</td></tr>
</table>

Inference	*Deconstruction and Demolition have equal impacts; costs of heavy equipment in Demolition is similar to costs of transport of labor over the longer duration of Deconstruction projects*			
Equipment and Labor Rates	**Moderate** impact due to shorter duration of operations on site	**Medium** Impact	**Heavy** impact due to high level of skilled labor, and workforce training	**Medium** Impact
Inference	*Demolition is better than Deconstruction; costs of heavy equipment in Demolition is cheaper than employment of skilled labor, training, material handling, use of transport vehicles over the longer duration of Deconstruction projects*			
Value of Salvaged Materials	**Heavy** impact due to no recovery and recycling of building materials	**High** Impact	**Light** impact due to high quality recovery of building materials	**Low** Impact
Inference	*Deconstruction is better than Demolition as greater volume of material is salvaged, resold and recycled*			
Hazardous Material Abatement	**Heavy** impact due to the presence of asbestos and lead in abandoned homes	**High** Impact	**Heavy** impact due to the presence of asbestos and lead in abandoned homes	**Low** Impact
Inference	*Deconstruction and Demolition have equal impacts; presence of asbestos, lead and other contaminants in old houses requires abatement to be performed prior to any rehabilitation operations*			

Tax Exemption	**Heavy** impact due to no recovery and recycling of building materials	**Medium** Impact	**Light** impact due to recycling and resale of salvaged materials	**Medium** Impact
Inference	*Deconstruction is slightly better than Demolition as tax exemptions are provided on donation of salvaged materials; however, this is rarely executed by the Land Banks and contractors get to keep or sell the material*			
SOCIAL				
Public Health	**Heavy** impact due to hazardous nature of operations	**High** Impact	**Moderate** impact due to emphasis on manual labor and workforce training, but risk of exposure	**High** Impact
Inference	*Deconstruction and Demolition have equal impacts; risk of exposure to contaminants in old houses, and hazardous nature of work is similar in both approaches*			
Jobsite Safety	**Heavy** impact due to hazardous nature of operations	**Low** Impact	**Moderate** impact due to emphasis on manual labor and workforce training, but risk of exposure	**Low** Impact
Inference	*Deconstruction and Demolition have equal impacts; risk of exposure to contaminants in old houses, and hazardous nature of work is similar in both approaches – however, this facilitates better safety planning, site protection measures, and workforce training*			

Noise	**Heavy** impact due to use of equipment and machinery on-site	**High** Impact	**Light** or no impact due to more use of manual labor and small tools	**High** Impact
Inference	*Deconstruction is slightly better than Demolition as mechanical wrecking and tearing down of structures is not included; however, both approaches require structural dismantling and cause disturbances in the neighborhood*			
Job Creation and Community Involvement	**Moderate** impact due to more use of equipment and machinery on site	**Low** Impact	**Light** impact due to manual operations, secondary markets and growth of economy	**Low** Impact
Inference	*Deconstruction and Demolition have equal impacts; both processes employ labor, though Deconstruction requires more skill and training. Impacts would be better identified in large-scale projects, with greater opportunity for stakeholder, community, and worker participation*			

4.2.2. Hierarchical Order of Impacts

By drawing from their prior knowledge and history of decision-making with respect to rehabilitation operations for abandoned residential properties in Ingham County, the Land Bank assigned values to the different impact categories of the LCSA framework. The values were assigned with reference to the commonly used AHP scale for pair-wise comparisons in MCDA models. The relative weights for each impact category were then calculated by the author, as given in Table 3.10 in the previous Chapter.

Table 4.2 depicts the result of the AHP exercise, and affirms the hierarchical order of importance given to the 14 identified impacts of demolition and deconstruction across the environment, economy, and society, as determined by the Land Bank. From the results, it can be inferred that the social aspects of deconstruction and demolition face priority when it comes to mitigating the problem of abandonment in communities.

Table 4.2: Land Bank AHP Table for LCSA Framework

LCSA CRITERIA	IMPACT CATEGORY	RELATIVE WEIGHT
SOCIAL	JOBSITE SAFETY	0.1495
SOCIAL	JOB CREATION AND COMMUNITY INVOLVEMENT	0.1414
ECONOMIC	HAZARDOUS MATERIAL ABATEMENT	0.1346
ENVIRONMENTAL	LANDFILLING OF DEBRIS	0.1291
SOCIAL	PUBLIC HEALTH	0.0904
ECONOMIC	VALUE OF SALVAGE MATERIALS	0.0881
ECONOMIC	EQUIPMENT AND LABOR RATES	0.0878
ENVIRONMENTAL	ENERGY USE AND FUEL CONSUMPTION	0.0537
ECONOMIC	ENERGY AND FUEL COSTS	0.0376
ENVIRONMENTAL	SOIL POLLUTION	0.0227
ENVIRONMENTAL	AIR POLLUTION	0.0226
ENVIRONMENTAL	WATER POLLUTION	0.0225
ECONOMIC	TAX EXEMPTIONS	0.0106
SOCIAL	NOISE	0.0095

4.2.3. Observations of the Life Cycle Sustainability Assessment

This study aimed to address the solution to the problem of structural abandonment by employing a logical conclusion from various literature sources and from the acumen and expertise of stakeholders in the field of demolition and deconstruction by regarding the environmental, economic, and social impact categories of the two scenarios.

First, the LCSA framework incorporated 14 different impact categories of demolition and deconstruction that were identified from a review of literature, in order to understand the extent of consequences of utilizing either process over its lifecycle and within the boundaries defined by the study. The LCSA methodology then involved a qualitative assessment that determined the relative importance of the impact categories with respect to each other, to understand the priority of primary stakeholders, such as land banks, in their decision-making exercise.

In conclusion, the findings of the LCSA application are summarized below.

- Deconstruction was found to be a slightly better option than demolition, when taking into consideration its various environmental benefits. Despite catering to a reduction of approximately half of volume of debris being landfilled, i.e. 55 yd. instead of the 120 yd. in case of demolition in Scenarios 1 and 2 discussed in Chapter 3, the deconstruction approach involved using trucks and other vehicles for the transportation of salvaged materials to secondary recycling facilities, and labor to the site for a longer duration owing to the slower schedule of the project. This led to a uniform level of emissions and energy and fuel use across both demolition and deconstruction.

- The costs of hazardous material abatement for both demolition and deconstruction remained constant, due to the definite presence of contaminants such as lead, asbestos, etc. in old, abandoned houses. Further, the costs of employing heavy, mechanical equipment in demolition was found to make a similar impact when compared to the costs of employing skilled labor or training them to operate with the best deconstruction practices in the industry. Even though tax exemptions for donation of salvaged material was a beneficial aid to engage the deconstruction approach, it is typically found that all the material is salvaged and resold by the contractor executing the work, refraining the Land Bank from creating savings in the process. Deconstruction thus resulted in being much more expensive than demolition, due to the resources being utilized over the longer project schedule.

- Social criteria were found to be an important factor of consideration for the Land Bank, from the application of the AHP tool. It was determined that jobsite safety, public health, job creation, and community engagement were all designated as a priority for the welfare of distressed communities. As this assessment was weighed over a very small scale of operation in Lansing, Michigan, deconstruction and demolition approaches were both found to be at par with each other in terms of the level of impact. However, it would be interesting to evaluate the differences that a technologically advanced and well-planned deconstruction sector could make in the future.

- Furthermore, in discussion with the Ingham County Land Bank, the availability of time was determined to be another factor of high relevance. It is of utmost importance to the local governments, municipalities, planning departments and other organizations in charge of the redevelopment of communities that the demolition of the dilapidated housing stock be completed in all urgency. This is done for the neighborhoods to increase or remain in value, keeping maintained properties on the tax roll, and holding the density of households to the maximum extent possible. Moreover, despite all the advantages of deconstruction with respect to the high potential of repurposing materials and low volume of landfilled debris, the costs incurred in the process unfortunately deem it to be an inconvenient expenditure of the taxpayers' money. Consequently, due to cheaper landfill tipping fees, lower energy costs, and a lower degree of concern for noise nuisances in Michigan, demolition results in being held as the default approach for rehabilitation of abandoned homes.

4.3. SUMMARY

The goal of this research was to create an LCSA framework to identify and provide measures for the various impact categories of both demolition and deconstruction processes across facets of the environment, economy and society. Following is a discussion of the work done under the objectives of the research:

Objective 1: Analyze the practices of demolition and deconstruction.

Several academic journal papers, thesis reports, demolition and deconstruction guides were studied to provide an understanding of the various impact categories associated with the implementation of demolition and deconstruction processes for the rehabilitation of abandoned residential property and blighted communities. It was determined that there were 14 different categories across the boundary of demolition and deconstruction approaches, which could potentially impact the facets of the environment, economy, and society. These were incorporated in the LCSA framework that was created to address the impacts of the processes over a lifecycle perspective, in order to find a sustainable solution to the problem of structural abandonment.

Objective 2: Review the implementation of process-based and hybrid LCA models in the construction industry, and understand the LCSA of a process.

After performing a detailed review of literature and studying the various practices and techniques employed in executing the LCA of a process, the importance of developing a sustainable assessment framework that could serve as a decision-support tool for major stakeholders in the industry with regard to utilizing the approaches of demolition and deconstruction was established. The methodology for creating an LCSA framework was then determined, by incorporating the judgment and opinions of the primary stakeholders, i.e. land banks, who are responsible for the rehabilitation of distressed communities in Michigan.

<u>Objective 3</u><u>:</u> Create the LCSA framework.

Several different literature resources were studied to determine the loadings and methods of assessment of the 14 identified impact categories for demolition and deconstruction processes. Following this, two different steps for implementing the LCSA framework were established. The first step included analyzing the level of the impact across demolition and deconstruction, to evaluate which process would be a better option to adopt in the long run, while the second step involved determining the hierarchical order of preference of the impact category by using an AHP exercise, to understand the priority of the stakeholders who control the decision-making process. This resulted in a number of different findings for the impact categories and their loadings, which were analyzed and summarized in Section 4.2 above.

<u>Objective 4</u><u>:</u> Test the LCSA framework.

The LCSA methodology was tested in a real-world scenario by analyzing two case studies based in Lansing, Michigan. The Ingham County Land Bank, who was in charge of executing the demolition and deconstruction projects for the two abandoned houses, was asked to assist in the assessment by participating in a survey and interview process. This was followed according to the methodology established for the LCSA framework discussed as a part of Objective 3, and the findings are presented earlier in the chapter. The survey is presented for reference in the Appendix section of this report. It was concluded that future research should employ the survey and collect data based on a larger sample size, and potentially include the acumen of other relevant players and participants in the industry with regard to the implementation of demolition and deconstruction approaches, such as the demolition and deconstruction contractors, members of the neighborhood where the activity takes place, etc.

4.4. RECOMMENDATIONS

The concept of the LCSA framework is relatively new in the field of process-based lifecycle evaluations, and the modeling of the different tools and techniques that can be utilized to execute a complete and accurate study is still in progress. Even though the assessments have broadened their scope by including several variations of economic and social aspects, the methodology of creating a holistic decision-support is still lacking a definite interpretation. Moreover, demolition and deconstruction processes are still executed in a piecemeal fashion by governmental authorities, and require in-depth analysis to be able to apply the LCSA framework and acquire a dependable solution for the problem of structural abandonment. Some of the limitations of this study, and possible areas of future research in the direction of an LCSA framework for demolition and deconstruction are discussed below.

4.4.1. Research Limitations

The research had some limitations pertinent to its scope and boundary of study, and the author's opinion of the primary considerations in this context are the following:

- *Methods of Impact Assessment*: The research was primarily limited due to the lack of weighting and measurement of the impact categories across the environment, economy, and society. Even though the proposed LCSA framework incorporates the different types of loadings involved in demolition and deconstruction processes, the assessment is subjective and does not take the functional units of measurement in a real-world scenario into consideration. Further, as the different impact categories have varying units of measurement, a standardized weighting scheme or a sustainability index needs to be introduced into the LCSA framework to be able to make valid comparisons across the impact categories.

- *Limited Involvement of Stakeholders*: The research based its inferences on the perspective and opinions of only one of the major stakeholders in the industry, i.e., the land banks. An increased involvement of other stakeholders and professionals from the demolition and deconstruction industry would have rendered the LCSA framework to be more accurate in its findings, and served the true objective of establishing the holistic nature of the research.

4.4.2. Areas of Future Research

Demolition and deconstruction of abandoned residential property are a major part of policy-making and planning for a sustainable future, and will definitely continue to grow as the industry and communities continue to progress and develop. This research is just laying the groundwork for the scope of future research. Some important topics that have the potential for research in the future are listed out below.

- *Accurate and Comprehensive Database*: The LCSA framework requires field measurements of all the impact categories of demolition and deconstruction and their loadings, to execute a reliable assessment and generate a viable solution for addressing the problem of abandonment. Social impacts especially need to be attested to by the changes in economic dynamics of geographic locations and metrics for quantitative data. Comprehensive and detailed surveys and interviews with stakeholders, site analyses, field inspections, quantitative evaluations, etc. are recommended for expanding the scope of the study in future LCSA investigations.

- *Unified Impact Assessment System*: As discussed earlier, comparing the significance of the environmental (LCA), economic (LCC), and social (SLCA) impact assessments relative to each other proves to be a tedious and difficult task as the basis of assessment and the units for each impact category are different. A unified impact assessment system that can indicate the ultimate outcome, with the help of a standardized weighting scheme or a sustainability index, needs to be introduced into the LCSA framework to be able to make valid comparisons across the impact categories.

- *Design for Deconstruction*: The primary barriers for deconstruction today are found to be the long duration of the project and the low quantity of material that is available for recovery, owing to the design and construction of residential buildings. This results in demolition being the preferred alternative for the rehabilitation of the abandoned housing stock. Buildings that are designed for deconstruction, by utilizing features such as modular framing and repositionable walls, can effectively reduce the labor hours and costs consumed in deconstruction projects, and also retain the quality and integrity of the salvageable building materials. Research on Design for Deconstruction (DfD) is thus another important direction for future scope of work associated with the LCSA methodology that needs further clarity and definition.

- *Planning and Policy-making*: The LCSA framework, with its multi-impact lifecycle perspective, should aim to advocate strategies for better interconnectivity and communication among governmental agencies, contractors, secondary markets, and economic clusters. Future research should focus on facilitating policy interventions in the form of Design for Deconstruction and Building Automation measures, to be able to achieve common goals with regard to the rehabilitation and progress of distressed communities, and hence, reach a sustainable solution for issues such as structural abandonment.

4.5. CONCLUSION

The realm of research is still in its nascent stages. However, this research hopes to shed light on the problem of structural abandonment, and provides an understanding of both processes of demolition and deconstruction from a life cycle perspective, by analyzing and evaluating their different impacts across the environment, economy, and society. Consequently, the research results in the creation of a decision-support tool in the form of a proposed LCSA framework that can be utilized in the selection of demolition and deconstruction techniques for the rehabilitation of distressed communities in the U.S. in the future.

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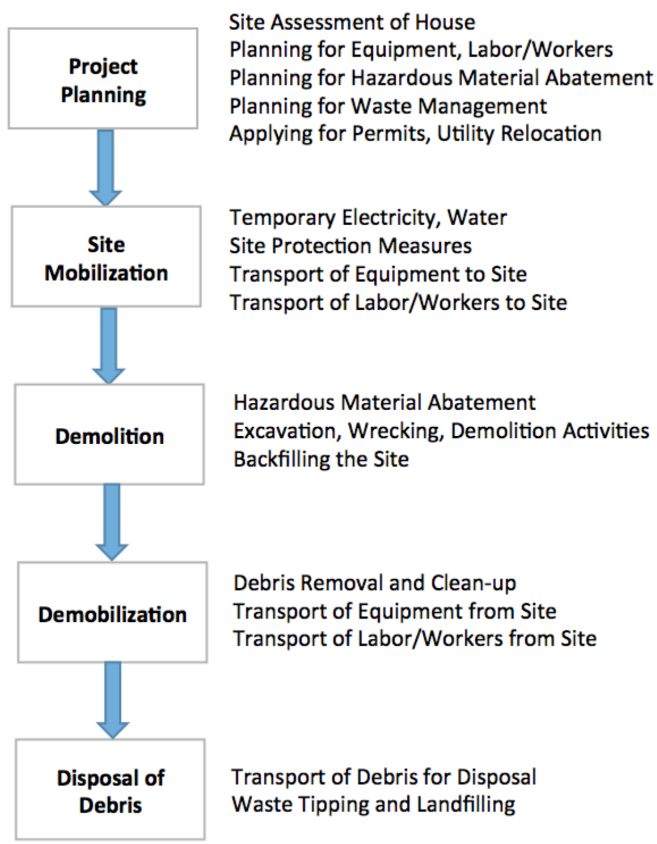
APPENDIX

Life Cycle Assessment of Demolition and Deconstruction Study Survey

PART A

For the purpose of the research, 14 impact categories are identified as a consequence of demolition and deconstruction approaches. Each category has a different loading (functional unit of measurement) associated with it. The boundary of the study is confined to the onsite operations and the transport of equipment, labor, debris, etc. to landfills and secondary recycling centers. The boundary and constituent aspects of a typical demolition project is shown as an example.



Based on the data provided by the following rehabilitation case studies undertaken by the Land Bank, please answer if the process of demolition or deconstruction had a more favorable impact and why.

- Demolition project: 524 Baker Street, Lansing MI
- Deconstruction project: 1214 Massachusetts Ave, Lansing

IMPACT CATEGORY		LEVEL OF IMPACT	
		DEMOLITION	DECONSTRUCTION
ENVIRONMENTAL			
Landfilling of Debris (Volume of debris)			
Pollution	Air (Emissions, fumes, dust)		
	Water (Runoff)		
	Soil (Erosion due to exposure)		
Energy Use and Fuel Consumption (Electricity, Fuel)			
ECONOMIC			
Energy and Fuel Costs			
Equipment and Labor Rates			
Value of Salvaged Materials			
Hazardous Material Abatement			
Tax Exemption			
SOCIAL			
Public Health			
Jobsite Safety			
Noise			
Job Creation and Community Involvement			

Is there anything else you would like to mention about the potential impacts of demolition and deconstruction of abandoned properties that has not been addressed above?

PART B

The Analytic Hierarchy Process is used in multi-criteria decision analyses with multiple impact categories, when the relative importance of each category needs to be determined against another category. This pair-wise scheme of comparison is evaluated on the basis of the following table:

INTENSITY OF IMPORTANCE	EXPLANATION
1	Equal Importance (Both criteria contribute equally to decision)
3	Moderate Importance (One criterion slightly favored over the other)
5	Strong Importance (One criterion strongly favored over the other)
7	Very Strong Importance (One criterion very strongly favored over the other)
9	Extreme Importance (One criterion is favored over the other with highest possible order of affirmation)

The first exercise (AHP 1) seeks to find the relative importance of each of the 14 impact categories pertinent to demolition and deconstruction processes. The second exercise (AHP 2) aims to understand the relative importance of environmental, economic, and social impacts when taking informed decisions for the rehabilitation of abandoned property. Please find the AHP worksheet attached as an .XLS file (Table 3.2 in Chapter 3).

*