COST PREDICTION MODEL FOR DECONSTRUCTION AND IMPACT OF DESIGN FOR DECONSTRUCTION

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ABSTRACT

Along with construction of new buildings, removing of old or abandoned buildings is an important aspect of urban development. Usually, demolition is the preferred building removal method. But, due to its adverse effect on the environment, new concepts like deconstruction and design for deconstruction (DfD) have emerged. Even though deconstruction is more environment friendly, it is difficult to estimate deconstruction costs of a project due to its complex nature and hence still not popular building removal method in the industry. This research offers cost prediction model for deconstruction and a study of impact of design for deconstruction on deconstruction costs and time.

With the help of Predictive Modeling, a process used in predictive analytics to create a statistical model of future behavior, a model based on Case Based Reasoning (CBR) method for estimating deconstruction costs was developed using 'Python' programing language. Input variables and their weights required for developing the model were established based on the available literature and by analyzing the interviews of deconstruction Project Managers and Estimators conducted based on analytical hierarchy process (AHP). Deconstruction case studies necessary for working of the model were collected from deconstruction contractors.

Further, in order to study the impact of DfD on deconstruction costs and time, a one story 900 S.F. house was considered for deconstruction. Deconstruction costs and time for this house when typically designed were calculated using RS Means, and based on the literature and the author's knowledge of deconstruction, deconstruction costs and time for the similar house with five defined DfD features were calculated. It was concluded that incorporating DfD reduces both time and costs of deconstruction.

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1. INTRODUCTION

1.1. Overview

Construction of new buildings and structures is an essential aspect of urban development, but one cannot neglect the existing ones. Every structure has its life and once the condition of the structure is not conducive for the purpose it was built, it has to be renovated or removed. History explains that for development, removing of old or abandoned structure is important in order to maintain the sense of security and harmony (Zahir and Syal, 2015).

1.1.1. Demolition

The typical option for building removal is to demolish the building and haul the waste to landfills. Demolition can be defined as an engineering project where a building or structure that needs to be removed from a site, after reaching the end of its useful life, is knocked down with the help of heavy equipment or manual tools and rendered into rubble and debris (Zahir and Syal, 2015). It involves pulling down the building with heavy equipment such as hydraulic excavators and bulldozers, leading to destruction of the building in fairly quick time, making it relatively uncomplicated building removing method.

Due to the demolition process explained above, cost associated with it is fairly straightforward to calculate. Also, several cost estimation tools and techniques like RS Means and Building Journal website for demolition are available in the market. It is important to notice that most demolition activities have minimal labor involvement with relatively short project durations. Even so, substantial engagement of mechanical equipment leads to high costs for demolition projects (Pun et al., 2005).

Demolition creates pile of mixed debris on site, a large proportion of which is sent to landfill due to its lack of separation and contamination. As a result, material reuse and recycling is less likely to occur. Hence, due to larger landfill costs and low or zero benefits from building material reuse and recycling, cost profile of mechanical demolition is affected (Chini and Bruening, 2003). Limited landfill capacity along with the difficulty of developing new landfills has caused regulators to set plans for reducing the disposal of solid waste in landfills (Dantata et.al, 2004).

In the United States, the major component of non-municipal solid waste consists of Construction and Demolition (C&D) debris which is about 143 million metric tons (MMT) annually (Chini and Bruening, 2003). Due to lack of recycling and reuse of the construction material, extraction of raw materials for new construction is needed. The emission of wastes created by this practice also exerts heavy pressure on the environment.

1.1.2. Deconstruction

In order to make building removal more efficient, dismantling with the aim of producing high quality reusable and recycling materials at reasonable costs is a promising approach. (Schultmann and Rentz, 2002). Disassembly of buildings in order to recover maximum amount of material for reuse and recycle is called as deconstruction. It is also known as green demolition, un-building or reverse construction (EPA, 2008). This method of building removal is more labor intense with much less use of heavy equipment.

Deconstruction of buildings has several advantages over conventional demolition. It increases the diversion rate of demolition debris from landfills, develops "sustainable" economic through reuse and recycling and enhances environmental protection, both locally and globally. Deconstruction also conserves the environment by reducing extraction of raw materials for new construction (Chini and Bruening, 2003). Compared to Demolition's loop of building management, deconstruction closes the loop of resource use, as seen in the Figure1.1 below.

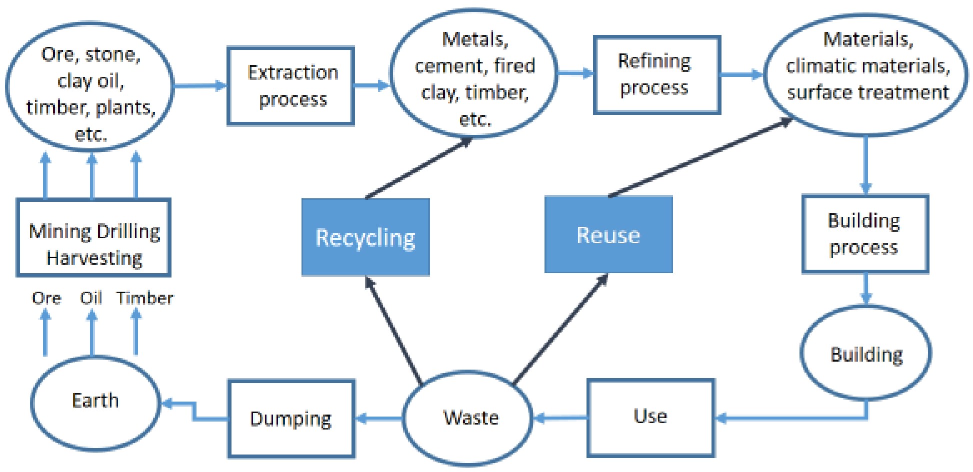


Figure 1.1 - Closed loop in material life cycle (EPA, 2008)

The benefits of deconstruction are not just limited to environmental advantages, but also includes associated cost. Studies on deconstruction in the past few years have shown that the cost can be less than demolition because of the value of the salvaged materials and the avoided disposal costs (Endicott, et al., 2005).

1.2. Need Statement

Due to its environmental friendly practices with cost savings from recovered materials, many consider deconstruction to be comparatively better building removal method than demolition. It is theoretically possible to dismantle every building and re-use or recycle most if not all the components. However, in practice it is difficult, expensive and has achieved success only on very small projects (Morgan et.al, 2005). Hence, many owners and contractors still prefer demolition over deconstruction. This points to a need to understand the reason behind the lack of adoption of deconstruction despite having environmental and economic benefits.

1.2.1. Cost estimation of deconstruction

As explained by Macozoma (2002), deconstruction is a process of selectively and systematically dismantling buildings to reduce the amount of waste created and generating a supply of high value secondary materials that are suitable for reuse and recycling . Contrary to demolition, deconstruction is more labor intense with less use of mechanical equipment. It is more complicated process along with increase in safety of both material and labor. Also, requirement of highly skilled labor and long project duration makes deconstruction less likely method to be adopted by the contractors. Further, deconstruction being fairly new, there has not been any development in making a cost estimation model for calculating the cost of removal of the building and recoverable cost of reusable and recycled material. Hence, due to complications associated with deconstruction and lack of cost estimation tool, contractors tend to choose demolition over deconstruction.

1.2.2. Effect of building design on deconstruction cost

Although deconstruction appears to be relatively better economically and environmentally, not all buildings are good candidates for deconstruction because they were not designed and built to be deconstructed. Buildings today are generally put together in such a way that recovery of anything except the most isolated and valuable components is minimal (Morgan et al., 2005). Due to the complex building design, highly skilled labor are required to dismantle the building components cautiously. It involves high risk for labor and also the material recovered is of ordinary quality. Hence, both time and cost of the deconstruction process increases.

Nevertheless, this problem can be solved. The new trend in construction industry is to design and build the buildings for deconstruction. Design for deconstruction or design for disassembly is a technique of designing in order to deconstruct in future. It considers the entire lifecycle of a building including design, manufacturing, construction, renovation, operation and eventually deconstruction. Incorporating design for deconstruction in new construction offers great potential for reuse of material and largely closing the loop of mining and extraction of raw materials (EPA, 2008). That being said, a comparative study of deconstruction cost between typically designed building and a similar building designed for deconstruction needs to be composed in order to understand cost benefits of design for deconstruction.

1.2.3. Prediction Model

Construction cost estimation involves predicting labor, material, equipment, utilities and other costs associated with a project. Many factors such as construction type, location, size, unforeseen conditions, scheduling, and the disposal, recycling, reuse of material are considered in the cost estimation of a project. It is a process that attempts to predict the final cost of a future project because the accuracy of estimation of costs is a critical factor in the success of a project.

Predictive modeling is a process used in predictive analytics to create a statistical model of future behavior. In other words, it leverages statistics to predict outcomes. Predictive analytics is the area of data mining concerned with forecasting probabilities and trends. A predictive model is made up of a number of predictors, which are variable factors that are likely to influence future behavior or results (Search Data Management, 2015). Hence, a predictive model for estimating costs of a deconstruction project will substantially increase the success rate in the deconstruction industry.

Predictive models developed over the years for cost estimation of a new construction are based on three types; Multiple Regression Analysis (MRA), Neural Networks (NNs) and Case-Based Reasoning (CBR) (Kim et.al, 2004). MRA is an extension of simple linear regression, whereas Neural Network is a computer system modeled on the human brain and nervous system. CBR is the process of solving new problems based on the solutions of similar past problems. Figure 1.2 explains the process of CBR model.

Preliminary study suggests that CBR gives fairly good results along with better clarity of explanation and time (Kim et.al, 2004) and therefore may be suitable for deconstruction. However, detailed study of different models is required to select a suitable model for deconstruction.

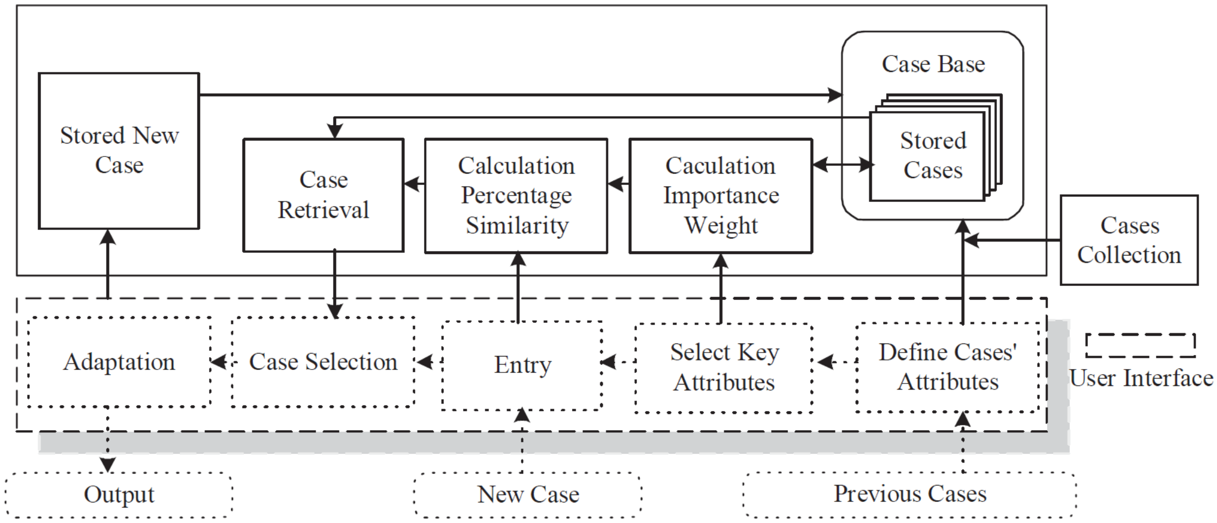


Figure 1.2. Case-based reasoning model (Kim et.al, 2004)

Based on the above discussions, it can be summarized that there is a need for the following:

- Estimating tool for calculating deconstruction costs of a building
- Study of deconstruction costs associated with design of the building

1.3. Research Scope and Goal

The scope of this paper is limited to deconstruction of low-rise residential buildings. It also uses the cost prediction models previously used for new construction as the basis for deconstruction cost model. As discussed earlier, the deconstruction cost of a building depends on the design used for its construction. Also, there is a lack of development in cost estimations tools for deconstruction. The goal of this research is to provide an understanding of the deconstruction costs associated with design of the building and the creation of a cost estimation model for deconstruction.

1.4. Research Objectives and Methodology

The focus of this study is to identify and compile literature and summarize in order to understand various approaches in developing cost prediction models in construction and deconstruction cost associated with different design elements of a building. Following are the objectives of this research along with the proposed methodology:

1. Analyze various existing cost prediction models and select a suitable one for deconstruction
   - Literature review:

   Numerous academic papers, thesis reports and case studies offer in depth knowledge about different cost prediction models developed. Aim is to collect and understand different cost prediction models developed for new construction.
   - Analysis and observation:

   From different prediction models studied, a suitable model for deconstruction will be chosen with appropriate justification.

2. Study deconstruction process and identify elements affecting deconstruction costs
   - Literature review:

   Based on various case studies, academic papers, industry reports and manuals on deconstruction, factors affecting deconstruction costs will be identified.
   - Site visits, survey and contractor interviews:

   A limited number of site visits and interviews of deconstruction contractors will be carried out in order to understand the factors affecting deconstruction costs.

3. Develop a cost prediction model for deconstruction based on the analysis

   - Computer software:

   An apposite computer software will be used to develop the cost prediction model for deconstruction based on the achieved objectives 1 and 2.

4. Understand cost associated with different elements of design for deconstruction and discuss comparison of deconstruction costs of a residential building traditionally designed and designed for deconstruction

   - Literature review:

   Several case studies, academic papers, thesis reports, industry reports and manuals are available in these fields. This research aims to compile and analyze impact of building design on the deconstruction cost.

   - Analysis and observation:

   A comparison study of deconstruction cost for traditionally designed residential building and a similar residential building designed for deconstruction will be conducted in order to exhibit the impact of design for deconstruction.

1.5. Projected Outputs

This research will provide understanding of deconstruction cost variation due to different design elements of a residential building. It will also provide information and analysis about different cost prediction models used in construction to deliver a suitable model for cost estimation of deconstruction.

The comparison study will provide designers and contractors information about the importance of designing the building to make its removal at the end of its life cycle more economically and environmentally profitable. Also, the developed cost prediction model will assist contractors to estimate cost for deconstruction of a building with an assessment of cost gained from salvaged and reusable material.

The following outputs are expected to be achieved from this paper:

- Cost prediction model for deconstruction of a building
- Deconstruction cost variation due to different design approaches in a residential building

1.6. Summary

This chapter gives an overview of the need for studying deconstruction costs associated with different design approaches and the development of cost prediction model for deconstruction. It also gives an overview of the research scope, the goal and objectives, the methodology and projected output of the study. It recognizes the importance of changing current building design practices in order to make building removal sustainable which allows material reuse, closing the loop of resource use. Also, though there are few models and website for cost estimation of demolition cost, there is no model for estimating deconstruction cost. The following chapters will provide a literature review of different cost prediction model developed in construction industry and design for deconstruction.

2. LITERATURE REVIEW

2.1. Overview

This chapter provides an overview of the literature reviewed for the research. The literature review is based on three broad topics of cost aspects of demolition, deconstruction and design for deconstruction. Demolition is reviewed for its different approaches and cost estimation of demolition projects. Deconstruction is reviewed for its environment, social and economic benefits. Finally, design for deconstruction is introduced along with its impact on cost of deconstruction.

2.2. Demolition

As mentioned in the previous chapter, demolition is the typical building removal method. According to Diven & Shaurette (2010), "Demolition is an engineered project to reduce a building, structure, paved surface, or utility infrastructure through manual and/or mechanized means, with or without the assistance of explosive materials to piles of mixed rubble and debris. Demolition usually provides the quickest method of removing a facility and segregates the debris or rubble into various components for recycling where practicable." Hence, from the definition of demolition by Diven & Shaurette, demolition can be classified as manual demolition, mechanical demolition, implosion demolition or any combination of the three. Among these, implosion is usually used in demolition of high-rise buildings and manual demolition has become unpopular post 1950 due to the development in the construction technology (Pun et al., 2005). Therefore, in the residential market, which is the focus of this research, mechanical demolition becomes the main option.

2.2.1. Mechanical demolition

Mechanical demolition involves knocking down buildings through mechanical tools such as cranes, bulldozers, excavators, rams and wrecking ball, leading to destruction of the building in fairly quick time.

Even though mechanical demolition process has the capability of destroying the building in fairly quick time, it also has some drawbacks. Mechanical demolition normally results in a pile of mixed debris on site, which is likely to be sent to landfill due to its lack of separation and contamination (Pun et al., 2005). As a result, material reuse and recycling is not likely to occur. Failing to optimize building materials can result in their residual lifecycle expectancy not being fully exploited, which is not a sustainable use of building material (Diven & Shaurette, 2010). Also, it impacts the environment due to disposal of material to landfills and wastage of resources.

Further, demolition process creates pollution. Concrete breaking, handling of debris and hauling process are main sources of dust from building demolition. Burning of waste and diesel fumes generated by mechanical equipment also affect the air. Noise pollution arise from the demolition works including, but not limited to, the use of specified powered mechanical equipment such as pneumatic breakers, excavators and generators, etc., scaffolding, erection of temporary works, loading and transportation of debris, etc. The noise can affect the workers, and the public in the vicinity of the demolition site (EPA, 2008).

Additionally demolition does not benefit communities as it is more dependent on use of heavy machinery than labor.

Although demolition has these disadvantages, it is still the preferred building removal method. Demolition takes less time destroying the building and cost associated with it is fairly direct to estimate due its process of pulling down the building and dumping it to landfill.

2.2.2. Cost estimation of demolition project

An approximation of the probable cost of a project, computed on the basis of available information and various factors that impact cost is called cost estimation. According to Guy (2001) the net cost for demolition project is: (Demolition + Disposal) – (Salvage value). The factors on which the costs of demolition project depends are (Zahir & Syal, 2015):

- Preparatory estimating tasks
- Project location
- Available information
- Schedule
- Weather
- Regulatory requirements
- Project size
- Available resources

- Salvage
- Dumping cost
- Quantity takeoff

Along with the understanding of these factors, the estimator must have the knowledge of expected production rates each task to be performed in a demolition project. This can be recognized from previous experiences or job records of the company or the use of databases, such as R.S. Means, that facilitates construction cost data reference book (RS Means, 2014).

2.2.2.1. RS Means building construction cost data (RS Means, 2014)

RS Means provides cost information to the construction industry so contractors in the industry can provide accurate estimates and projections for their project costs. It has become a data standard for government work in terms of pricing, and is widely used by the industry as a whole (whatis.com, 2016). All the cost data has been divided into 50 divisions according to the master format system of classification and numbering.

Division 2- Existing Conditions; provide cost data relating to various cost components of demolition and deconstruction projects. Particularly the sub-divisions i.e. 02 40 00 Demolition and structure Moving, provide cost data for selective demolition. This subdivision does not include rubbish handling and disposal, hazardous material handling, etc. Each of these items should be estimated using other sub-divisions in the data base (Zahir & Syal, 2015).

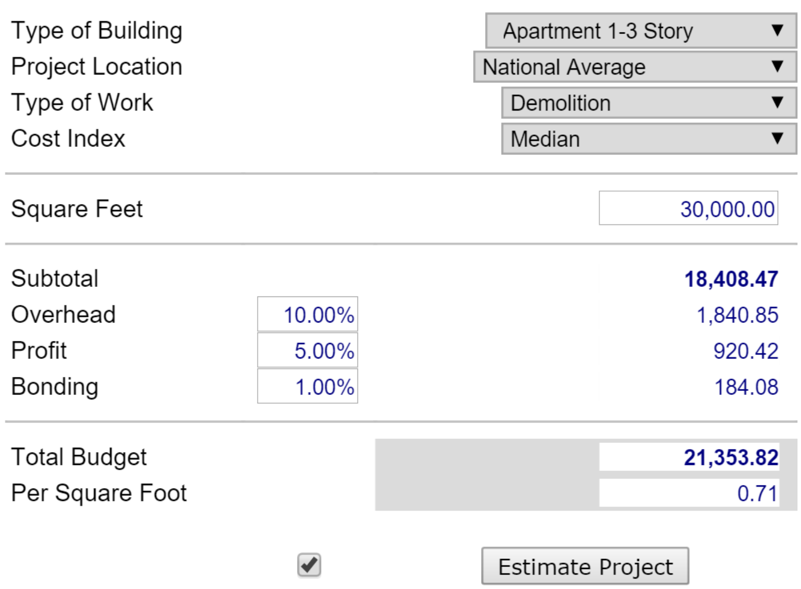
Subdivision 02 41 16 provides cost data for structure demolition based on the type and size of structures. Even though these costs do not include hauling and dumping of debris, removal of hazardous material, it can be found in other subdivisions i.e. 02 50 00 Containment of hazardous waste, 02 80 00 Hazardous material disposal should be used in combination with this subdivision to estimate the overall cost of demolition projects (Zahir & Syal, 2015). Some of the costs are provided below. Table 2.1 shows demolition cost of residential structures based on area, type of construction and number of story of the building.

Table 2.1. Demolition cost of various residential structures based on type, height and area of structures (RS Means, 2014)

Type of structure	Area	Total cost
Single family, wood construction	1,600 s.f	$5,725
Single family, wood construction	3,200 s.f	$11,500
Two family, wood construction	2,400 s.f	$8,575
Two family, wood construction	4,200 s.f	$15,300
Three family, 3 story, wood construction	3,200 s.f	$11,500
Three family, 3 story, wood construction	5,400 s.f	$19,100

2.2.2.2. Buildingjournal.com

"Buildingjournal.com" also serves as a cost estimation tool for demolition projects. It is an online database which provides unit cost of demolition works based on project size, type, cost index and location. Examples from this online cost database have been presented below. While it can be used as a good reference to calculate demolition cost, it should be noted that various cost items, that is, the presence of hazardous material removal and disposal, have not been clearly defined in this cost database. Where these items can highly effect the overall cost of the project. Figure 2.1-2.3 below show cost estimation of various projects based on their height.



Type of Building		Apartment 1-3 Story
Project Location		National Average
Type of Work		Demolition
Cost Index		Median
Square Feet		30,000.00
Subtotal		**18,408.47**
Overhead	10.00%	1,840.85
Profit	5.00%	920.42
Bonding	1.00%	184.08
Total Budget		**21,353.82**
Per Square Foot		0.71
		Estimate Project

Figure. 2.1 Cost estimation of demolition for apartments which are 1 to 3 story high, cost index is medium and with National Average using the online source (http://buildingjournal.com/commercial-construction-estimating-demolition.html, 2016).

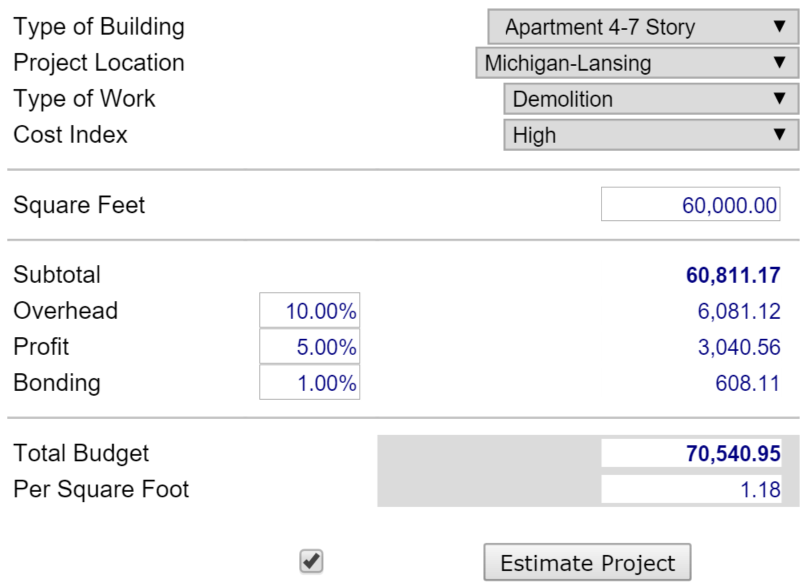


Figure. 2.2 Cost estimation of demolition for apartments which are 4 to 7 story high, cost index is high and the location is Lansing, MI using the online source (http://buildingjournal.com/commercial-construction-estimating-demolition.html, 2016).

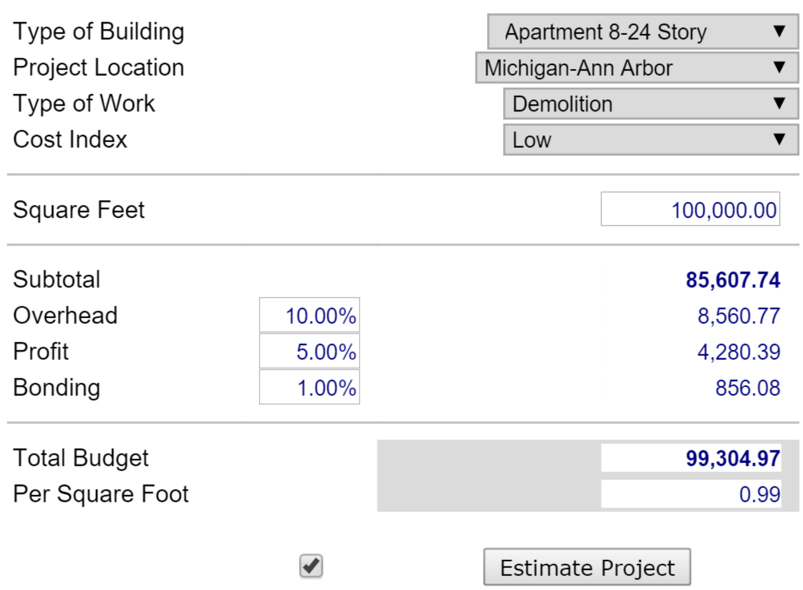


Figure. 2.3 Cost estimation of demolition for apartments which are 8 to 24 story high, cost index is low and location is Ann Arbor, MI using the online source (http://buildingjournal.com/commercial-construction-estimating-demolition.html, 2016)

From the above database it can be seen that the cost of demolition for apartment buildings increases as the number of stories or height of the building increases. This is due to various factors, that is, the increased cost of safety, increased cost of material handling and removal, etc. But buildingjournal.com estimates the demolition costs without considering the details of the type of structure and material used among many other important factors that highly affect the cost of demolition project (Zahir & Syal, 2015). Compared to this tool RS Means cost database provides a more comprehensive estimation of demolition projects.

2.3. Deconstruction

As the name suggests deconstruction is reverse of construction where the building is taken down into basic materials such as lumber, steel, windows, equipment, etc. with the goal of preserving maximum value of the recovered material. Materials recovered from the deconstruction process fall into one of three broad categories: reused, recycled and disposed. Reused and recycled materials typically amount to 85% of a building's total weight (Endicott, et al., 2005). This represents a huge opportunity to reduce growing problem of increasing landfills and societal pressures toward sustainability.

Further, according to Guy et al. (2003), reuse 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. Also, due to deconstruction, there are many opportunities for recycling other materials along the way.

2.3.1. Benefits of deconstruction

Current building removal practice harms the environment by depleting finite landfills resources and contributing to the increase of energy consumption (Marzouk & Azab, 2013). Even though demolition projects have relatively short project durations, engagement of mechanical equipment leads to high costs for demolition (Pun et al., 2005). It is very important to give priority to the environment in addition to conventional project objectives, such as cost, duration, quality and safety. Deconstruction is capable of providing economic, social, and above all else, environmental advantages (Chini and Bruening, 2003).

2.3.1.1. Environmental benefits

The following are the environmental benefits of deconstruction (EPA 2008; Frisman, 2004):

- Increases diversion rate of demolition debris from landfills, hence saves landfill space.
- Saving natural resources that would otherwise be used for mining and timber cutting
- Potential reuse of building components
- Increased ease of materials recycling
- Reducing job site pollution from dust, airborne lead and asbestos
- Sustainable economic development through reuse and recycling

2.3.1.1.1. Reuse

When material is used again for its original purpose it is called ‘reuse’ (Popular Network, 2016). In demolition, the entire building is knocked down and sent to the landfills making reuse highly difficult. The deconstruction process tends to have least impact on the amount of change to the existing building components by carefully dismantling each constituent. If possible, the best situation is to reuse the whole building or the components in a new combination. Hence, this practice uses the least energy as it does not change the material form (Endicott et al., 2005). After the deconstruction of a building, some parts of the salvaged components and materials can be sold on-site, taken to the warehouse, or consigned to other resellers and sold to the public. Other materials may either be shipped to low-income markets or donated to other nonprofit agencies (Zahir and Syal, 2015). According to "The Reuse People" (as cited in Endicott, et al., 2005), reused materials generally include appliances, architectural pieces, bricks, cabinets, doors, electrical, flooring, structural steel, windows, lumber and plumbing.

2.3.1.1.2. Recycle

According to Popular Network (2016), recycled material is a waste that has been turned into a new product. In deconstruction, the first step is to dissemble the building at the end of its life, followed by the second step, separation of used materials. In the third step, the used materials are reproduced and transformed to new products (EPA, 2008). Currently, buildings are not designed in order to deconstruct at the end of their life cycle, making the separation difficult for recycle. Due to this difficulty the recycled materials are of low quality. Presently, the recycled materials include aluminum, asphalt, asphalt shingles, carpet, cast iron, concrete, glass and scrap steel (Endicott, et al., 2005).

2.3.1.2. Social benefits

The following are the social benefits of deconstruction (EPA 2008; Frisman, 2004):

- Creates jobs because it requires more labor
- Deconstruction's basic skills are easily learned, enabling unskilled and low-skilled workers to receive on-the-job training
- Provides the impetus for community-oriented enterprises such as deconstruction service companies.

2.3.1.3. Economic benefits

Deconstruction takes more time compared to demolition of a building. Also, skilled labor force is required for deconstruction. Hence, the labor cost in the deconstruction process is higher than the demolition. Although, according to "The Reuse People" (as cited in Endicott et al., 2005), deconstruction costs 30-50% less than demolition when the revenues from salvaged materials are factored into the equation. This difference is calculated by taking the overall costs of the deconstruction operation and adding the value of the salvaged materials. The study by Guy et al. (2003), shows average cost of demolition of a residential building is $5.36 per square foot. Whereas the deconstruction cost is $4.38 when the salvaged value of recovered material is considered. Furthermore, Greer suggests that there are (as cited in Endicott et al., 2005) tax saving opportunities for an individual on the sale of salvaged building materials. In the Bay Area, the tax savings for an individual can be up to 35% of the sale.

This section reviewed the benefits of deconstruction. The case study of deconstruction project in New Orleans post the hurricanes in the next section will help to understand the impact and the benefits of deconstruction better.

2.3.2. Case Studies

In the following section, two case studies are provided that have implemented deconstruction. The studies shows the benefits of adopting deconstruction. The first case study is of deconstruction project conducted after the hurricanes Katrina and Rita. The second one is a pilot study of six houses deconstructed in Gainesville, Florida to examine the cost effectiveness of deconstruction.

2.3.2.1. Economic and environmental impacts of deconstruction in post-Katrina New Orleans (Denhart, 2009)

In 2005, hurricanes Katrina and Rita hit Gulf region of the United States. The region was left with nearly $100 billion in damages including severe or total destruction of 275,000 homes. Mercy Corps (MC), a global humanitarian aid agency, responded to this disaster with an innovative deconstruction program aimed at human empowerment and environmental protection.

MC decided to deconstruct four homes among the destroyed homes. Where it takes one worker two days to demolish an average house with heavy machinery, it takes five-six workers 10–15 days to deconstruct it. Thus, MC saw deconstruction as a means of providing training and jobs. Approximately 50 different types of materials were recovered from the four houses. The cost to deconstruct these four houses totaled $49,950, for an average cost per square foot of $8.34 with 44 tons of recoverable material.

Out of the four destroyed homes, Mercy Corps salvaged enough material to build three new ones. The process, a first phase of reconstruction, also provided four to five times as many jobs as demolition and converted 44 tons of "landfill debris" into $60,000 of product for a local market place devastated by disaster. Hence, this study shows the economic, social and environmental benefits of deconstruction.

2.3.2.2. Building Deconstruction: Reuse and Recycling of Building Materials

The Center for Construction and Environment (CCE) deconstructed six (6) houses during 1999-2000 to study the cost effectiveness of deconstruction and salvage when compared to traditional demolition. One of the six residential structures has been presented here as a case study of the deconstruction cost estimation. The selected building is identified as '2930 NW 6th Street', located in Gainesville, Florida, built in 1900.

This was a one-story house of 2014 SF including the garage of approximately 500 SF. The house was wood raised on brick piers, the garage was a CMU wall construction on concrete slab. This building had several additions and several layers of interior finishes, i.e. two wood floors and two roof finishes, a metal roof laid over an asphalt roof. The interior walls were predominantly plaster and lathe. The plaster was separated from the lathe to see if the lathe could be recycled or used for fuel in pottery kilns. This project was affected by a summer heat wave and several rain days. The site had ample room for the layout of de-nailing areas and roll-offs, and did not require extensive site work to make space around the building.

Deconstruction costs were collected for labor, other costs, disposal costs, environmental assessment and salvage costs. This case study represents a situation where there are no materials storage, inventory, and sales personnel costs. Materials are given a retail value and deducted from the deconstruction costs for a net deconstruction costs without the additional costs for overhead on the materials themselves. Figure 2.4 extracted from the case study report shows a summary of the cost for the deconstruction of '2930 NW 6th Street' house. It also compares it with the demolition cost.

COSTS		**Total Net Demolition**			**Total Net Deconstruct**		
Permit		50.00			50.00		
Asbestos survey		1,200.00			1,200.00		
Asbestos abatement		740.00			740.00		
Disposal		5,873.67	96.67	tons	1,344.01	22.12	tons
Toilet		63.00			63.00		
Supplies		10.00			637.93		
Labor and Equipment		3,504.36			8,469.38		
Total Costs		11,441.03	**5.68**	**per SF**	12,504.32	**6.21**	**per SF**
REVENUES							
Salvage		0.00			9,415.00	**4.67**	**per SF**
Total Net Costs		11,441.03	**5.68**	**per SF**	3,089.32	**1.53**	**per SF**

Figure. 2.4 Economic summary table for '2930 NW 6th street (Guy, 2001)

The summary displays cost effectiveness of deconstruction. Deconstruction cost was $6.21 per square feet compared to $5.68 of demolition. But when salvage value of the recovered material is considered, the deconstruction cost dropped down to $1.53 per square feet.

Labor productivity data was collected for supervision, deconstruction, demolition, processing, non-production, clean-up / disposal and loading/unloading. Table 2.2 below shows the percentage and number of labor hours spent on each of the categories of work.

Table. 2.2 Labor time by work categories (Guy, 2001)

Category Hours									
House #		Super	**Decon**	**Process**	Demo	**Dis/Clean**	Non-Pro	Load	**Total**
2930	hr	60.50	**179.50**	**204.80**	0.00	**100.00**	52.75	80.00	**677.55**
Percentage	%	8.93	**26.49**	**30.23**	0.00	**14.76**	7.79	11.81	**100**
Hours / SF		0.030	**0.089**	**0.102**	0.000	**0.050**	0.026	0.040	**0.336**

It can be seen that almost 678 hours were spent on this building which is significant amount of time compared to demolition. But, looking at the economic advantage of deconstruction, slightly extra time can be acceptable.

The average gross deconstruction cost for all six houses was $6.47/SF, which is approximately 26% higher than demolition. Disposal costs for deconstruction were 15% of the total costs. Gross deconstruction cost is the first cost of the deconstruction which includes all labor and disposal but does not include any salvage revenues. Asbestos and lead surveys and remediation was an average of $0.97/SF or 15% of the costs for deconstruction.

The average salvage value was $3.28/SF and the price of salvaged lumber was estimated at between 25-50% of new lumber retail value in local stores. The price of other items were estimated as very low costs for used goods, based on the experience of an used building materials store owner/operator in Gainesville, Florida.

2.3.3. Cost estimation of deconstruction project

After reviewing environmental problems of using demolition and benefits of deconstruction, it is clear that adoption of deconstruction is important. Deconstruction is fairly new building removal method. So, unlike demolition, there has not been a significant progress in creating cost estimation tools for predicting deconstruction costs of a project. Recently, United States Environmental Protection Agency (EPA) developed a 'Checklist for Assessing the Feasibility of Building Deconstruction for Tribes and Rural Communities' and 'Building Material Reuse and Recycling Estimating Tool'.

2.3.3.1. <u>Checklist for Assessing the Feasibility of Building Deconstruction for Tribes and Rural Communities</u> (EPA, 2015)

EPA designed this checklist in order to be used by various tribes and rural communities irrespective of size and geographic location. Checklist and Building Material Reuse and Recycling Estimating Tool together assists tribes and rural communities to determine potential costs and benefits of reuse, recycling, and disposal options for various types of deconstruction materials.

The checklist provides general guidance to tribe and town staff, deconstruction managers, and building owners who are planning or already conducting deconstruction projects based on several key factors such as:

- Condition of the building and materials
- Types and quantities of potential reusable and recyclable materials
- Presence of hazardous material
- Access to building reuse and recycling markets.

The checklist provides a three step process in assessing the technical and economic feasibility of building deconstruction – Pre-Building Assessment, Building Inventory, and Economic Assessment.

a) Pre-Building Assessment helps tribes and rural communities prepare for building deconstruction by analyzing local conditions, regulations, markets and opportunities for maximizing economies of scale.
b) Building Inventory requires a physical walk through to collect detailed information of type, quality, condition, and quantity of materials; space for equipment and storage/processing of removed materials; presence of hazardous materials; and site and safety constraints for deconstruction.
c) Economic Assessment requires identification of local building material reuse and recycling facilities, transportation options, disposal fees, and labor costs.

After completion of the checklist, the information collected (e.g., type, quantity, condition, etc.) is then entered into the Building Material Reuse and Recycling Estimating Tool to determine potential costs and benefits of reuse, recycling, and disposal options of the building deconstruction materials.

Although the checklist is precise and detailed, it requires an expert to make the decision. The checklist was developed for experienced staff in building deconstruction of tribes and town or by deconstruction contractors hired by the tribes and town who are familiar with building material types, and methods for estimating and calculating material amounts, and identifying hazardous materials. The checklist cannot be used by those who are new to or unfamiliar with the deconstruction process.

✓ ***Evaluate Site/Building Accessibility factors.*** Rate each of the following site accessibility factors as high, medium, or low.

Accessibility factor	High	Med	Low
Site is accessible by existing roads			
Determine the levels of vehicle and pedestrian traffic in proposed areas of deconstruction (e.g. may impact building removal permit requirements)			
Clear access to all sides of the building			
Absence of vinyl siding			
Adequate space for material storage and material processing stations (if applicable)			
Site clear of ancillary structures, trees, etc.			
Other			

➲ *A medium to low access rating typically indicates an increase in the labor to ready the site to deconstruct, store, sort, and/or process materials onsite, thus, increasing overall project costs.*

✓ ***Assess How the Building was Constructed****:* Rate each of the following structural factors as high, medium, or low.

Structural factor	High	Med	Low
Size of structural or weight bearing members (e.g., beams, columns, walls, foundation).			
Extent, how, where weight bearing members are connected or joined to other structural members.			
Numbers of walls and corners to the exterior footprint			
Roof complexity			
Other			

➲ *A Building with a high or medium rating typically indicates an increase in the level of skill, time and planning required to safely dismantle a building, thus an increase in the overall cost.*

✓ ***Evaluate Interior Accessibility****:* Rate the extent of the following factors that may impede access to or reduce the amount of recoverable interior building materials as high, medium, or low.

Interior Accessibility factor	High	Med	Low
Drywall			
Treated Wood			
Carpet, linoleum, other materials covering hardwood floors			
Other interior finishes			
Size of structural or weight bearing members (e.g., beams, columns, walls, foundation).			
Other			

Figure. 2.5 Checklist for assessment of Accessibility factor, Structural factor and Interior Accessibility factor

(EPA, 2015)

2.3.3.2. Building Material Reuse and Recycling Estimating Tool (EPA, 2015)

The estimating tool is a spread sheet in which expert of deconstruction or deconstruction contractor enters his numbers based on his experience and the analysis of the checklist. It is used to them through a five-step process to determine the potential cost or benefit of building deconstruction and material recovery vs. traditional building demolition and material disposal:

- Estimating Building Deconstruction with Material Recovery Project Costs

  In this step, the expert enters estimated recoverable material quantity, labor cost and transportation cost of recycled material which can be analyzed from the checklist.

- Estimating Value of Recoverable Building Materials

  According to the checklist, the expert makes a call on the cost of the recoverable material based on the local market and amount estimated in the first step.

- Estimating Avoided Disposal and Transportation Costs with Building Deconstruction and Material Recovery

  Due to deconstruction, waste from the landfill is diverted. In this step, estimated dumping and transportation cost is entered considering the waste wasn't diverted.

- Estimating Potential Total Cost without Building Deconstruction and Material Recovery

  Once the expert enters the estimated labor cost if the project used demolition, it gives the demolition cost of the project.

- Calculating Potential Deconstruction and Material Recovery Project Cost or Benefit

Calculates deconstruction cost and demolition cost based on the previous step and compares for cost saving. Figure 2.6 will help to understand the five steps discussed

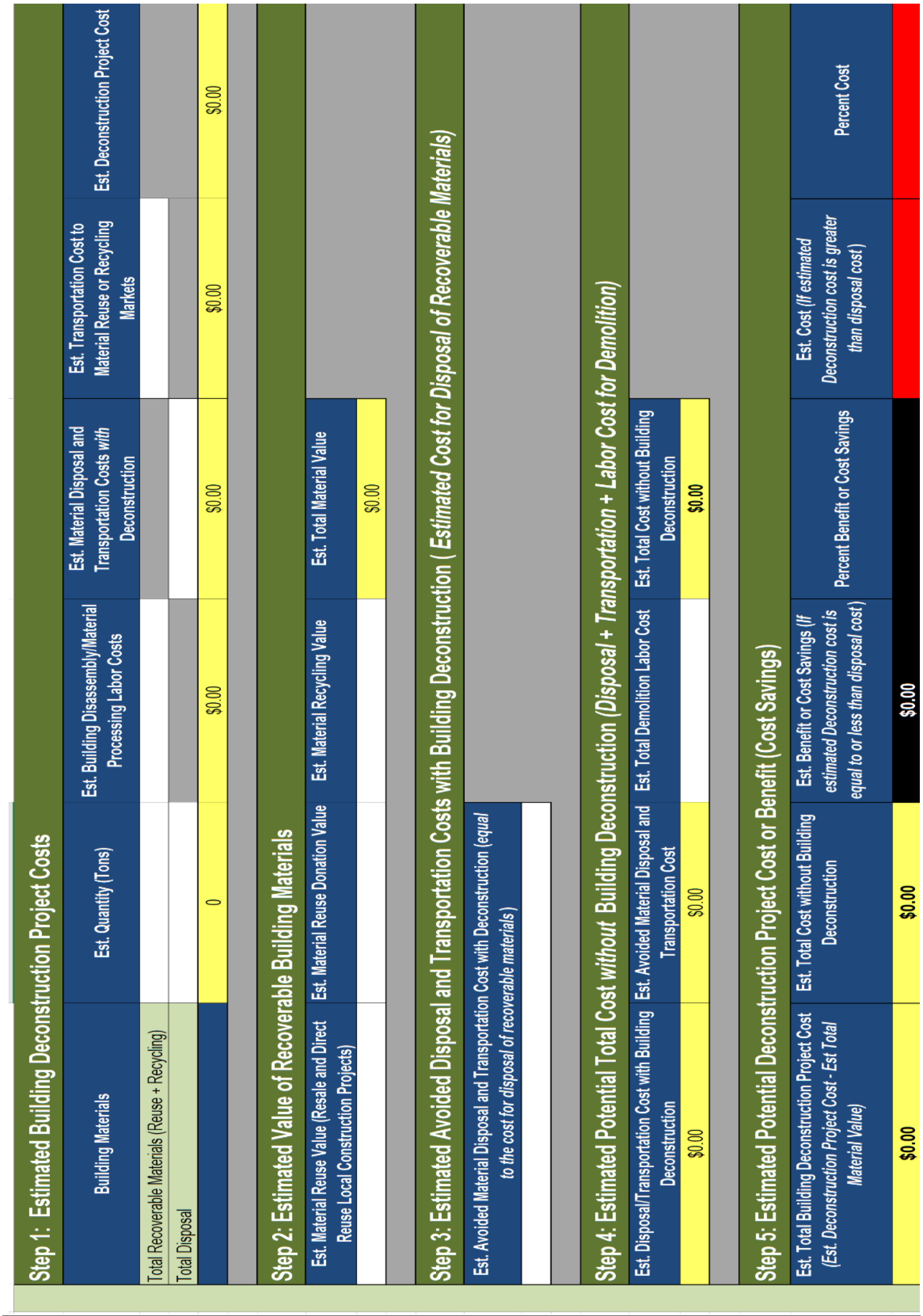


Figure. 2.6 Spreadsheet to calculate deconstruction costs and compare with demolition costs

(EPA, 2015)

2.4. Design for Deconstruction (DfD)

Current building removal practice results in a pile of mixed debris on site, which is likely to be sent to landfill due to its lack of separation and contamination. Due to lack of reuse and recycle, for new construction extraction of raw material is required. The ultimate goal of the Design for Deconstruction (DfD) is to responsibly manage end-of-life building materials to minimize consumption of raw materials (EPA, 2006). The overall environmental impact of end-of-life building materials can be reduced by finding ways to reuse them in another construction project or recycle them into a new product. Architects and engineers can contribute to this by designing buildings that facilitate adaptation and renovation.

The raw resources are mined from earth and are processed into construction material, using a lot of energy and resources needed for the process from mining to transportation to manufacturing, and are simply disposed of as waste to landfills. Deconstruction helps us to recover material from the waste which can be reused and recycled. Material salvaged from a deconstruction project is valued based on the function it can provide in being used for new construction when assembled and therefore material are more valuable to be reused than to be recycled. The challenge is that these materials were not put together to be recovered and reused. Webster states (as cited in Zahir & Syal, 2015) the goal of design for deconstruction is to figure out how to put buildings together so that they can be economically taken apart and reused in new construction and this can be seen in Figure 2.7.

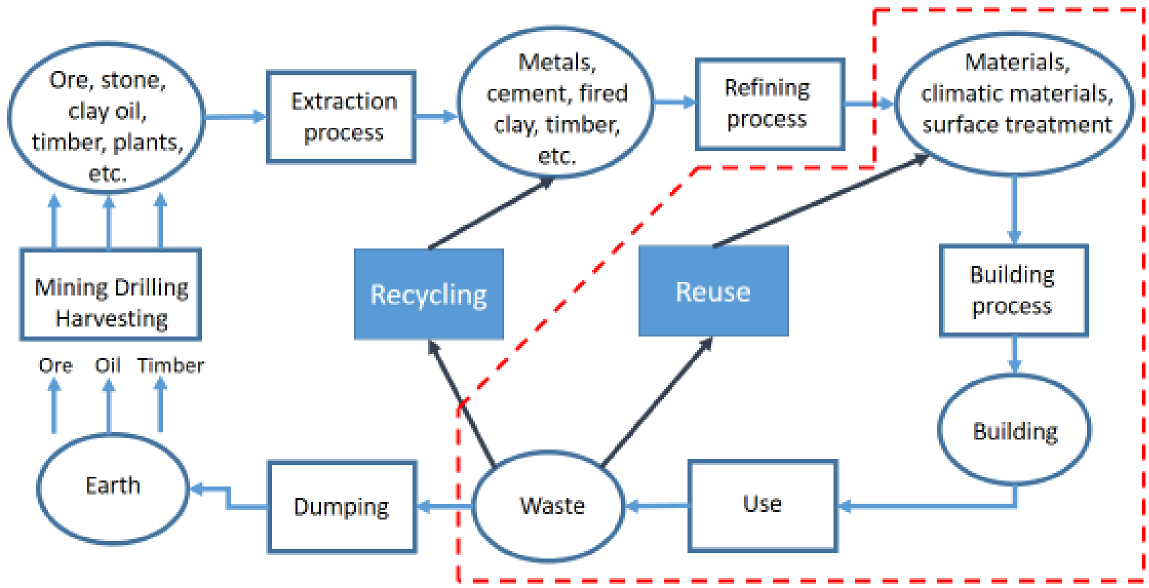


Figure. 2.7 Closed loop in material life cycle showing maximum use of resources due to design for deconstruction (EPA, 2008)

Another important aspect of Design for Deconstruction is to provide structural system with flexibility to reconfigure spaces. The utilities and infrastructure of the buildings to be easily accessible for maintenance and upgrade (EPA, 2006). According to EPA (2006), the principles of Design for Deconstruction are applied at three levels of buildings and structures: materials, assemblies and building systems.

2.4.1. Material

Different materials have different properties and functions which can affect the cost of the building and also material recoverable cost. Hence, selection of material should be done with caution. Even though using non-hazardous materials over hazardous materials can greatly increase the cost of a project, the cost can be recovered by reusing this materials at the end of the life cycle of the building. If they still have to be used for performance reasons, they should be tagged and identified properly so that they can be handled with caution at the end of their useful life (EPA, 2006).

Composites should be avoided where possible as it complicates the separation of individual material for reuse. Using fewer material types simplifies deconstruction. For example, automobile dashboards used to be complex assemblies of numerous materials that made recycling impractical. Newer technology allows the use of a single resin for an entire assembly that can be readily recycled. If the architectural aspects and performance allow, fewer material types with careful interface should be considered (EPA, 2008).

Using less material to realize a design makes a building design less complicated, requires less labor and reduces the waste of resources during construction, and also requires less labor to deconstruct (EPA, 2006). Also, using the salvaged material from existing buildings will help to minimize waste, incorporate reused material and support the market for reuse of material.

2.4.2. Assemblies

Assemblies are building blocks of architecture. They dictate how materials and components come together to create a complete structure. According to the definition of deconstruction, it incorporates the field of disassembly. Hence, in order to disassemble the structure less adhesive and sealants should be used where possible and be replaced by simple and stronger fittings and fasteners. Glues and chemicals damages material when removed, instead the use of bolts, screws and mechanical connections are favored (EPA, 2006).

Without degrading the quality of the material and assembly, it should be readily accessible and where possible exposed to allow maintenance and disassembly. For example, to replace a window, there shouldn't be a need to cut and patch drywall and stucco (EPA, 2006).

Modularity and prefabrication of assemblies and components can promote reconfiguration, reuse and recycle to a large extent. Fewer but larger components are favored. The assemblies should be modularized only when it makes it easier to construct and deconstruct (EPA, 2006).

2.4.3. Building systems

Infill, substructure, enclosure, mechanical, electrical, HVAC, etc. are often tangled to accommodate each other. Disentangling all these systems from each other makes it easier to maintain individual systems and facilitate adaptation and deconstruction of each system (EPA, 2006).

Utilities often require regular maintenance and replacing. Hence, separating and making utilities such as HVAC, plumbing, electricity, etc. readily accessible will help with flexibility and adaptability. This will not only help during the life time of the building, but also during the end of the lifecycle, as it is much easy to recover and reuse if in good condition.

Design for deconstruction also aims to separate or disentangle the utilities from the structure. If the utilities are disentangled from the interior walls of the building, the walls assemblies can be adjusted as needed during the lifetime of the building to create a flow of effectiveness (EPA, 2006).

2.4.4. Building information

Keeping record of all the concepts of design for deconstruction implemented in building construction with drawings and photographs of the utilities before they are concealed behind walls and ceilings is highly important. These documents can be used to reconfigure assemblies, components and spaces as needed during use and can also help with deconstruction at the end of the lifecycle of the building (EPA, 2006). This information should be maintained throughout the life time of the building. Also, a deconstruction plan should be prepared based on the construction process for future reference.

2.5. Summary

This chapter reviewed demolition and recognized mechanical demolition to be suitable for residential buildings. Environmental impacts from demolition activities are large and deconstruction can work to offset the environmental impacts of the building related waste. Deconstruction not only diverts wastes from landfills, but it also reduces greenhouse gas emissions by reducing the need to extract and ship new materials and also gives rise to a new industry of skilled jobs.

With demolition being the typical building removal method, there is ample information about the associated costs. The cost estimation tools reviewed for demolition, EPA's checklist and estimating spreadsheet for deconstruction will assist to develop a cost estimation model for deconstruction in the next chapter. Also, the concepts of design for deconstruction studied will aid to analyze the complexity of the building, which will benefit in calculating deconstruction costs.

3. PREDICTION MODEL

3.1. Introduction

Predictive modeling is a process of applying a statistical model or data mining algorithm to data for the purpose of predicting new or future observations (Shmueli, 2010). In other words, a predictive model is made up of a number of predictors, which are variable factors that are likely to influence future behavior or results. In predictive modeling, data is collected for the relevant predictors, a statistical model is formulated, predictions are made and the model is validated as additional data becomes available. Predictions include point or interval predictions, prediction regions, predictive distributions, or rankings of new observations.

3.2. Prediction model for construction cost estimation

The construction industry is characterized by high levels of risks and uncertainties. So, the accuracy of estimation of construction costs in a construction project becomes an important factor in the success of the project (Lee S. et al., 2011). Construction managers and estimators have to rely on their knowledge, experience, and cost-estimation techniques to estimate the cost of a construction project in its early stages due to limited information. Hence, knowledge of previous occasions is essential to provide solutions for current or future projects (An et al., 2006). As defined earlier predictive modelling forecasts future based on different factors from previous instances. Therefore, a cost prediction model based on the factors such as construction type, location, size, unforeseen conditions, scheduling, etc. from the previous projects helps in estimating costs for new projects. Over the years, there have been several prediction models like multiple regression model, neural network model and case-based reasoning (CBR) model developed to estimate cost of new construction projects (Kim et al., 2004).

3.2.1. Multiple regression model

Multiple regression model has a well-defined mathematical basis and is an extension of simple linear regression (Kim et al., 2004). It predicts the value of a variable based on the value of two or more other variables. The variable of which value is to be predicted is called the dependent variable. While, the variables we are using to predict the value of the dependent variable are called the independent variables. Multiple regression analysis (MRA) for cost estimation of a construction project can be represented in the form of:

$$Y = C + b_1X_1 + b_2X_2 + \cdots + b_n.X_n;$$

where Y is the total estimated cost, and X_1; X_2;...; X_n are measures of independent variables that may help in estimating Y . For example, X_1 could be the measure for the gross floor area, X_2 the number of stories, etc., C is the estimated constant, and b_1; b_2; ... ; b_n are the weights estimated by regression analysis, given the availability of some relevant data.

However, according to Kim et al. (2004), regression model has few disadvantages. It has no clearly defined approach that will help estimators choose the cost model that best fits the historical data to a given cost estimating application, i.e. it fails to explain which independent variable to be considered based on the available data. Hence, the variables influencing the estimation must be reviewed in advance. Also, it is difficult to use a large number of input variables.

3.2.2. Neural network model

Neural network (NN) model is a computer system modeled on the human brain and nervous system. The inter-neuron connection strengths known as synaptic weights are used to store the knowledge. This learning ability of neural networks gives an advantage in solving complex problems whose analytic or numerical solutions are hard to obtain (Gunaydin & Dogan, 2004).

When presented with sets of data consisting of inputs associated with output(s), NN learns through training (Creese and Li, 1995). Therefore, NN is capable of drawing upon real life experience in an accurate and consistent manner. Major benefits of using neural network based cost models include non-reflection of individual assumptions and the identification of near best parameters for lower cost and higher quality solutions (Moselhi et al., 1991).

In designing neural network model for construction cost prediction, principle of back-proportion, i.e. the initial system output is compared to the desired output, and the system is adjusted until the difference between the two is minimized, is generally used (Kim et al., 2004). As seen in the Figure 3.1, NN is divided in 3 layers; the input layer, the hidden layer and the output layer. The input and the output layer are nothing but independent and dependent variables as in the regression model.

The function of the hidden layer is to extract and remember the useful features and the sub features from the input patterns to predict the outcome of the network (Rafiq et al., 2001). Therefore, an effective number of processing elements is usually determined by trials for the hidden layers, since there is no rule to determine it.

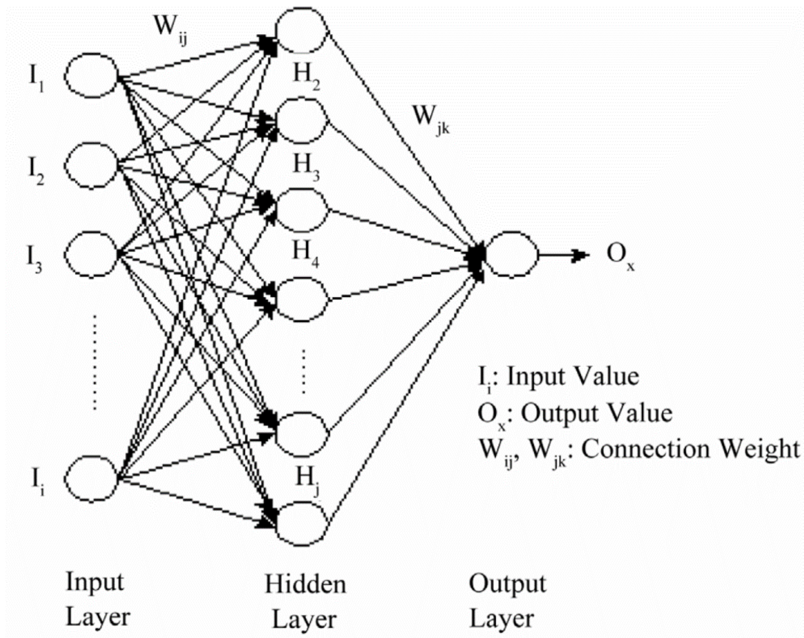


Figure. 3.1 Neural network structure (Kim et al., 2004)

Even though neural network model can be used to construct high-level nonlinear function estimation models and their use does not impose any limit on the number of input variables, the main disadvantage is that the black box techniques and knowledge acquisition process are very time-consuming (Creese and Li, 1995; Kim et al., 2004). Bode (1998) concluded in his research report that the accuracy of the neural network is largely impacted if there are not a large number of cases for learning algorithm. Smith and Mason (2010) also examined the performance of neural network. They suggested that the problem of model commitment became more complex as the dimensionality of the independent variable set grew.

3.2.3. Case-based reasoning model

The construction industry utilizes experience and knowledge of previous occasions to provide solutions for current problems. Case based reasoning (CBR) has grown to be an artificial intelligence (AI) based method that offers an alternative for solving construction related problems that require extensive experience (Dogan et al., 2006). A case-based reasoning model solves new problems by adopting solutions that were used to solve old problems. CBR systems have been developed in recent years for all branches of construction, for example, architectural and/or structural design, duration and/or cost estimation, construction process, safety planning, bid decision making, selection of method, and management, etc. (Kim et al., 2004).

A CBR system, inspired by the remembering of similarities in experts' reasoning, consists of four sub-processes (Kim et al., 2004):

- Old cases, which represent experiences that the system acquired, are stored in a case base.
- When a new case is presented to the system, the CBR system retrieves one or more stored cases similar to the new case according to the percentage similarity.
- Users attempt to solve the new case by adapting the retrieved case(s), and the adaptation is based on the differences between the stored cases and the new case, unless the retrieved old case(s) is a close match, and this retrieved case probably has to be revised.
- The new solution is retained as a part of the stored cases throughout the test

Generally, CBR models for construction uses the following equation to calculate the percentage similarity, which indicates the similarity between one or more of the stored cases and a new case (Kim et al., 2004).

$$\text{Percentage similarity}(N,S) = \frac{\sum_{i=1}^{n} f(N_i,S_i)\times w_i}{\sum_{i=1}^{n} w_i}\times 100(\%)$$

where N is the new case, S is the stored case in the case base, 'n' is the number of variables in each case, 'i' is an individual variable from 1 to n, 'f' is a similarity function for variable 'i' in cases N and S, and w_i is the importance weight of variable 'i'.

Similarity function can be defined as:

$$\left|\frac{N_i - S_i}{S_i}\times 100\right| \leqslant 10(\%)$$

If the value of the new case's variable matched above equation, the value of f(Ni; Si) is 1, otherwise it is 0 (Kim et al., 2004). After the percentage similarity of all the cases are calculated, the cost data in the case base are ranked. The top ranked case is selected and the cost corresponding to the top ranked case is selected as a recommended cost for the new construction project. This procedure is illustrated in Figure 3.2.

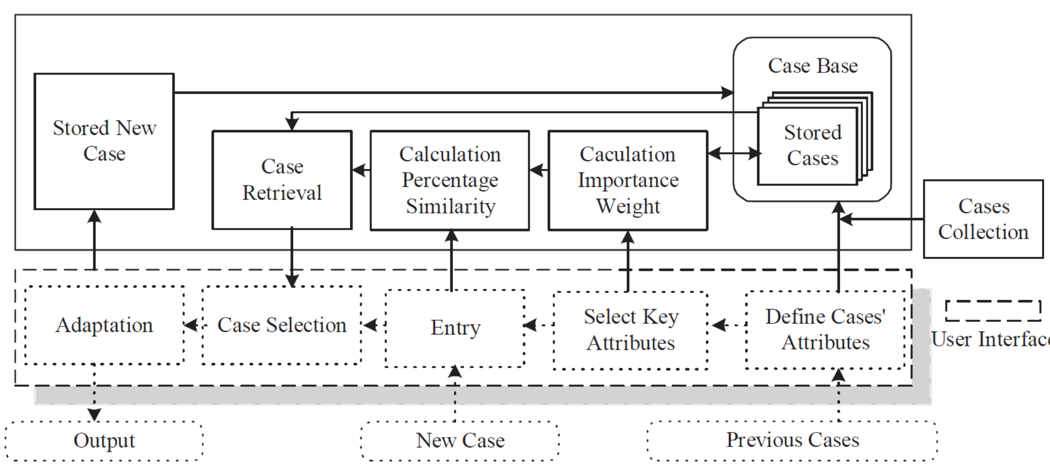


Figure. 3.2 Case based reasoning model (Kim et al., 2004)

3.3. Comparison of cost prediction models

Numerous studies have been conducted to compare these cost prediction models. Squeira (1999) presented an automated cost estimating system for low-rise structural steel buildings. This study showed that the neural network model outperformed regression. The estimated costs and actual costs were compared using a couple of examples. NN model had 5% - 18% variance between estimated and actual cost, whereas by regression it was 11% - 57%. Kim et al. (2004) conducted a comparison study of all three models using a data set containing 530 historical costs. The NN model gave more accurate estimation results than the CBR or MRA models. The Mean Absolute Error Rate (MAER) values for NN, CBR and MRA models were 2.97, 4.81 and 6.95 respectively.

Thus, from different studies, it is clear NN models give better cost estimates than the other two models. However, neural networks also have the disadvantage that its knowledge acquisition process is a black box, whereas the statistical approach is a white box technique. In other words, the user cannot get any information that shows the effect of one input variable on one output variable (Bode, 1998; Yeh, 1998). Also, NN model takes a very long time to tune the weights in the net to generate an accurate model for a complex and nonlinear system (Yeh, 1998, Creese and Li, 1995).

Further, Kim et al. (2004) concluded that the CBR model was more effective with respect to the clarity of explanation in estimating construction costs, than the other models. Ease of updating and consistency in the variables stored are major factors for the construction cost model is its long-term use. In these respects, the CBR model can be more useful for estimating construction costs.

Also as determined by Bode (1998) in his research report, the accuracy of the neural network model is largely impacted if there are not a large number of cases for learning algorithm. As deconstruction is fairly new concept and deconstruction industry has not significantly flourished, there are very few cases available for learning algorithm for cost prediction model. So, the results obtained from neural network method might not be that accurate. Therefore, it can be established that CBR model will be the most appropriate cost prediction model for deconstruction. The following Table 3.1 compares the three models based on the above discussion.

Table 3.1. Comparison of the three cost prediction models

	Multiple Regression Model	**Neural Network Model**	**Case Based Reasoning Model**
Cost prediction accuracy	Not good	Very good	Good
Clarity of explanation	Good	Not good (termed as black box technique)	Superior
Time to construct an accurate model	Decent	Very time consuming	Less time consuming compared to NN model
Deconstruction adaptability		Low	Good

3.4. Cased Based Reasoning model for deconstruction costs

Based on the above discussion it is the author's opinion that CBR model will be the most appropriate cost prediction model for deconstruction, and therefore, its model structure needs to be recognized. The model derives the output, i.e. the estimated cost based on the input (independent) variables and their respective weights. In order to develop a framework for the model, input variables for deconstruction and their respective weights needs to be established.

3.4.1. Input variables

An extensive study of academic papers, thesis reports and case studies available for deconstruction and case-based reasoning prediction model helps to determine the input variables for the model. Table 3.2 comprises of the list of input variables that govern the cost of deconstruction along with the justification and range of each input variable.

3.4.2. Weight of the input variables

In a prediction model there are several input variables, but every input variable does not have the same impact on the output. Weights are importance, or the impact, of the variables on the desired output. There are quite a few methods to determine the weight of a variable such as equal weight method, gradient decent method and analytic hierarchy process.

3.4.2.1. Equal weights method

Equal weight is a type of weighting that gives the same importance to each input variable in the model. When the importance, or the impact, of the variables cannot be determined, this weighting system is used. The variance of the results obtained using this weighting system are mostly huge because even the least impactful variable is given equal weight as the most impactful variable (An et al., 2006).

Table 3.2. List of input variables with range for cost prediction model for deconstruction

Sr. No.	Input variables	Reason	Range	Description	References
1	Age of the building	Quality of the material can be interpreted by the age of the building	Number	Difference of the year the building is being deconstructed and the year it was built in.	EPA checklist (2015)
2	Condition of the building	Water or fire damages to building. If the damages are high, recoverable material will be less which will increase the overall cost	Percentage (0-100)	Higher the percentage better is the condition. More than 75% indicates very low water or fire damages and holes in the structure and less than 30% is the opposite.	EPA checklist (2015)
3	Design complexity of the building	High rating indicates an increase in the level of skill, time and planning required to safely dismantle a building, thus an increase in the overall cost	Category (High, Medium & Low)	High being highly complicated and accordingly Medium and Low. Highly complicated design indicates low material quality, more labor required to remover material.	EPA checklist (2015)
4	Hazardous Building Materials	High number of hazardous building material means low amount of recoverable material and high safety	Category (High, Medium & Low)	High means large amount of lead, asbestos and other hazardous materials present in wood, paint, plumbing and electrical work which increases safety and directly the labor cost to remove it. Also, the amount of material recovered is less. Medium means fairly less amount of these material and Low indicates negligible amount of hazardous material	EPA checklist (2015); Guy, B. (2001)
5	Building Material Reuse and Recycling Markets	The absence of local markets may result in higher costs to transport materials to markets, which can greatly impact the economic viability of deconstruction	Category (High, Medium & Low)	Category High indicates the good market condition and Low means market not so favorable for reused and recycled materials	EPA checklist (2015)

6	Location	Depending on the location, the labor and equipment cost may vary. Also, high cost of dumping will increase the cost of the project	Category (High, Medium & Low)	Category High indicates low labor, equipment and dumping cost and consequently Medium and Low	An et al., 2006; Guy B. (2001)
7	Site/ Building Accessibility	Low accessibility indicates an increase in the labor to ready the site to deconstruct, store, sort, and/or process materials onsite, thus, increasing overall project costs	Category (High, Medium & Low)	High indicates significant amount of space available near the building for staging and holding dumping equipment. Low suggests the building tightly placed between other structures which restricts the deconstruction activities.	EPA checklist (2015); Guy, B. (2001)
8	Building area	Size of the building affects the use of equipment and safety precautions, both measured by time and expense	0 to 6000 SF	Area	EPA checklist, (2015); Dogan et al. (2006)
9	Amount of recoverable building material	Amount of recoverable material affects the overall cost of the project. More the recoverable cost, less overall cost of the project	Percentage (0-100)	More than 75% indicates material highly recoverable whereas less than 30% indicates the extracted material mostly goes to landfill.	Guy, B. (2001)
10	Number of floors	The number of floors has a direct effect on the structural design and consequently cost of removing of columns. Also, with number of floors safety increases which increases labor cost	Numeric (1 to 3)	-	Dogan et al. (2006); Guy, B. (2001)

For example, An et al. (2006) developed a cost prediction model for construction of multi-story building. The independent (input) variables and their respective weights using equal weights, gradient decent and analytical hierarchy methods are shown in Figure 3.3.

Attributes	**Equal weight**	**Gradient descent method**	**AHP**
Gross floor area (m^2)	0.1111	0.2157	0.2200
Number of stories	0.1111	0.1168	0.0490
Total unit	0.1111	0.1798	0.1010
Unit area (m^2)	0.1111	0.1447	0.1840
Location	0.1111	0.1052	0.1230
Roof types	0.1111	0.0225	0.0480
Foundation types	0.1111	0.0690	0.1090
Usage of basement	0.1111	0.0226	0.0340
Finishing grades	0.1111	0.1237	0.1340
Total	**1.0000**	**1.0000**	**1.0000**

Figure. 3.3 Weights of variables (An et al., 2006)

As seen in the Figure 3.3, the importance of the variables like gross floor area and roof types or location and usage of basement are same in the equal weight method. Whereas, gradient decent method (GDM) and analytical hierarchy process (AHP) rates each variable different. This affects the effectiveness of the model which can be seen from the results. The mean absolute error rate (MAER) for equal weight model was 5.24 compared to 4.9 and 4.27 of GDM model and AHP model respectively. Hence, using equal weight method for determining weights will give less accurate estimates than gradient decent method (GDM) and analytical hierarchy process (AHP) method.

3.4.2.2. Gradient descent method (GDM)

It's a computational process in order to determine weights of the variables. Several random cases are selected from the case base as the target case, and the other cases in the case base that are most similar to these random cases are found based on a set of initial attribute weights. These weights are then increased or decreased according to how well the attribute values match. After examining several random cases, the resulting weight is normalized and added to the current weight vector. These processes are repeated until the user-defined stopping criterion is reached (Yau & Yang, 1998).

However, it is difficult to understand the procedure for determining the importance weights by a computational process (An et al., 2006). Also, the accuracy of the weights calculated for deconstruction by this process is questionable as it needs significant number of cases in order to normalize the weights. Deconstruction being relatively fresh concept, acquiring large number of cases is fairly difficult.

3.4.2.3. Analytic hierarchy process (AHP)

Analytic hierarchy process (AHP) was developed in the early 1970s to help individuals and groups deal with decision-making problems. AHP uses hierarchic structures to represent a decision-making problem and then develops priorities for the alternatives based on the decision maker's judgments throughout the system (Saaty, 2008).

AHP determines the relative importance of a variable through pairwise comparison of the all the variables. Furthermore, consistency of judgments can be assessed from the comparison matrix obtained from the survey for the evaluations within an acceptable level (Saaty, 2008).

In general, AHP modelling passes through three stages: (1) structuring a complex problem in the form of a simple hierarchy; (2) comparing the decision elements using the pairwise method; and (3) computing the relative weights of the decision elements (An et al., 2006). Hence, AHP is method is fairly easy to understand and implement along with attaining better results as seen from the work of An et al. (2006).

Based on this discussion, in the author's opinion AHP method will be the most appropriate method to determine weights of the variables for cost prediction model for deconstruction. The weights can be determined by the interviews conducted of deconstruction experts for comparing input variables using pairwise method.

3.5. Summary

This chapter reviewed different prediction models previously used for cost estimation of new buildings and structures. After comparing regression, neural network and case-based reasoning model, it was learned that case-based reasoning model is the most appropriate model for estimation of deconstruction costs. Further, based on the available literature on prediction model and deconstruction, ten input variables which have impact on the deconstruction costs were determined. It is established that AHP method will be most appropriate to determine weight of the variables. For that purpose interviews of limited number of deconstruction experts/ Estimator/ Project Manager were conducted which are described and analyzed in the next chapter. The input variables established in this chapter and their weights in the next chapter will help in developing deconstruction cost prediction model.

4. COST PREDICTION MODEL FOR DECONSTRUCTION

4.1. Overview

One of the objectives of this research study is to develop a cost prediction model for calculating deconstruction costs. Various academic papers, thesis reports, case studies, industry reports and manuals available in the field of deconstruction and prediction model were reviewed and discussed in the previous chapters.

Based on the information presented and analysis developed, it was established that Case Based Reasoning model is the most suitable model for estimating deconstruction costs of a project. Hence, for this model ten input variables that affect the deconstruction costs of a project were determined.

Additionally, in the previous chapter it was also recognized that analytical hierarchy process (AHP) method would be the most appropriate method to determine weight of the input variables. Therefore, in order to determine weight of the input variables using AHP method a limited number of interviews of deconstruction experts, i.e. Estimators and Project Managers were carried out.

Also, deconstruction contractors were contacted to collect data of deconstruction projects for the database. This database is required for extracting information to predict the cost of the new project. This chapter will explain the data collected through the interviews, analysis of this data and development of prediction model to calculate deconstruction costs based on the data collected and analyzed.

4.2. Data collection

With the intention of deducing the weight of the input variables for cost prediction model for deconstruction, interviews of deconstruction experts, i.e. Estimators and Project Managers were conducted. This section explains the scope and the structure of the interviews.

4.2.1. Scope of the interviews

Deconstruction is relatively new building removal method and hence there are not a lot of deconstruction contractors. Typically demolition contractors engage in deconstruction. Due to the composite interview structure, explained in the next section, it was recognized that in-person interviews were required to explain the interview structure more efficiently to the experts for obtaining better results. Therefore, locally recognized seven deconstruction Estimators/ Project Managers were contacted for the purpose of discussing deconstruction costs. Out of the seven recognized deconstruction experts in the Michigan area contacted, the author was able to successfully communicate with three experts. Two of the three experts were Project Managers of their own company which employ in demolition, deconstruction and salvage services. Combined together, both have worked over 800 partial deconstruction projects and 55 full deconstruction projects in past 10 years in Michigan. The other expert interviewed works for the government and has supervised and managed over 70 partial deconstruction, 10 full deconstruction and 450 demolition projects in past 7 years in Michigan and Ohio region. A graph reflecting the experience of these experts interviewed in the field of deconstruction can be seen in Figure 4.1.

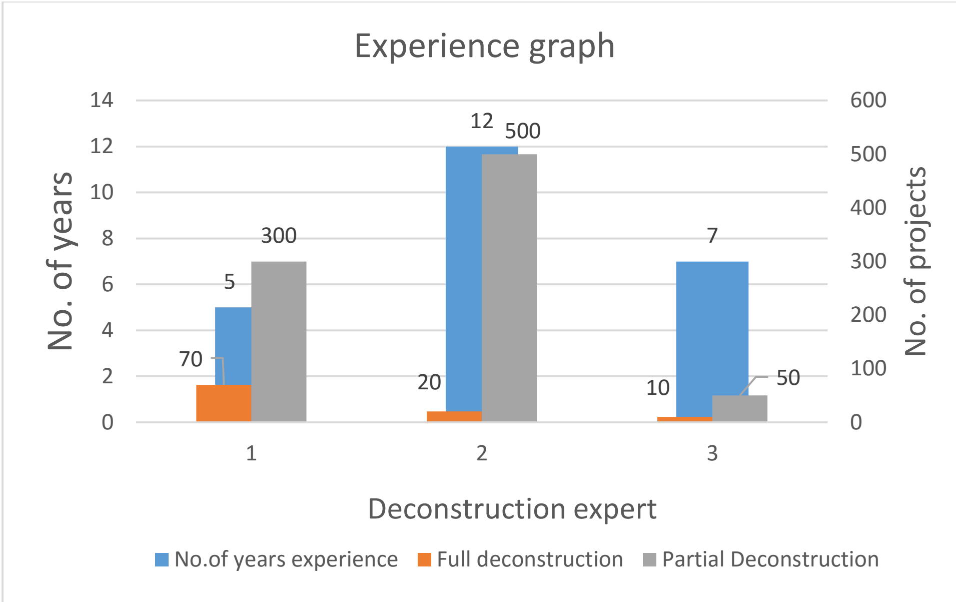


Figure 4.1. Experience of the deconstruction experts interviewed

The three experts were interviewed by the procedure explained in the following section. The data collected was analyzed to obtain weight of the input variables. All the experts were also asked to share details of deconstruction projects they recently executed for storing the cases in prediction model database. Details about the database is explained later in the chapter.

4.2.2. Interview structure

It was established in the previous chapter that analytical hierarchy process (AHP) method will be used to determine weight of the input variables. AHP determines the relative importance of a variable through pairwise comparison of the all the variables and then computing the relative weights of each variable. In order to compare the input variables a reference scale is needed. There are several reference scales used for comparison like percentage scale (0 to 100%), level scale (high, medium and low) and number scale (0 – 9). For this study, a number scale described in Table 4.1 that indicates how many times more important one variable is over another variable is used (Saaty, 2008).

Table 4.1. The fundamental scale of absolute numbers (Saaty, 2008)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	-
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	-
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	-
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	-
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

In order to understand the scale and its implication Saaty (2008) explained a simple example of relative consumption of drinks in the US. As shown in Figure 4.2, an interviewee compares a drink indicated on the left with another indicated at the top and answers the question: How many times more, or how strongly more is that drink consumed in the US than the one at the top? The interviewee then enters the number from the scale that is appropriate for the judgment. For example, number 9 in the (coffee, wine) position means that coffee consumption is 9 times wine consumption. Automatically, the interviewee uses 1/9 in the (wine, coffee) position. Note that water is consumed more than coffee, so one enters 2 in the (water, coffee) position, and ½ in the (coffee, water) position. The interviewee always enters its reciprocal in the transpose position.

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

Figure 4.2 Relative consumption of drinks (Saaty, 2008)

Similar to the coffee example, the relative importance of the deconstruction cost variables compared to the each other can be determined. Firstly, the deconstruction experts were provided with the information of the study followed by the list of all the input variables and their scope determined as in Table 3.2 in the previous chapter. With the help of the same coffee example, the process of pairwise comparison of input variables was explained to the deconstruction experts. Once they had the understanding of each input variables and scale of number for comparison, they were asked to fill the comparison matrix as shown in the Figure 4.3 based on their knowledge and experience in the field of deconstruction.

The completely filled comparison matrix from all the experts were then saved in the records with the purpose of analyzing the matrix to determine weight of each variable.

	Age of the building	Condition of the building	Design Complexity of the building	Hazardous Building Materials	Building Material Reuse and Recycling Markets	Location	Site/ Building Accessibility	Building area	Amount of recoverable building material	Number of floors
Age of the building	1									
Condition of the building		1								
Design Complexity of the building			1							
Hazardous Building Materials				1						
Building Material Reuse and Recycling Markets					1					
Location						1				
Site/ Building Accessibility							1			
Building area								1		
Amount of recoverable building material									1	
Number of floors										1

Figure 4.3 Relative importance of deconstruction cost variables

4.3. Analysis of the interviews

After the interviews of the deconstruction experts were conducted, the completed comparison matrix were analyzed to determine the weight of each variable of deconstruction cost prediction model. In order to determine weight of a variable, its entire row of the matrix is added and then divided by the total sum of all the rows (Saaty, 2008). Result of one of the interviews is shown in Figure 4.4 followed by the procedure to determine the weight of a variable. Results of all the interview can be found in Appendix B.

	Age of the building	Condition of the building	Complexity of the building	Hazardous Building Materials	Building Material Reuse and Recycling Markets	Location	Site/ Building Accessibility	Building area	Amount of recoverable building material	Number of floors
Age of the building	1	1/9	1/6	1/2	1/5	1/3	1/4	1/9	1/2	1/3
Condition of the building	9	1	2	6	3	7	4	1	1	4
Complexity of the building	6	1/2	1	5	1	1	1/2	1/5	1/3	2
Hazardous Building Materials	2	1/6	1/5	1	1/2	1	1	1/6	1/5	1/2
Building Material Reuse and Recycling Markets	5	1/3	1	2	1	1	3	1/5	1/3	1
Location	3	1/7	1	1	1	1	1	1/8	1/7	1/3
Site/ Building Accessibility	4	1/4	2	1	1/3	1	1	1/3	1/4	1
Building area	9	1	5	6	5	8	3	1	2	5
Amount of recoverable building material	2	1	3	5	3	7	4	1/2	1	4
Number of floors	3	1/4	1/2	2	1	3	1	1/5	1/4	1

Figure 4.4 Result of one of the interviews

4.3.1. Procedure of determining weight

From the comparison matrix in figure 4.4, in order to determine the weight of the variable 'Age of the building', firstly all the numbers in that row were added and it was called 'x'. Therefore,

$$x = \{1+ 1/9 + 1/6 + 1/2 + 1/5 +1/3 + 1/4 + 1/9 + 1/2 + 1/3\} = 3.51.$$

Similarly, all the numbers in their respective row were added as seen in Figure 4.5. The sum of all the numbers in all the rows were added and was called 'y'. Finally, the weight of each variable was calculated by dividing respective 'x' value with 'y' as seen in Figure 4.5.

	Age of the building	Condition of the building	Design Complexity of the building	Hazardous Building Materials	Building Material Reuse and Recycling Markets	Location	Site/ Building Accessibility	Building area	Amount of recoverable building material	Number of floors	Total of each row 'x'	Weight 'x/y'
Age of the building	1	1/9	1/6	1/2	1/5	1/3	1/4	1/9	1/2	1/3	3.51	**0.019**
Condition of the building	9	1	2	6	3	7	4	1	1	4	38.00	**0.202**
Design Complexity of the building	6	1/2	1	5	1	1	1/2	1/5	1/3	2	17.53	**0.093**
Hazardous Building Materials	2	1/6	1/5	1	1/2	1	1	1/6	1/5	1/2	6.73	**0.036**
Building Material Reuse and Recycling Markets	5	1/3	1	2	1	1	3	1/5	1/3	1	14.87	**0.079**
Location	3	1/7	1	1	1	1	1	1/8	1/7	1/3	8.74	**0.046**
Site/ Building Accessibility	4	1/4	2	1	1/3	1	1	1/3	1/4	1	11.17	**0.059**
Building area	9	1	5	6	5	8	3	1	2	5	45.00	**0.239**
Amount of recoverable building material	2	1	3	5	3	7	4	1/2	1	4	30.50	**0.162**
Number of floors	3	1/4	1/2	2	1	3	1	1/5	1/4	1	12.20	**0.065**
										Total 'y'	**188.25**	

Figure 4.5 Weight calculation of each variable

4.3.2. Final weight of each variable

Based on the procedure described above, every interview comparison matrix was analyzed to determine the weight of each input variable for deconstruction costs. The following table 4.2 show the weights of each variable determined from each interview. The final weight of each variable is calculated by taking the average of all values of that weight obtained from the analysis of each interview. The average is taken because it predicts the most probable outcome.

Table 4.2. Final weight calculation of the input variables

Interview	**1**	**2**	**3**	**Average**
Input variables				
Age of the building	0.019	0.026	0.0159	**0.020**
Condition of the building	0.202	0.180	0.1887	**0.190**
Complexity of the building	0.093	0.068	0.0361	**0.066**
Hazardous Building Materials	0.036	0.096	0.0617	**0.064**
Building Material Reuse and Recycling Markets	0.079	0.037	0.0757	**0.064**
Location	0.046	0.048	0.0266	**0.041**
Site/ Building Accessibility	0.059	0.080	0.0890	**0.076**
Building area	0.239	0.220	0.2291	**0.230**
Amount of recoverable building material	0.162	0.139	0.1797	**0.160**
Number of floors	0.065	0.106	0.0975	**0.089**

4.4. Deconstruction case bank

Case Based Reasoning prediction model requires primarily input variables, weight of the input variables and database of number of projects from which the model extracts the data to estimate cost of the new project. For this study input variables and their respective weight has been determined. With the purpose of having significant number of cases, the author contacted deconstruction contractors for acquiring details of residential projects they deconstructed in recent years. Also, the contractors were asked to scrutinize the project based on the input variables of this model. The details of one of the deconstruction cases collected for the model can be seen in the Table 4.3. The details of all the cases collected is available in Appendix C. According to statistics, the accuracy of the result keeps on increasing with the increase in the volume of observations (Celeste et al., 1963). Hence, the accuracy of the estimate will keep on increasing as the number of cases increase in the database.

4.5. Development of Cost Prediction Model For Deconstruction

In the previous sections ten input variables were determined and their weights were calculated based on the analysis of the interviews conducted of deconstruction Estimators and Project Managers. The weight of the input variables were calculated by using the method of analytical hierarchy process (AHP). Also, deconstruction case studies were collected in order to generate database required for cost prediction. Based on this information, a model was developed on Case Based Reasoning method, established to be most suitable method in the previous chapter, to estimate deconstruction costs of a project.

Table 4.3. List and detail information of deconstruction projects collected

Sr. No.	Input variables	Range	Case 1	Description
			Hamtramck, MI	
1	Age of the building	**Number**	85	The building was built in 1930 and was deconstructed in 2015
2	Condition of the building	**Percentage (0-100)**	80%	The building structure had very less physical damages
3	Complexity of the building	**High, medium & low**	Low	It was simple 2 story non-complex structure with gentle sloped roof and according to the contractor, easy to deconstruct
4	Hazardous Building Materials	**High, medium & low**	Low	The content of hazardous material was extremely low
5	Building Material Reuse and Recycling Markets	**High, medium & low**	Medium	The building being in Hamtramck, MI fairly close to Detroit; the market for reused and recycled material is considered to be moderate
6	Location	**High, medium & low**	High	For this deconstruction project, highly skilled labor were available with pretty reasonable rate
7	Site/ Building Accessibility	**High, medium & low**	High	The building was located in the corner lot giving easy access for deconstruction activities from 2 sides along with open space behind the building
8	Building area	**Area (0 - 6000 sq. ft.)**	1862	
9	Amount of recoverable building material	**Percentage (0-100)**	90%	Majority of the construction material was wood and due to highly good condition majority of the material was recovered
10	Number of floors	**Numeric (1 to 3)**	2	
		Deconstruction Cost	$ 22,000	
		Amount recovered from resale of materials	$15,000	
		Net deconstruction cost	$7,000	

4.6. Python

In order to develop a Case Based Reasoning (CBR) prediction model for estimating deconstruction costs 'Python' was used. Python is a programming language that helps in integrating systems more effectively. It is "an interpreted, object-oriented, high-level programming language with dynamic semantics" (python.org, 2016). The reason for choosing Python is its design philosophy. It emphasizes code readability, and its syntax allows programmers to express concepts in fewer lines of code (McConnell S., 2004). Its high-level built in data structures, combined with dynamic typing and dynamic binding, make it very attractive for Rapid Application Development (Kuhlman D., 2011). Also, it is easily accessible and freely distributed online on their website. A complete syntax of the model developed for cost estimation of a deconstruction project using Python is available in Appendix D.

4.7. Functioning of the model

The weight associated with each input variable drives the percentage of similarity between the project whose deconstruction cost is to be determined (test project) and all the stored deconstruction project in the database (stored projects). Higher the weight of an input variable, more the influence on the similarity of the project. For example, the square foot area and number of floors of a stored project is 1500 sq.ft. and 2 respectively. The square foot area of the first test project is 1500 sq.ft. with 1 floor and the square foot area of the second test project is 2500 sq.ft. with 2 floors. The percentage of similarity between the stored project and the first test project will be more than the stored project and the second test project because the weight of the input variable 'area' is more than the weight of the input variable 'number of floors' (Refer Table 4.2 for weights).

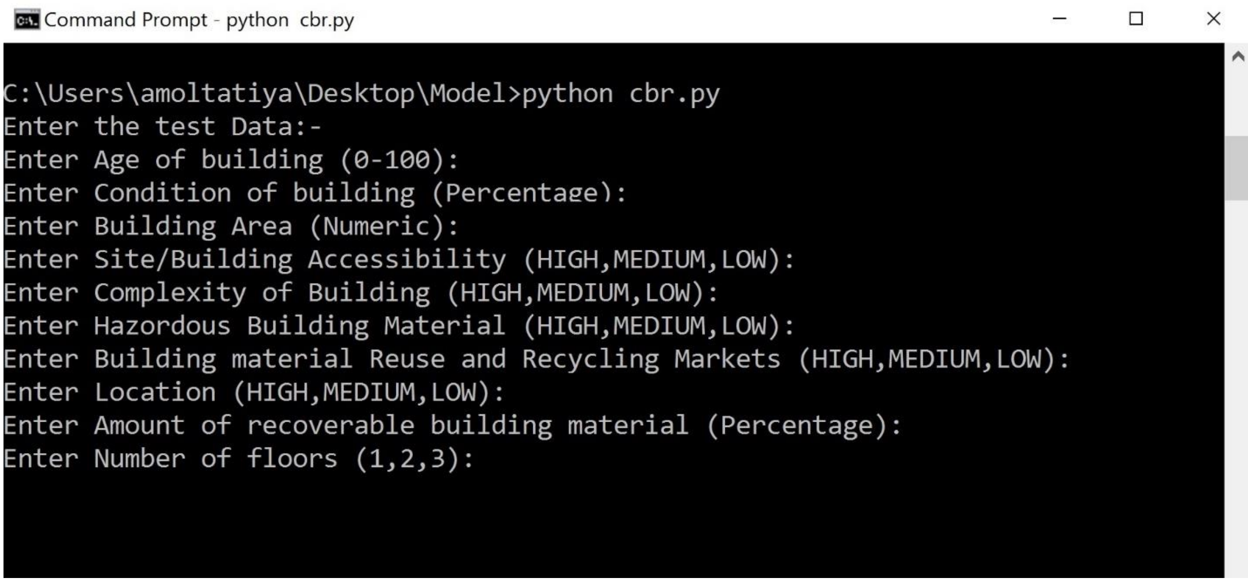


Figure. 4.6 Data Entry window

When the questions in the 'Data Entry' window as seen in the Figure 4.6 are answered and the model is run, the percentage similarity is calculated by using the following equation, which indicates the similarity between one or more of the stored projects and the test project.

$$\text{Percentage similarity}(N, S) = \frac{\sum_{i=1}^{n} f(N_i, S_i) \times w_i}{\sum_{i=1}^{n} w_i} \times 100(\%)$$

where N is the new project and S is the stored project in the case base. 'n' is the number of variables in each case. In this model 'n' is equal to 10. 'i' is an individual variable from 1 to 'n', 'f' is a similarity function for variable 'i' in projects N and S, and w_i is the weight of variable 'i' (Kim et al., 2004).

Similarity function can be defined as:

$$\left| \frac{N_i - S_i}{S_i} \times 100 \right| \leqslant 10(\%)$$

If the value of the new project's variable matched the above equation, the value of $f(N_i; S_i)$ is 1, otherwise it is 0. After the percentage similarity of all the projects are calculated, the cost data in the case base are ranked, i.e. the stored project with highest percentage of similarity with the test data is ranked at the top. The top ranked project's square foot cost is selected as the recommended square foot cost for the new deconstruction project.

4.8. Step-by-step working of the model

For understanding the model, its working is explained in this section with an example. Consider a 2 story residential building of 3800 sq.ft. of which deconstruction cost is to be estimated. All the characteristics required to estimate deconstruction costs of this building are in the Table 4.4 below.

Table 4.4. Input values of test project

Input Variable	Input value
Age of the building	75
Condition of the building	75%
Design complexity of the building	Low
Hazardous Building Materials	Medium
Building Material Reuse and Recycling Markets	High
Location	High
Site/ Building Accessibility	High
Building area	3800
Amount of recoverable building material	42%
Number of floors	2

STEP 1: Open python's command prompt window. The window will appear as in Figure 4.7.

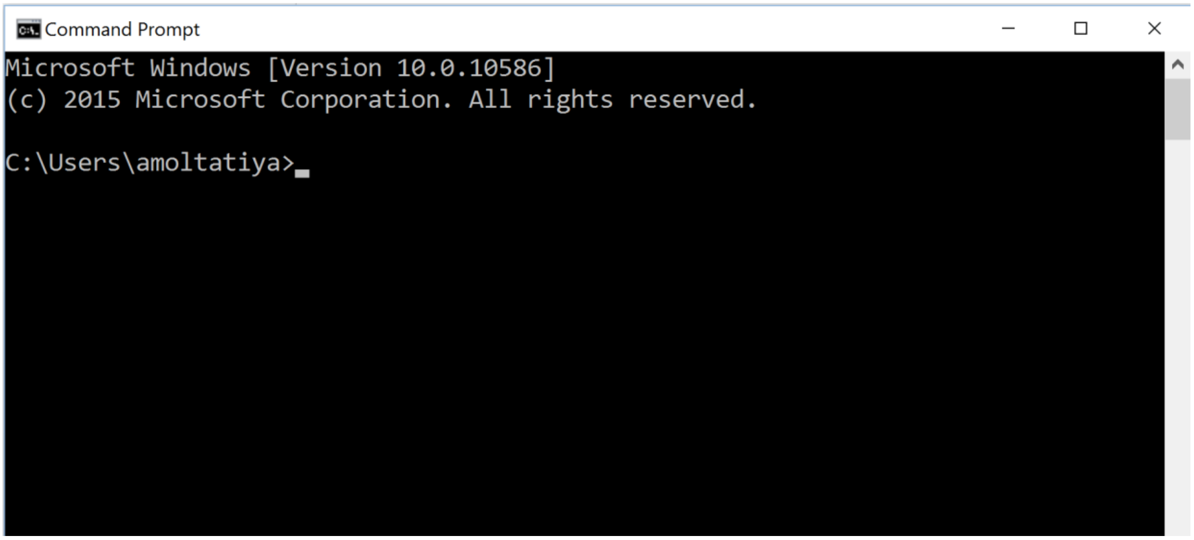


Figure. 4.7 Python's command prompt window

STEP 2: Change the path of the python program to location of the model's python file as in Figure 4.8. In this case the location of the model's python file is, 'C:\Users\amoltatiya\Desktop\Model'. Also, the name of the model's python file is 'cbr.py' and that of the database is 'observation'.

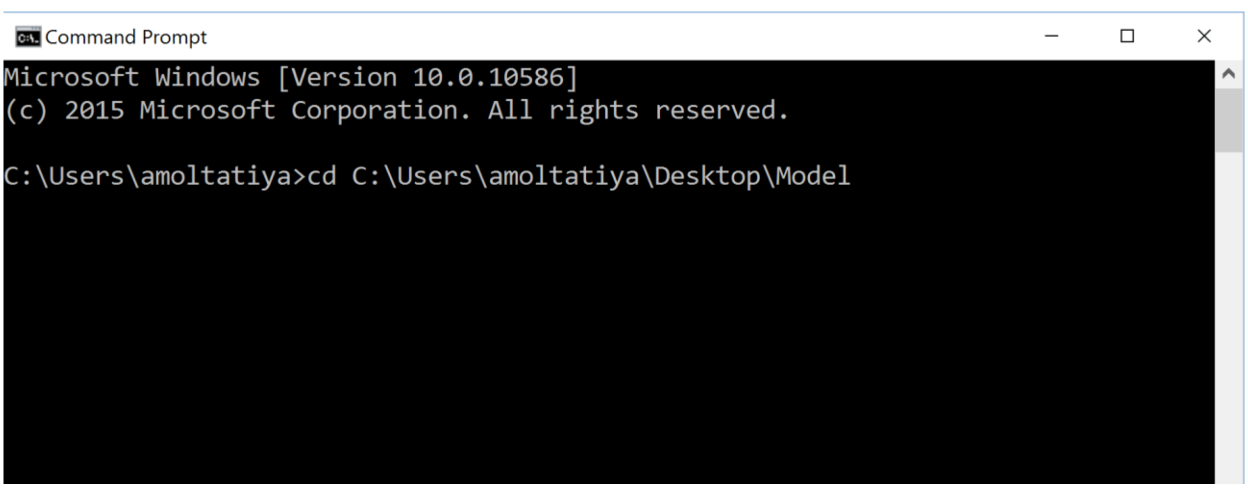


Figure. 4.8 Changing the path of the program

STEP 3: To start the model, type ‘python cbr.py’.

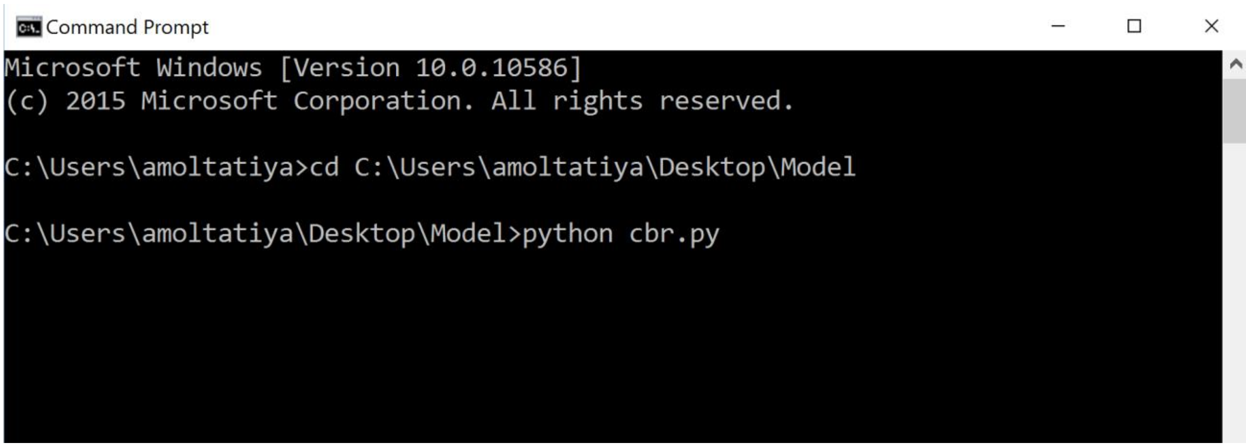


Figure. 4.9 Initializing the model

STEP 4: Enter all the input values of Table 4.4 with respect to question asked in command prompt. Once all the values are entered the window will look like Figure 4.10.

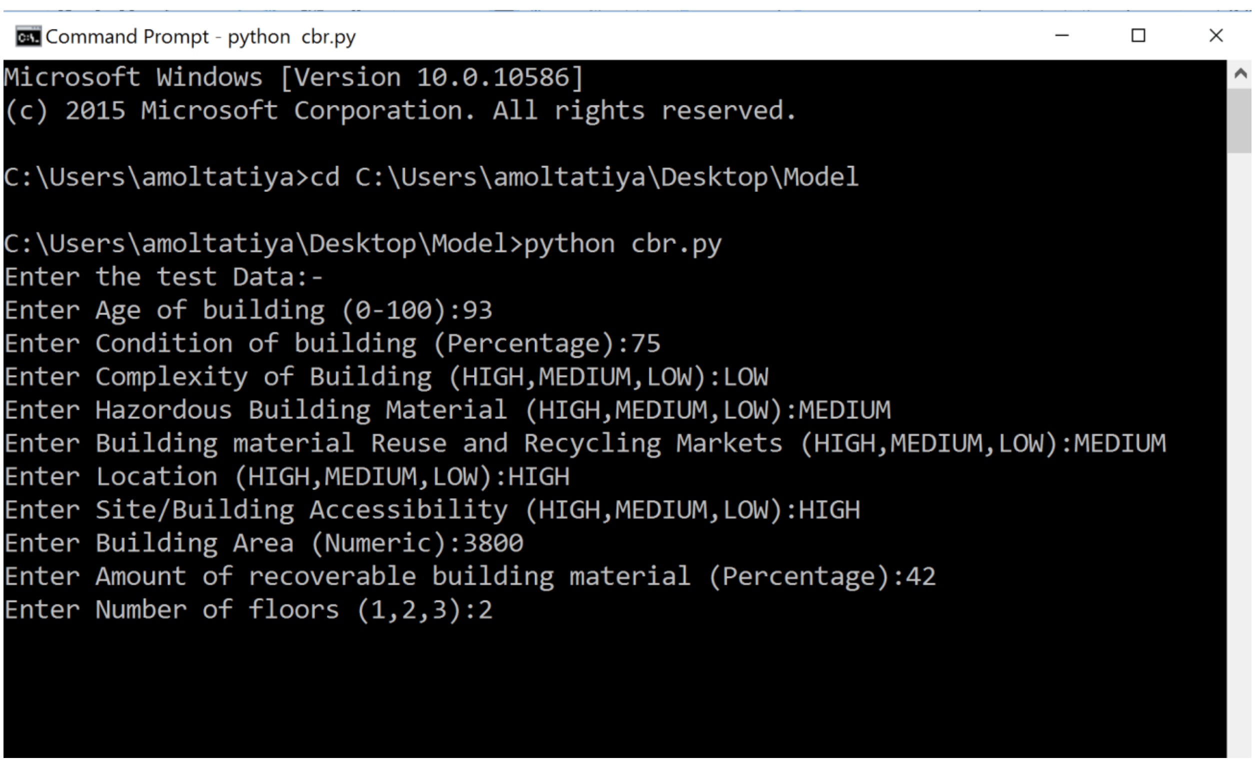
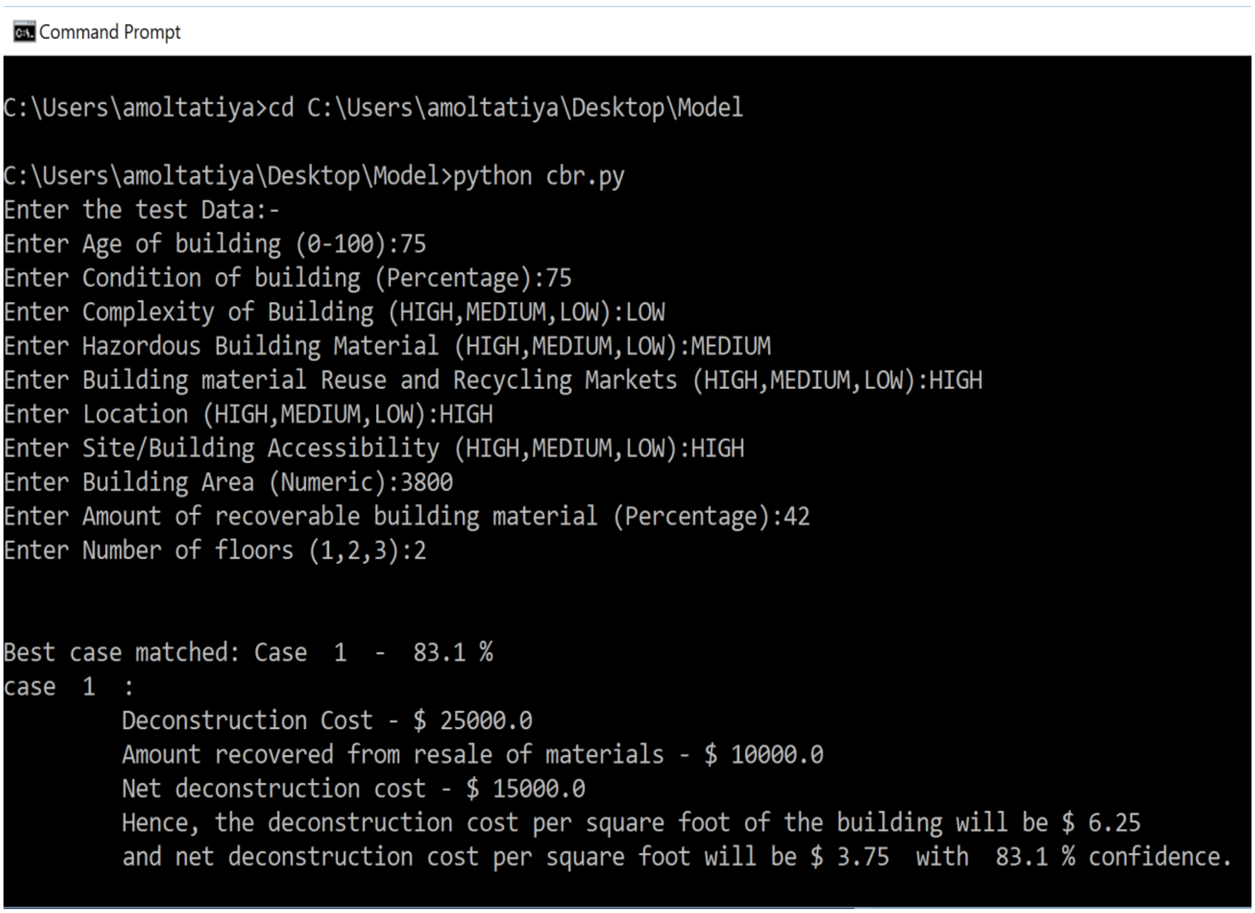


Figure. 4.10 Data Entry window

STEP 5: Run the model by clicking 'Enter'. As seen in the Figure 4.11, the model gives an output which shows the top ranked similar project in the database along with its percentage of similarity, deconstruction cost of that project, amount recovered from resale of materials and net deconstruction cost.

Hence, as the test project and the top ranked case are 83.1% similar, the model gives the deconstruction cost of the test project as \$6.25/sq. ft. and net deconstruction cost as \$3.75/sq. ft. with 83.1% confidence on the result.



```
Command Prompt

C:\Users\amoltatiya>cd C:\Users\amoltatiya\Desktop\Model

C:\Users\amoltatiya\Desktop\Model>python cbr.py
Enter the test Data:-
Enter Age of building (0-100):75
Enter Condition of building (Percentage):75
Enter Complexity of Building (HIGH,MEDIUM,LOW):LOW
Enter Hazordous Building Material (HIGH,MEDIUM,LOW):MEDIUM
Enter Building material Reuse and Recycling Markets (HIGH,MEDIUM,LOW):HIGH
Enter Location (HIGH,MEDIUM,LOW):HIGH
Enter Site/Building Accessibility (HIGH,MEDIUM,LOW):HIGH
Enter Building Area (Numeric):3800
Enter Amount of recoverable building material (Percentage):42
Enter Number of floors (1,2,3):2


Best case matched: Case  1  -  83.1 %
case  1  :
        Deconstruction Cost - $ 25000.0
        Amount recovered from resale of materials - $ 10000.0
        Net deconstruction cost - $ 15000.0
        Hence, the deconstruction cost per square foot of the building will be $ 6.25
        and net deconstruction cost per square foot will be $ 3.75  with  83.1 % confidence.
```

Figure. 4.11 Output window

4.9. Performance and future of the model

Currently the model's database of the deconstruction projects is limited. There are ten cases available with their characteristics according to the input variables and the deconstruction costs. As the database is limited the accuracy of the model is limited. But, according to statistics, the accuracy of the model will keep on increasing with the increase in the volume of database (Celeste et al., 1963). The larger the database, the more accurate will be the results of the model. This can be explained by testing the model with varying cases in the database.

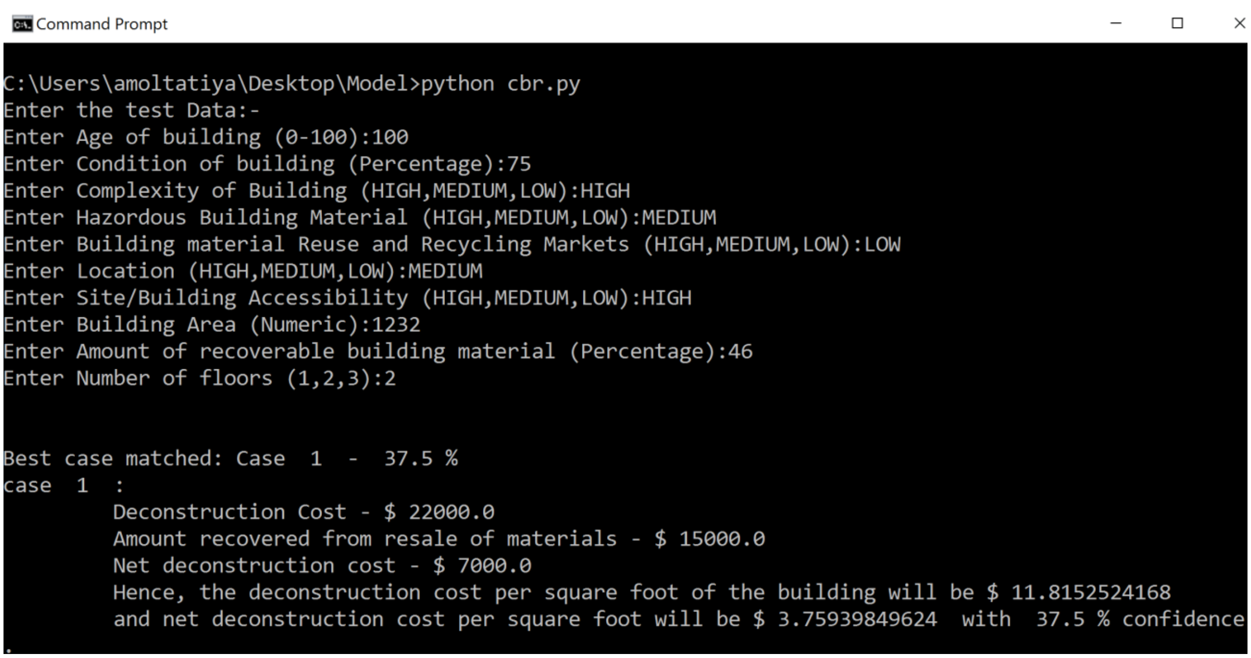
Out of the ten cases available, one case is considered as test case. Its deconstruction cost will be estimated thrice; once with three cases in the database, then with six cases in the database and finally with nine cases in the database. Every time the estimated cost will be compared with the actual deconstruction cost to check the accuracy of the model.

Considering a case of 2 story residential building of area 1232 sq. ft. in Lansing, MI as the test case. The building was built in 1914 and was deconstructed in 2014. The condition of the building adjudged by the contractor was 75% as the overall condition was pretty good. The building contained lead paint and asbestos materials. Due to steep slope and multiple fixed partition walls, it had high design complexity. The contractor confirmed that about 46% of the building material were recovered. The material recovered were mainly wood, sinks, windows and concrete. According to the contractor, it cost them $24,600 to deconstruct the building and they were only able to make $4,771 from the recovered material. Hence, deconstruction cost of the building was $19.97/sq.ft. and net cost was $16.09/sq.ft. The input value obtained from the contractor are represented in the Table 4.5.

Table 4.5. Input values of the project

Input Variable	Input value
Age of the building	100
Condition of the building	75%
Design complexity of the building	High
Hazardous Building Materials	Medium
Building Material Reuse and Recycling Markets	Low
Location	Medium
Site/ Building Accessibility	High
Building area	1232
Amount of recoverable building material	46%
Number of floors	2

As explained earlier, the deconstruction cost for this building was determined by having three, six and nine cases in the database and Figures 4.12, 4.13 and 4.14 show their results respectively.



```
Command Prompt

C:\Users\amoltatiya\Desktop\Model>python cbr.py
Enter the test Data:-
Enter Age of building (0-100):100
Enter Condition of building (Percentage):75
Enter Complexity of Building (HIGH,MEDIUM,LOW):HIGH
Enter Hazordous Building Material (HIGH,MEDIUM,LOW):MEDIUM
Enter Building material Reuse and Recycling Markets (HIGH,MEDIUM,LOW):LOW
Enter Location (HIGH,MEDIUM,LOW):MEDIUM
Enter Site/Building Accessibility (HIGH,MEDIUM,LOW):HIGH
Enter Building Area (Numeric):1232
Enter Amount of recoverable building material (Percentage):46
Enter Number of floors (1,2,3):2


Best case matched: Case  1  -  37.5 %
case  1  :
        Deconstruction Cost - $ 22000.0
        Amount recovered from resale of materials - $ 15000.0
        Net deconstruction cost - $ 7000.0
        Hence, the deconstruction cost per square foot of the building will be $ 11.8152524168
        and net deconstruction cost per square foot will be $ 3.75939849624  with  37.5 % confidence
.
```

Figure. 4.12 Results with three cases in the database

Command Prompt

```
C:\Users\amoltatiya\Desktop\Model>python cbr.py
Enter the test Data:-
Enter Age of building (0-100):100
Enter Condition of building (Percentage):75
Enter Complexity of Building (HIGH,MEDIUM,LOW):HIGH
Enter Hazordous Building Material (HIGH,MEDIUM,LOW):MEDIUM
Enter Building material Reuse and Recycling Markets (HIGH,MEDIUM,LOW):LOW
Enter Location (HIGH,MEDIUM,LOW):MEDIUM
Enter Site/Building Accessibility (HIGH,MEDIUM,LOW):HIGH
Enter Building Area (Numeric):1232
Enter Amount of recoverable building material (Percentage):46
Enter Number of floors (1,2,3):2


Best case matched: Case  4  -  46.8 %
case  4  :
         Deconstruction Cost - $ 11742.0
         Amount recovered from resale of materials - $ 1000.0
         Net deconstruction cost - $ 10742.0
         Hence, the deconstruction cost per square foot of the building will be $ 6.49087893864
         and net deconstruction cost per square foot will be $ 5.93808734107  with  46.8 % confidence
.
```

Figure. 4.13 Results with six cases in the database

Command Prompt

```
C:\Users\amoltatiya>cd C:\Users\amoltatiya\Desktop\Model

C:\Users\amoltatiya\Desktop\Model>python cbr.py
Enter the test Data:-
Enter Age of building (0-100):100
Enter Condition of building (Percentage):75
Enter Complexity of Building (HIGH,MEDIUM,LOW):HIGH
Enter Hazordous Building Material (HIGH,MEDIUM,LOW):MEDIUM
Enter Building material Reuse and Recycling Markets (HIGH,MEDIUM,LOW):LOW
Enter Location (HIGH,MEDIUM,LOW):MEDIUM
Enter Site/Building Accessibility (HIGH,MEDIUM,LOW):HIGH
Enter Building Area (Numeric):1232
Enter Amount of recoverable building material (Percentage):46
Enter Number of floors (1,2,3):2


Best case matched: Case  9  -  69.4 %
case  9  :
         Deconstruction Cost - $ 27240.0
         Amount recovered from resale of materials - $ 3406.0
         Net deconstruction cost - $ 23834.0
         Hence, the deconstruction cost per square foot of the building will be $ 15.4421768707
         and net deconstruction cost per square foot will be $ 13.5113378685  with  69.4 % confidence.
```

Figure. 4.14 Results with nine cases in the database

Comparison of the actual and the estimated deconstruction costs of the project as in Table 4.6 reflects that as the percentage similarity of the stored case and the test case increases, the accuracy of the estimated deconstruction cost increases. Also, increase in the number of cases in the database increases the chances of achieving maximum similarity between the cases.

Table 4.6. Comparison of results with varying cases in database

Results	**Actual cost**	**Estimated cost with 3 cases in the database**	**Estimated cost with 6 cases in the database**	**Estimated cost with 9 cases in the database**
Percentage similarity		37.50%	46.80%	69.40%
Deconstruction cost per sq. ft.	$19.97	$11.82	$6.49	$15.44
Net deconstruction cost per sq. ft.	$16.06	$3.76	$5.94	$13.51
Variance in deconstruction cost		$8.15	$13.48	**$4.53**
Variance in net deconstruction cost		$12.30	$10.12	**$2.55**

4.10. Limitations of the model

The model has some limitations:

1. The model is perfect for conceptual estimate. With the help of the model one can estimate an approximate cost of deconstruction of a project. But, as it does not scrutinizes a project in detail, this model will not give accurate estimate of the deconstruction costs.

2. As the number of the cases at the moment in the database are low, the model lacks precision. Nevertheless, as the cases in the database increases the model will give much better outputs. Kim et.al (2004) used 530 cases in the database for the CBR model developed for construction costs estimation of residential buildings. The Mean Absolute Error Rate (MAER) for the model was 4.81%. Hence, the author believes that with at least 350 cases in the database, the model will attain 90% accuracy.
3. Currently, the range of most of the input variables are categorized in three categories; i.e. high, medium and low. This wide scale was selected to obtain better output from the model. But, the accuracy of the result with this scale will not be significant. Once the size of the database is expressively increased, the range of the input variables should be switched to number Likert scale for exactness.
4. At present, all the cases in the database are from Michigan and were recently deconstructed. Hence, the model might give incorrect estimates for different location and year of deconstruction. In order to address this glitch, location and year factors similar to RS Means should be incorporated.

4.11. Summary

In this chapter, weight of the input variables for the model for estimating deconstruction costs were determined using analytical hierarchy process (AHP) method. Limited number of interviews were conducted and analyzed to establish weight of the variables. In this chapter the goal of the research study of developing the model was achieved with the help of python programming language. Also, by testing the model with varying cases in the database it was justified that the accuracy of the model will increase with increase in the database.

5. IMPACT OF “DESIGN FOR DECONSTRUCTION” ON DECONSTRUCTION COSTS AND TIME

5.1. Introduction

As discussed earlier, one of the most important issue the building industry is facing today is related to the increase in its environmental efficiency. This efficiency can be achieved by creating the potentials for closed loop material cycling of building products as shown in Figure 2.7 (EPA, 2008). One of the critical problems of today’s building construction is that buildings are made in such a way that when they are required to be removed, low quantity of the material is recovered. The main reason for this low recovery is the fact that different functions and materials comprising a building system are integrated in one closed and dependent structure which does not allow alterations. The design of sustainable building deals with optimization of appropriate materials and energy use and optimization of appropriate construction methods and connections between building components (Durmisevic & Brouwer, 2015). Unfortunately, the construction industry is mainly focused on the improvement of the assembly techniques but very little to ease the disassembly process. Therefore, most of transformations within the building end up with demolition and waste disposal. Even when these structures are deconstructed in order to recover materials instead of dumping them in landfills, highly skilled labors are required to remove them carefully which consumes significant amount of time and cost. In this chapter, a cost comparison study of a typically designed building and a similar building designed for deconstruction will be conducted with the help of a small example house.

5.2. Standard features of building designed for deconstruction

For the purpose of conducting the cost comparison study, five standard features of design for deconstruction were considered for incorporation in an example house.

5.2.1. Windows

Two alternate window details were developed to address the issues of providing the ability to remove the windows without touching the cladding and components around the window frame (EPA, 2006). As shown in Figure 5.1, an unequal leg aluminum window is installed from the outside against flashing that is lapped under the exterior finish. This flashing ensures a water-tight connection between the window and cladding, but allows the window to be removed without touching the cladding. This makes the window removing process easy which can be performed quickly saving labor cost while removing or installing. Also, when window is recovered during deconstruction, it is expected to be less damaged compared to the traditional one. Thus, higher salvage cost can be recovered for the window. Hence, adopting window design for deconstruction can save cost on labor and gain better salvage value.

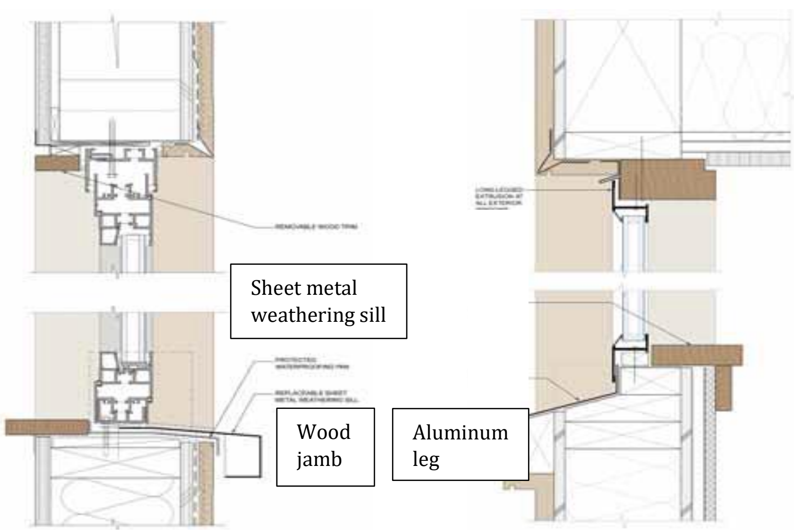


Figure 5.1 Removable window details. Source: (EPA, 2006)

5.2.2. Exterior siding

Normally the siding is nailed to the frame, but that creates holes in the wood and makes it difficult to remove the wood without damaging it. Also, several labor hours are invested in the de-nailing activity. Many alternate details are provided which included: use of tongue and groove method with the used of metal clips to hold the panels, use of channels for sliding the panels into the frame, use of very strong double stick tape (EPA, 2006). Some of these detailing are shown in figures 5.2 through 5.5. Use of tongue and groove, metal clips or channels for siding helps to salvage the wood at the end of lifecycle of this building and reuse it. It also makes its installing and removing easier. This shows adopting these design can save cost on labor while deconstruction and gain better salvage value.

Figure. 5.2 Siding attached with double stick tape.

Source: (EPA, 2006)

Figure. 5.3 Siding attached with C-channels.

Source: (EPA, 2006)

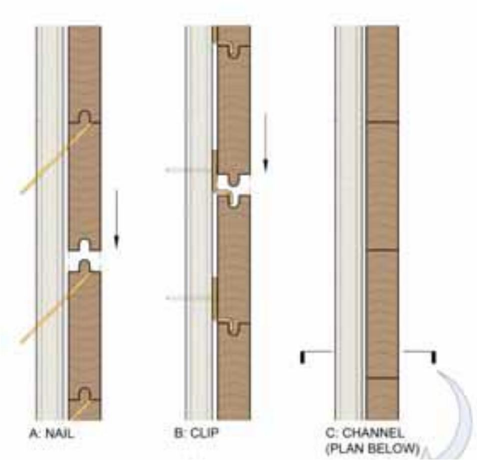


Figure. 5.4 Siding construction detail.

Source: (EPA, 2006)

Figure 5.5 Siding done with Tongue and Groove method with clips.

Source: (EPA, 2006)

5.2.3. Modular framing

One of the way to make structural framing system facilitate deconstruction is by using fewer but larger components to minimize the amount of labor; design in a repetitive modular fashion, simplify connections, use fewer high capacity fasteners with easy access for removal; and keep it simple and visible so it's readily understood how things come apart. This allows for ease in disassembly and remodeling, and it incorporates fewer high capacity fasteners for the structure which can be removed easily in the future.

Figure 5.6 Conventional 16" o-c framing
Source: (EPA, 2006)

Figure 5.7. 24" o-c framing.
Source: (EPA, 2006)

One approach is that the structure to be based on 24" on-center module instead of a 16" on-center wood frame. This approach saves up to 30 percent in lumber needs which also decreases the labor requirement for construction as well as deconstruction (EPA, 2006). Figures 5.6 and 5.7 show the conventional framing method and the modular framing method.

5.2.4. Repositioning Interior walls

Long spans and beam construction reduce interior structural elements and allow for structural stability when removing partitions and envelope elements. The interior walls can be moved and relocated as shown in Figures 5.8 and 5.9 without creating any waste or compromising structural integrity of the structure (EPA, 2008). The utilities are disentangled from the interior walls so they are not a problem when moving the walls.

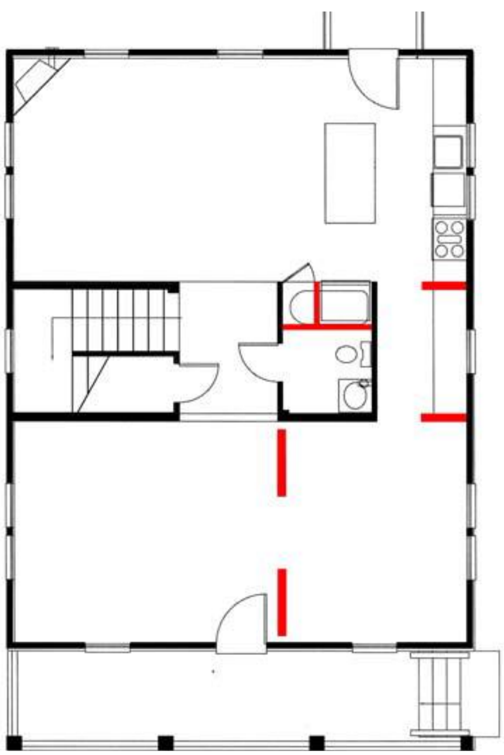


Figure 5.8 Current plan

Source: (Korber, et. all, 2006)

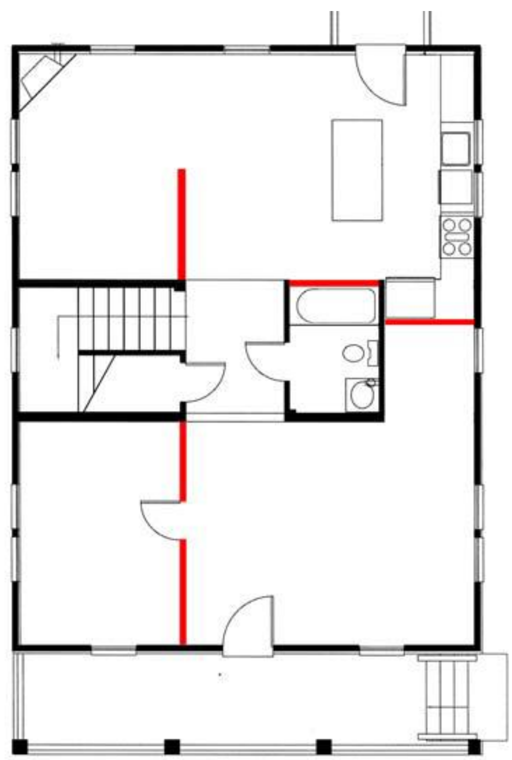


Figure 5.9 Potential future plan

Source: (Korber, et. all, 2006)

Repositionable walls are significantly different from the traditional stick framing home design, in which interior walls are necessary to hold up the roof. Any changes to wall arrangements in this traditional design not only destroy the wall materials, but create structural problems that often result in the generation of substantial waste materials through extensive re-framing or, in some cases, demolition because the home requires too much remodeling to meet new space needs (EPA, 2008). The wall sections can then be reused as is, or combined to create new configurations to meet the homeowner's needs. Figure 5.10 shows details of movable interior wall that are without glue or nails required to attach the parts.

Figure 5.10 Photos showing Construction details of the movable walls. (Korber, et. all, 2006).

5.2.5. Relocating plumbing and electrical system

The electrical and plumbing systems are bundled in a central location to avoid running them through all the interior walls. These duct works are placed in the attic and crawl spaces to keep them untangled from the interior walls to be able to disassemble the interior walls without having to deal with the utilities (EPA, 2008). As a result, the maintenance and removal of the utilities when required is made easier. The wooden frame of the structure does not accommodate the utilities, which results in fewer holes in the wood framing which increases its value to be salvaged in the end of the lifecycle of the building.

5.3. Example House

In order to understand the effect of the above noted five designs on deconstruction costs, deconstruction estimates of typically designed house and a similar house designed with these designs are compared along with the specifications of the house.

A typical one floor residential house with one bedroom, kitchen, living and bath as in Figure 5.11 is considered. The house has standard specifications and are broadly represented in Table 5.1.

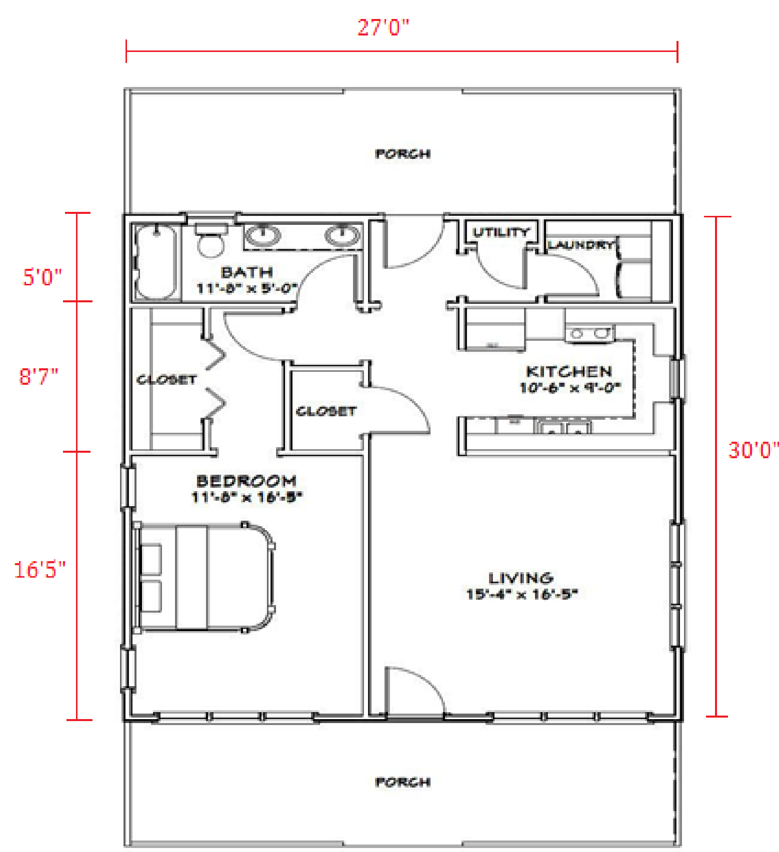


Figure 5.11 Plan of the example house (Source: https://www.pinterest.com/explore/shed-floor-plans/)

Table 5.1. Standard specifications of the example house

Item	Description
Area	900 Sq.ft.
No. of Floors	1
Height of the floor	10 feet
Foundation	Spread footings with 4" slab on grade (SOG) for foundation
Framing	Exterior framing is 2" X 6" studding @ 16"oc with 1/2" OSB wall sheathing panels and 1" rigid insulation and interior framing is 2" X 4" studding @ 16"oc
Siding	Wood vinyl sidings (Lead and asbestos free)
Roof and ceiling	Gable roof with trusses stick built @ 16" oc. The ceiling is typically built
Flooring	Wooden flooring
Electrical work	Typical electrical work and house assumed to have 8 fluorescent lamp
Doors and Windows	Typical double solid core doors and windows
Plumbing	Typical plumbing work
Appliances	Typical kitchen and bath appliances and finishes

5.4. Demolition and Deconstruction costs

For comparing the effect of the above mentioned design for deconstruction (DfD) features, deconstruction costs comparison was performed between traditionally designed example house and the similar house designed with the above mentioned design features.

5.4.1. Quantities

The quantity take-off for deconstruction projects is different than typical construction take-off. For example, framing is calculated in linear foot in which total length of lumber is calculated whereas in typical construction take-off framing is calculated in board foot. Table 5.2 shows quantities of each building component.

Table 5.2. Quantities of building components

Sr. No.	Description	Unit	Quantity
1	Counter top lavatory	Each	1
2	Kitchen Sink	Each	1
3	Water closet	Each	1
4	Bathtub	Each	1
5	Shower	Each	1
6	Fluorescent , (2 lamps)	Each	4
7	Cooking Stove	Each	1
8	Countertops	LF	20
9	Cabinets (wood)	LF	15
10	Typical doors	Each	6
11	Typical Window	Each	9
12	Drywall, Exterior Wall	SF	1,250
13	Drywall, Interior Wall	SF	1,750
14	Roof Framing (30 X 27) (16oc)	LF	750
15	Wood sidings	SF	1,200
16	Wall Framing, Interior	LF	800
17	Wall Framing, Exterior	LF	900
18	Flooring	SF	810
19	SOG, 4"	SF	900

5.4.2. Demolition cost for the example house

Demolition cost was calculated using RS Means (2014). The demolition cost of the structure without foundation for single story family house is approximately $3.60/sq.ft. (RS Means – 02 41 16.13 1000) and demolition of 4" SOG is $5.10/sq.ft. (RS Means – 02 41 16.17 0240). The building considered for this study was 900 sq.ft. Hence, the demolition cost based on the square foot cost of demolition from RS Means comes up to $7,830.00.

5.4.3. Deconstruction costs for typically designed example house

Deconstruction costs of the typically designed example house, for the quantities calculated above, were estimated using RS Means (2014). Table 5.3 shows the estimated deconstruction cost for each component

Table 5.3. Deconstruction costs of the example house when typically designed

Sr. No.	Description	Unit	Quantity	Deconstruction cost per unit	Total Deconstruction cost	Reference (RS Means-02 42 10.20)
Plumbing and Electrical fixtures						
1	Counter top lavatory	Each	1	$56.50	$56.50	0100
2	Kitchen Sink	Each	1	$64.50	$64.50	0110
3	Water closet	Each	1	$56.50	$56.50	0140
4	Bathtub	Each	1	$90.50	$90.50	0180
5	Shower	Each	1	$151.00	$151.00	0200
6	Fluorescent, (2 lamps)	Each	4	$28.50	$114.00	0320
Appliances and Millwork						
7	Cooking Stove	Each	1	$35.00	$35.00	0510
8	Countertops	LF	20	$11.30	$226.00	0620
9	Cabinets (wood)	LF	15	$28.50	$427.50	0610
Doors and Windows						
10	Typical doors	Each	6	$118.00	$708.00	0730
11	Typical Window	Each	9	$67.50	$607.50	0820
Interior structure						
12	Drywall, Interior Wall	SF	1,750	$0.51	$892.50	0910
13	Wall Framing, Interior	LF	800	$0.74	$592.00	2150
Roof						
14	Roof Framing (30 X 27) (16oc)	LF	750	$1.19	$892.50	2020
Exterior structure						
15	Wood sidings	SF	1,200	$0.70	$840.00	2200
16	Drywall, Exterior Wall	SF	1,250	$0.51	$637.50	0910
17	Wall Framing, Exterior	LF	900	$0.57	$513.00	2300
Flooring and Foundation						
18	Flooring	SF	810	$0.45	$364.50	2160
19	SOG, 4"	SF	900	$5.10	$4,590.00	4010
					$11,859.00	

5.4.4. Deconstruction costs for the example house with DfD features

When the five features explained above are incorporated in this house, the deconstruction cost decreases. Due to modular framing, i.e. 24'"oc, the exterior framing decreases from 900 LF to 600LF. Further, cost code 02 42 10.20 0812 in RS Means gives value for deconstructing windows without casement and cladding. This value can be used to calculate deconstruction cost for new window design.

Additionally, incorporating moveable interior walls and repositioning plumbing and electrical work, significantly reduces cost of removing interior framing. As it is obvious that removing electrical work, drywall and then deconstructing each stud of the frame takes lot more time than un-screwing the entire wall, only 50% reduction of deconstruction cost for interior wall frame is considered. Also, it should be noted that if there are no interior walls, RS Means suggests to deduct the entire deconstruction cost of the building by 50% (RS Means- 02 41 16.13 5000). Thus, it is reasonable to assume 50% reduction in deconstruction costs of just interior framing when repositionable interior walls are used. Similarly, de-nailing each siding takes more time than sliding each siding out of a channel/frame, only 30% reduction in deconstruction cost for siding is considered. Table 5.4 shows the estimated deconstruction cost for each component with the mentioned five design features.

5.4.5. Deconstruction costs comparison

The deconstruction cost from Tables 5.3 and 5.4 are $11,859 and $10,622 respectively or $13.17/sq.ft and $11.8/sq.ft respectively. This clearly indicates incorporating these design features decreases deconstruction cost of a building. It should be noted that the size of the building is relatively small and hence the difference between the costs is relatively less.

Table 5.4. Deconstruction costs of the house when designed with DfD design features

Sr. No.	Description	Unit	Quantity	Deconstruction cost per unit	Total Deconstruction cost	Reference (RS Means-02 42 10.20)
Plumbing and Electrical fixtures						
1	Counter top lavatory	Each	1	$56.50	$56.50	0100
2	Kitchen Sink	Each	1	$64.50	$64.50	0110
3	Water closet	Each	1	$56.50	$56.50	0140
4	Bathtub	Each	1	$90.50	$90.50	0180
5	Shower	Each	1	$151.00	$151.00	0200
6	Fluorescent, (2 lamps)	Each	4	$28.50	$114.00	0320
Appliances and Millwork						
7	Cooking Stove	Each	1	$35.00	$35.00	0510
8	Countertops	LF	20	$11.30	$226.00	0620
9	Cabinets (wood)	LF	15	$28.50	$427.50	0610
Doors and Windows						
10	Typical doors	Each	6	$118.00	$708.00	0730
11	**Typical Window**	**Each**	**9**	**$58.50**	**$526.50**	**0812**
Interior structure						
12	**Drywall, Interior Wall**	**SF**	**1,750**	**$0.26**	**$455.00**	**-**
13	**Wall Framing, Interior**	**LF**	**800**	**$0.37**	**$296.00**	**-**
Roof						
14	Roof Framing (30 X 27) (16oc)	LF	750	$1.19	$892.50	2020
Exterior structure						
15	**Wood sidings**	**SF**	**1,200**	**$0.49**	**$588.00**	**-**
16	Drywall, Exterior Wall	SF	1,250	$0.51	$637.50	0910
17	**Wall Framing, Exterior**	**LF**	**600**	**$0.57**	**$342.00**	**2300**
Flooring and Foundation						
18	Flooring	SF	810	$0.45	$364.50	2160
19	SOG, 4"	SF	900	$5.10	$4,590.00	4010
					$10,621.50	

As the size of the building increases the difference between the costs will also increase. Also, only five design features were incorporated. Increasing the number of design features for deconstruction will increase this difference in costs.

Further, the quality of the material recovered from the building designed for deconstruction will be considerably better than the quality of the material recovered from the typically designed building. Hence, the salvage value will be much better, making net deconstruction cost for building designed for deconstruction fairly less than typically designed building. RS Mean provides an estimated salvage value of the materials recovered from the buildings that were typically designed in division 02 42 10.10. While, salvage value of the materials recovered from the buildings that are DfD are required to be determined.

5.5. Effect of design for deconstruction on deconstruction time

One of the reasons, demolition is still preferred over deconstruction, is time. Compared to deconstruction, demolition is fairly quick. In order to promote deconstruction, its duration needs to be shortened and this can be achieved by incorporating design for deconstruction. Design for deconstruction helps to reduce the labor hours which affects both cost and time. A comparison of the deconstruction time for the earlier defined example house, when typically designed and when designed for deconstruction, is presented in this section.

5.5.1. Deconstruction time for typically designed example house

Deconstruction time of the typically designed example house, for the quantities in Table 5.1, was estimated in labor hours using RS Means (2014). Table 5.5 shows the estimated deconstruction time for each component.

Table 5.5. Deconstruction time of the example house when typically designed

Sr. No.	Description	Unit	Quantity	Labor hours per unit	Total Deconstruction hours	Reference (RS Means-02 42 10.20)
Plumbing and Electrical fixtures						
1	Counter top lavatory	Each	1	1.000	1.00	0100
2	Kitchen Sink	Each	1	1.143	1.14	0110
3	Water closet	Each	1	1.000	1.00	0140
4	Bathtub	Each	1	1.600	1.60	0180
5	Shower	Each	1	2.667	2.67	0200
6	Fluorescent, (2 lamps)	Each	4	0.500	2.00	0320
Appliances and Millwork						
7	Cooking Stove	Each	1	0.615	0.62	0510
8	Countertops	LF	20	0.032	0.64	0620
9	Cabinets (wood)	LF	15	0.160	2.40	0610
Doors and Windows						
10	Typical doors	Each	6	1.600	9.60	0730
11	Typical Window	Each	9	0.889	8.00	0820
Interior structure						
12	Drywall, Interior Wall	SF	1,750	0.009	15.75	0910
13	Wall Framing, Interior	LF	800	0.013	10.40	2150
Roof						
14	Roof Framing (30 X 27) (16oc)	LF	750	0.021	15.75	2020
Exterior structure						
15	Wood sidings	SF	1,200	0.012	14.40	2200
16	Drywall, Exterior Wall	SF	1,250	0.009	11.25	0910
17	Wall Framing, Exterior	LF	900	0.010	9.00	2300
Flooring and Foundation						
18	Flooring	SF	810	0.008	6.48	2160
19	SOG, 4"	SF	900	0.080	72.00	4010
					185.70	

5.5.2. Deconstruction time for the example house with DfD features

When the five features explained above are incorporated in this house, the deconstruction time decreases. Due to modular framing, i.e. 24'"oc, the exterior framing decreases from 900 LF to 600LF and hence decreases time required for deconstruction. Further, cost code 02 42 10.20 0812 in RS Means gives labor hours per unit for deconstructing windows without casement and cladding. This value can be used to calculate deconstruction time for new window design.

Deconstruction of interior walls is relatively swift when the walls are movable compared to typical interior walls. Even though, it is understandable that removing electrical work, drywall and then deconstructing each stud of the frame takes lot more time than just un-screwing the entire wall, only 50% reduction of deconstruction time for interior wall frame is considered. Similarly, de-nailing each siding takes more time than sliding each siding out of a channel/frame, only 30% reduction in deconstruction time for siding is considered. Table 5.6 shows the estimated deconstruction cost for each component with the mentioned five design features.

5.5.3. Deconstruction time comparison

When deconstruction time is compared from the Tables 5.5 and 5.6, it can be seen that incorporating design for deconstruction reduces labor hours from 185 to 165 for the example house. Thus, when the size of the building increases and number of projects are large, substantial amount of deconstruction time can be reduced if the building was designed for deconstruction.

Table 5.6. Deconstruction time of the house when designed with DfD design features

Sr. No.	Description	Unit	Quantity	Labor hours per unit	Total Deconstruction hours	Reference (RS Means-02 42 10.20)
Plumbing and Electrical fixtures						
1	Counter top lavatory	Each	1	1.000	1.00	0100
2	Kitchen Sink	Each	1	1.143	1.14	0110
3	Water closet	Each	1	1.000	1.00	0140
4	Bathtub	Each	1	1.600	1.60	0180
5	Shower	Each	1	2.667	2.67	0200
6	Fluorescent, (2 lamps)	Each	4	0.500	2.00	0320
Appliances and Millwork						
7	Cooking Stove	Each	1	0.615	0.62	0510
8	Countertops	LF	20	0.032	0.64	0620
9	Cabinets (wood)	LF	15	0.160	2.40	0610
Doors and Windows						
10	Typical doors	Each	6	1.600	9.60	0730
11	**Typical Window**	**Each**	**9**	**0.762**	**6.86**	**0812**
Interior structure						
12	**Drywall, Interior Wall**	**SF**	**1,750**	**0.005**	**7.88**	**-**
13	**Wall Framing, Interior**	**LF**	**800**	**0.007**	**5.20**	**-**
Roof						
14	Roof Framing (30 X 27) (16oc)	LF	750	0.021	15.75	2020
Exterior structure						
15	**Wood sidings**	**SF**	**1,200**	**0.008**	**10.08**	**-**
16	Drywall, Exterior Wall	SF	1,250	0.009	11.25	0910
17	**Wall Framing, Exterior**	**LF**	**600**	**0.010**	**6.00**	**2300**
Flooring and Foundation						
18	Flooring	SF	810	0.008	6.48	2160
19	SOG, 4"	SF	900	0.080	72.00	4010
					164.16	

Similarly, duration of each activity was calculated based on RS Mean's crew description. The list of the deconstruction activities is shown in Table 5.7. A schedule for deconstruction of typically designed example house and a schedule for the similar house designed for deconstruction were developed which can be seen in Figures 5.12 and 5.13 respectively.

Table 5.7. List of deconstruction activities

Name	Deconstruction activity
A	Electrical & plumbing fixtures, and appliances & millwork
B	Roofing
C	Doors and Windows
D	Interior wall - Drywall
E	Sidings
F	Exterior wall – Drywall
G	Exterior and Interior Framing
H	Flooring
I	Foundation

As the size of the example house is small the effect on the schedule is minimal. In order to demonstrate the effect of DfD on the schedule, half a day duration is considered as minimum duration. It can be seen that one day is reduced due to incorporation of mentioned DfD features, i.e. 14% reduction in the working days.

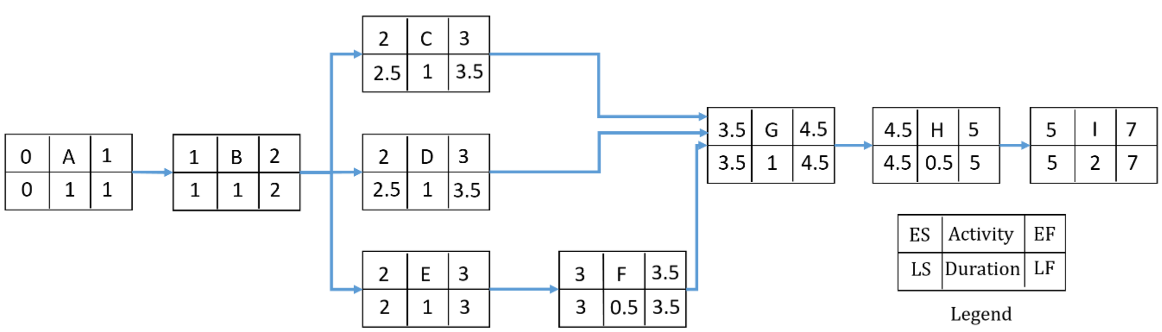


Figure 5.12 Deconstruction schedule of the typically designed example house

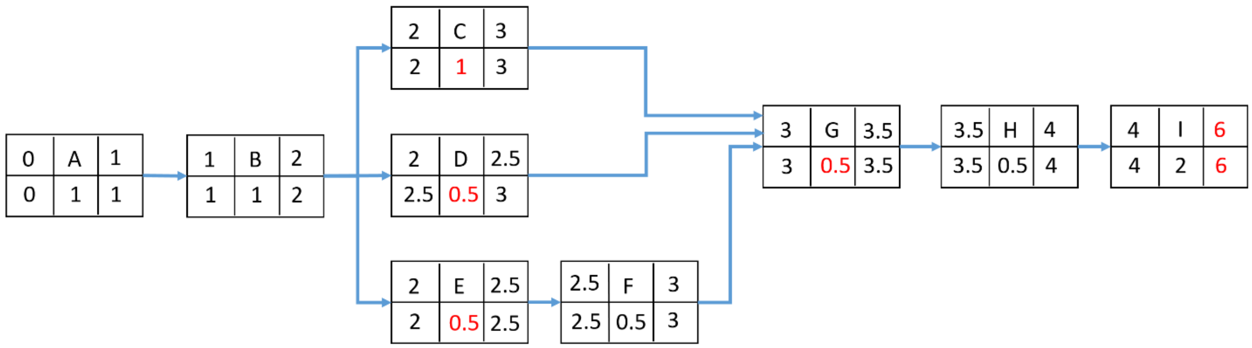


Figure 5.13 Deconstruction schedule of the example house when designed for deconstruction

5.6. Effect of design for deconstruction on construction cost

Changes in the design of the building may affect the cost of the construction. Depending on the design, it can decrease or increase the construction costs. As modular framing suggests changing wood framing from 16"oc to 24"oc with changing lumber size from 2 x 6 to 2 x 8 saves approximately 30% of lumber (EPA, 2006). Even though the cost of the 2 x 8 lumber is bit more than that of 2 x 6, significant amount of cost can be saved on reduced lumber and labor requirements for framing. Similarly, cost of installation of channels or making tongue & grove for sidings increases the material cost of the siding. But, the ease with which the siding is installed reduces the labor cost for siding which compensates or may even supersede the increase in the material cost.

On the other hand, in installing the window with DfD design, cost of installation of the aluminum leg increases along with its material cost. But, the overall cost of installing the window will not increase significantly. Also, incorporating movable interior walls requires the exterior structural framing to be stronger as the interior walls are non-load bearing. This increases the cost for constructing better columns and beams. But, moveable interior walls are readily available and are quick to install, therefore they require less labor hours compared to constructing interior frame, drywall and finishes. Thus, the increase in cost for constructing superior columns and beams can be compensated with decrease in labor cost for interior framing, drywall and finishes work.

5.7. Effect of design for deconstruction on prediction model

With incorporation of DfD features, the amount of material recovered will increase, which is one of the important input variable in the prediction model with 16% weightage on deconstruction cost. Also, it decreases the design complexity of the building which in turn reduces safety requirements for labor. The cost prediction model developed at present does not have stored cases of the buildings which were designed for deconstruction. Hence, the model will not estimate the costs of deconstruction with precision of a building with DfD features. In order to estimate costs of deconstruction of a building with DfD features, an additional input variable can be added in the model. This input variable will ask the question whether the building has DfD features incorporated. If the answer to this question is 'No', the model will run same as now, but if the answer is 'Yes', it will ask the number of DfD features incorporated. The amount obtained from resale of recovered material will increase with the increase in the number of DfD features, which will decrease the net deconstruction costs. However, a detailed study needs to be done in order to incorporate DfD in the prediction model.

5.8. Summary

This chapter addressed the fourth objective of the research. With the help of one story residential building, impact of design for deconstruction on deconstruction costs and time was presented. An example house was used for comparing cost and time of a typically designed house and a house designed with DfD features. It was concluded that incorporating design for deconstruction reduces both time and cost of deconstruction.

6. SUMMARY, CONCLUSIONS AND AREAS OF FUTURE RESEARCH

6.1. Introduction

This research study discussed different prediction models previously used to estimate construction costs. It also discussed deconstruction process and factors affecting the deconstruction costs. Based on this a suitable prediction model was developed for estimating deconstruction costs. Further, various design features of design for deconstruction were discussed. Its impact on deconstruction costs was established by comparing deconstruction costs of typically designed house and a similar house designed for deconstruction. This chapter presents a summary, observation and conclusion of the research based on the objectives that were initially identified. Finally, potential future areas of research are presented.

6.2. Summary, Observations and Conclusion

The goal of this research was to develop a cost estimation model for deconstruction and also to provide an understanding of the variation of deconstruction costs with changes in design of the building. Following is a discussion of the work done under the objectives of the research:

6.2.1. Objective 1: Analyze various existing cost prediction models and select a suitable one for deconstruction

Several academic papers, thesis reports and case studies available in the field of prediction modeling were studied. It was determined that there are primarily three different types of prediction models previously used for cost estimation of new buildings and structures. The three prediction models are regression model, neural network model and case-based reasoning model.

After studying and comparing these three models it was learned that even though neural network model gave the most accurate results, case-based reasoning model is the most effective model with respect to its accuracy, clarity of explanation and ease of updating the model compared to other models. Also, the accuracy of the neural network model is largely impacted if there are not a large number of cases for learning algorithm. As deconstruction is fairly new concept and the deconstruction industry has not significantly flourished, there are very few cases available for learning algorithm for cost prediction model. So, the results obtained from neural network model might not be that accurate. Hence, due to these reasons case based reasoning model was adjudged the most appropriate model for estimation of deconstruction costs.

6.2.2. Objective 2: Study deconstruction process and identify elements affecting deconstruction costs

After reviewing various case studies, academic papers, industry reports and manuals, the author determined ten factors (input variables) that affect the deconstruction costs of a project. The input variables included area of the building, amount of recoverable materials, amount of hazardous materials, site accessibility, etc. After the input variables were determined it was realized that not all input variables have equal degree of importance on deconstruction costs. In order to determine the importance (weight) of each of the variables different methods of determining weights were studied. It was concluded that analytical hierarchy process (AHP) method is the most suitable method to determine weights of the input variables of deconstruction costs among gradient decent method (GDM) and equal weight method. For determining weights using AHP method, a comparison matrix of input variable was created. A limited number of interviews of experienced deconstruction Project Managers and Estimators were conducted in order to fill the comparison matrix. The analysis of the interviews conducted were presented and weight of each of the input variables were determined. Also, with the purpose of having significant number of cases in the database, the details of several deconstruction projects were collected from the deconstruction contractors.

6.2.3. Objective 3: Develop a cost prediction model for deconstruction based on the analysis

Prediction model to estimate deconstruction costs was developed using 'Python' programming language. Python was selected because it emphasizes code readability, and its syntax allows a programmer to express concepts in fewer lines of code. Also, it is easily accessible and freely distributed online on their website. The coding was based on case based reasoning model which was determined to be the most suitable method for this study in objective 1. The input variables and their weights established in objective 2 were incorporated in the model. For cultivating database required for working of the model, deconstruction contractors were contacted for acquiring details of residential projects they deconstructed in recent years. Due to lack of sufficient cases in the database the accuracy of the model is limited. Nevertheless, it was determined by testing the model with varying cases in the database that the accuracy of the model will keep on improving with the increasing number of cases in the database.

6.2.4. Objective 4: Understand cost associated with different elements of design for deconstruction and discuss comparison of deconstruction costs of a residential building traditionally designed and designed for deconstruction

Different design elements of design for deconstruction (DfD) were studied with the help of a number of academic papers, case studies and industry reports available in this field. Five design feature of DfD, i.e. repositionable interior walls, moving electrical and plumbing work, modular framing and better window and siding design were selected and its deconstruction cost was determined based on RS Means (2014), literature review on DfD and the author's knowledge of deconstruction.

A one story residential building of 900 sq. ft. with typical building design was selected. Its deconstruction cost was estimated to be $11,859.00 by using RS Means (2014). Further, the five design features mentioned above were incorporated in this building and its deconstruction costs were estimated to be $10,621.50. Thus, it was recognized based on the estimates that deconstruction cost decreases with incorporating designs for deconstruction. Also, the salvage value of the material recovered from the building designed for deconstruction will be more than the typically designed building. Further, while discussing the effect of DfD on deconstruction time, it was estimated that the example house with the mentioned DfD features require 165 labor hours for deconstruction compared to 186 labor hours required when the similar house in typically designed. Impact on construction costs of the building due to design for deconstruction was also discussed. It was concluded that future construction should incorporate design for deconstruction for maximum economic and environmental benefits.

6.3. Areas of Future Research

Deconstruction and design for deconstruction are new concepts and will continue to grow. Costs associated with deconstruction are complex and require technical and managerial knowledge to successfully estimate the costs. There is a scope for further research in these fields. Some of the important topics on which research can be done in future are enlisted below.

- *Incorporating DfD in cost prediction model:* The author developed a cost prediction model for estimating deconstruction costs. Also, demonstrated the effect of design for deconstruction on deconstruction cost. Further study can be conducted in order to include effect of DfD on deconstruction costs in the prediction model.
- *Effect of DfD on construction costs:* It was briefly discussed in this study. A detailed research can be conducted to analyze different design features of DfD and their effect on the construction costs.
- *Value of salvaged material:* Comparison study of deconstruction costs of building typically designed and designed for deconstruction was conducted. Similarly, a comparison study can be done to analyze the market of salvaged materials which is recovered from the building designed for deconstruction and typically designed building. This will help to calculate the net deconstruction cost more accurately.

This research provides a tool for estimating the deconstruction costs of a project. The author hopes that the cost prediction model developed will assist the contractors to estimate deconstruction costs and hence draw them towards deconstruction over demolition. Also, the economic and environmental benefits of design for deconstruction demonstrated in this study will encourage designers to incorporate construction designs that are favorable for deconstruction, therefore, making the entire life-cycle of the building more environment friendly.

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APPENDIX A

Survey of Contractors

What to produce:

The objective of this survey is to understand deconstruction costs and method of estimation of deconstruction costs prevalent in the deconstruction industry. Following is the information I need to produce from this survey:

- Major factors that affect cost of deconstruction projects
- Importance (weight) of each factor which affects the deconstruction cost

What information is needed:

Based on the above mentioned objectives or information that needs to be produced, the survey intends to gather information on the practical aspects deconstruction from contractor's point of view. In order to achieve the above mentioned objectives the survey should be able to gather project specific information from the contractors on the following aspects:

- Information regarding the contractor
- Cost estimation or quantification process deconstruction projects.
- Major cost factors in deconstruction projects.

What questions to ask:

The first part of the survey will include questions regarding the background of the contractor, years of experience and area of specialty, etc. The contractor will be asked to provide information regarding deconstruction cost estimation practices.

I. BACKGROUND OF THE COMPANY/CONTRACTOR

1. Which of the following building disassembly businesses does your firm engage in?

a. Demolition
b. Deconstruction
c. Demolition and deconstruction
d. Salvage
e. Other……………..

2. What role do you play in the firm?

a. Owner
b. Construction/Project Manager
c. Estimator
d. Other……………………..

3. What state or geographic region do you mainly operate in?

4. How many deconstruction projects have you worked on and over how many years?

Deconstruction projects………………………

II. DETERMINING IMPORTANCE OF EACH VARIABLE FOR DECONSTRUCTION COST

After studying several academic papers, thesis reports and case studies available on deconstruction and prediction model, the author has determined the input variables for the cost prediction model for deconstruction.

Table 1. List of input variables for cost prediction model for deconstruction

Sr. No.	Input variables	Reason
1	Age of the building	Quality of the material can be interpreted by the age of the building
2	Condition of the building	Water or fire damages to building. If the daamages are high, recoverable material will be less which will increase the overall cost
3	Building area	Size of the building affects the use of equipment and safety precautions, both measured by time and expense
4	Site/Building Accessibility	Low accessibility indicates an increase in the labor to ready the site to deconstruct, store, sort, and/or process materials onsite, thus, increasing overall project costs
5	Complexity of the building	High rating indicates an increase in the level of skill, time and planning required to safely dismantle a building, thus an increase in the overall cost
6	Hazardous Building Materials	High number of hazardous building material means low amount of recoverable material and high safety
7	Building Material Reuse and Recycling Markets	The absence of local markets may result in higher costs to transport materials to markets, which can greatly impact the economic viability of deconstruction
8	Location	Depending on the location, the labor and equipment cost may vary. Also, high cost of dumping will increase the cost of the project
9	Amount of recoverable building material	Amount of recoverable material affects the overall cost of the project. More the recoverable cost, less overall cost of the project
10	Number of floors	The number of floors has a direct effect on the structural design and consequently cost of remoing of columns. Also, with number of floors safety increases which increases labor cost

But not every variable has equal importance is determining deconstruction cost. One of the method to determine importance of each variable is by analytic hierarchy process.

The analytic hierarchy process:

For comparisons, we need a scale of numbers that indicates how many times more important one element is over another element with respect to the criterion which they are compared. Table 2 exhibits the scale. Figure 1 exhibits an example in which the scale is used to compare the relative consumption of drinks in the USA. One compares a drink indicated on the left with another indicated at the top and answers the question: How many times more, or how strongly more is that drink consumed in the US than the one at the top? One then enters the number from the scale that is appropriate for the judgment: for example enter 9 in the (coffee, wine) position meaning that coffee consumption is 9 times wine consumption. It is automatic that 1/9 is what one needs to use in the (wine, coffee) position. Note that water is consumed more than coffee, so one enters 2 in the (water, coffee) position, and ½ in the (coffee, water) position. One always enters its reciprocal in the transpose position.

Table 2. The fundamental scale of absolute numbers

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

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

Figure 1- Relative consumption of drinks (Saaty, 2008)

Similar to the coffee example, the weight of the variables on which the deconstruction costs depends can be determined. Based on your knowledge and experience in the field of deconstruction industry, please fill out the following.

	Age of the building	Condition of the building	Design Complexity of the building	Hazardous Building Materials	Building Material Reuse and Recycling Markets	Location	Site/ Building Accessibility	Building area	Amount of recoverable building material	Number of floors
Age of the building	1									
Condition of the building		1								
Design Complexity of the building			1							
Hazardous Building Materials				1						
Building Material Reuse and Recycling Markets					1					
Location						1				
Site/ Building Accessibility							1			
Building area								1		
Amount of recoverable building material									1	
Number of floors										1

APPENDIX B

The comparison matrix results of the interview conducted of deconstruction Project Managers and Estimators in order to obtain weight of each of the variable using AHP method are in the figures below.

	Age of the building	Condition of the building	Design Complexity of the building	Hazardous Building Materials	Building Material Reuse and Recycling Markets	Location	Site/ Building Accessibility	Building area	Amount of recoverable building material	Number of floors
Age of the building	1	1/9	1/6	1/2	1/5	1/3	1/4	1/9	1/2	1/3
Condition of the building	9	1	2	6	3	7	4	1	1	4
Design Complexity of the building	6	1/2	1	5	1	1	1/2	1/5	1/3	2
Hazardous Building Materials	2	1/6	1/5	1	1/2	1	1	1/6	1/5	1/2
Building Material Reuse and Recycling Markets	5	1/3	1	2	1	1	3	1/5	1/3	1
Location	3	1/7	1	1	1	1	1	1/8	1/7	1/3
Site/ Building Accessibility	4	1/4	2	1	1/3	1	1	1/3	1/4	1
Building area	9	1	5	6	5	8	3	1	2	5
Amount of recoverable building material	2	1	3	5	3	7	4	1/2	1	4
Number of floors	3	1/4	1/2	2	1	3	1	1/5	1/4	1

Comparison matrix of the first interview

	Age of the building	Condition of the building	Design Complexity of the building	Hazardous Building Materials	Building Material Reuse and Recycling Markets	Location	Site/ Building Accessibility	Building area	Amount of recoverable building material	Number of floors
Age of the building	1	1/9	1/4	1/5	1/4	1/2	1/6	1/9	1/8	1/2
Condition of the building	[illegible]	1	5	6	4	7	5	1	1	4
Design Complexity of the building	[illegible]	[illegible]	1	1/2	1/4	1	1/5	1/7	1/4	1/4
Hazardous Building Materials	5	[illegible]	2	1	1	2/1	2/1	1/7	1/4	1/7
Building Material Reuse and Recycling Markets	4	4	4	1	1	2/1	4/1	1/7	1/5	1/4
Location	[illegible]	[illegible]	1	1/2	1/2	1	1/6	1/7	1/7	1/3
Site/ Building Accessibility	9	[illegible]	5	1/2	1/4	6	1	1/6	1/5	1/2
Building area	9	[illegible]	7	7	7	7	6	1	1	5
Amount of recoverable building material	8	[illegible]	[illegible]	4	5	7	5	1	1	4
Number of floors	[illegible]	[illegible]	[illegible]	[illegible]	4	[illegible]	2	[illegible]	[illegible]	1

Comparison matrix of the second interview

	Age of the building	Condition of the building	Design Complexity of the building	Hazardous Building Materials	Building Material Reuse and Recycling Markets	Location	Site/ Building Accessibility	Building area	Amount of recoverable building material	Number of floors
Age of the building	1	1/9	1/3	1/5	1/1	1/2	1/2	1/9	1/3	1/5
Condition of the building	9	1	2/1	1/2	2/1	8/1	3/1	1/1	1/3	1/1
Design Complexity of the building	3	1/2	1	2	2/1	1/2	1/2	1/5	1/1	1/2
Hazardous Building Materials	5	2	1/2	1	2	2	1/1	1/7	1/5	2
Building Material Reuse and Recycling Markets	1	1/2	1/2	1/2	1	1/1	1/3	1/3	1/2	1/2
Location	2	1/8	2	1/2	1	1	1/2	1/7	1/4	1/2
Site/ Building Accessibility	2	1/3	2	1	3	2	1	1/2	1/2	1/1
Building area	9	1	5	7	3	7	2	1	1/1	1/2
Amount of recoverable building material	3	3	1	5	2	4	2	1	1	1/1
Number of floors	5	1	2	1/2	2	2	1	2	1	1

Comparison matrix of the third interview

APPENDIX C

The details collected from the deconstruction contractors of residential projects recently deconstructed for storing cases in database are represented in the figures below.

	Sr.No	1	2	3	4	5	6	7	8	9	10			
	Input variables	Age of the building	Condition of the building	Complexity of the building	Hazardous Building Materials	Building Material Reuse and Recycling Markets	Location	Site/ Building Accessibility	Building area	Amount of recoverable building material	Number of floors			
Range	**Address**	**Number**	**Percentage (0-100)**	**High, medium & low**	**High, medium & low**	**High, medium & low**	**High, medium & low**	**High, medium & low**	**Area (0 - 6000 sq.ft)**	**Percentage (0-100)**	**Numeric (1 to 3)**	**Deconstruction Cost**	**Amount recovered from resale of materials**	**Net deconstruction cost**
Case 1	Lansing, MI	93	70%	Low	Low	Medium	Medium	High	4000	40%	2	$25,000.00	$10,000.00	$15,000.00
Case 2	Lansing, MI	90	40%	Medium	Low	Medium	Medium	Low	3200	25%	2	$22,000.00	$5,000.00	$17,000.00
Case 3	Lansing, MI	136	60%	Medium	Low	High	Medium	Low	6000	70%	2	$30,000.00	$21,000.00	$9,000.00
Case 4	Hamtramck, MI	86	80%	Low	Low	Medium	High	High	1862	90%	2	$22,000.00	$15,000.00	$7,000.00
Case 5	Inkster, MI	71	60%	Low	High	Medium	Medium	High	724	60%	1	$17,000.00	$7,000.00	$10,000.00

Details of projects 1 to 5 stored in database

	Sr.No	1	2	3	4	5	6	7	8	9	10			
	Input variables	Age of the building	Condition of the building	Complexity of the building	Hazardous Building Materials	Building Material Reuse and Recycling Markets	Location	Site/ Building Accessibility	Building area	Amount of recoverable building material	Number of floors			
Range	**Address**	**Number**	**Percentage (0-100)**	**High, medium & low**	**High, medium & low**	**High, medium & low**	**High, medium & low**	**High, medium & low**	**Area (0 - 6000 sq.ft)**	**Percentage (0-100)**	**Numeric (1 to 3)**	**Deconstruction Cost**	**Amount recovered from resale of materials**	**Net deconstruction cost**
Case 6	Lansing, MI	100	75%	High	Medium	Low	Medium	High	1232	46%	2	$24,600.00	$4,771.00	$19,829.00
Case 7	Lansing, MI	110	75%	High	Medium	Low	Medium	Low	1764	43%	2	$27,240.00	$3,406.00	$23,834.00
Case 8	Lansing, MI	105	70%	Medium	Medium	Low	Medium	Medium	1809	35%	2	$11,742.00	$1,000.00	$10,742.00
Case 9	Lansing, MI	99	60%	Medium	High	Low	Medium	Medium	1312	33%	2	$11,742.00	$2,000.00	$9,742.00
Case 10	Lansing, MI	102	40%	High	High	Low	Medium	Low	1576	25%	2	$11,742.00	$500.00	$11,242.00

Details of projects 6 to 10 stored in database

APPENDIX D

The complete syntax of the model developed for cost estimation of a deconstruction project using Python:

```
HIGH = 1
MEDIUM = 2
LOW = 3

CATEGORY_VAL = {'HIGH':1, 'MEDIUM':2, 'LOW':3}
CATEGORY = ['SITE', 'COMPLEX', 'HAZ', 'REUSE', 'LOC', 'RECOVER', 'FLOOR']
NUMERIC = ['COB', 'BAREA']

FEATURES_IDX = {
                    'AGE':0,
                    'COB':1,
                    'COMPLEX':2,
                    'HAZ':3,
                    'REUSE':4,
                    'LOC':5,
                    'SITE':6,
                    'BAREA':7,
                    'RECOVER':8,
                    'FLOOR':9,
                    'DE_COST':10,
                    'AMT_RCR':11
}
IDX_FEATURES = {
        0:'AGE',
        1:'COB',
```

```
    2:'COMPLEX',
    3:'HAZ',
    4:'REUSE',
    5:'LOC',
    6:'SITE',
    7:'BAREA',
    8:'RECOVER',
    9:'FLOOR',
    10:'DE_COST',
    11:'AMT_RCR'
}

class Driver:
    def __init__(self, fname):
        self.fobj = None
        self.fname = fname
        self.obs_data = {}
        self.weights = []
        self.test_data = []
        self.max_sim_id = 0
        self.max_sim_percent = 0


    def init(self):
        self.fobj = open(self.fname, 'r')
        self.weights = map(float, self.fobj.readline().split(','))

    def run(self):
        self.init()
        self.readData()
        self.test_data = self.get_test_data()
        #print 'weights',self.weights
        #print 'obs data:',self.obs_data
```

```
        self.get_similarity()
        print '\n\nBest case matched: Case ', self.max_sim_id, ' - ',self.max_sim_percent,'%'
        print 'case ',self.max_sim_id, ' :'
        net_cost = self.obs_data[self.max_sim_id][-2]-self.obs_data[self.max_sim_id][-1]
        sq_dc =
float(self.obs_data[self.max_sim_id][FEATURES_IDX['DE_COST']])/float(self.obs_data[self.max_sim_id][FEATU
RES_IDX['BAREA']])
        sq_ndc = float(net_cost)/float(self.obs_data[self.max_sim_id][FEATURES_IDX['BAREA']])
        print '\t Deconstruction Cost - $',self.obs_data[self.max_sim_id][-2]
        print '\t Amount recovered from resale of materials - $',self.obs_data[self.max_sim_id][-1]
        print '\t Net deconstruction cost - $',net_cost
        print '\t Hence, the deconstruction cost per square foot of the building will be $',sq_dc
        print '\t and net deconstruction cost per square foot will be $',sq_ndc,' with
',self.max_sim_percent,'%', 'confidence.'


    def get_similarity(self):
        weight_sum = sum(self.weights)


        #old_cat_idx = [0,3,4,5,6,7]
        #old_num_idx = [1,2,8,9]
        #4-2, 5-3, 6-4, 7-5, 3-6, 2-7, 8-8, 9-9
        cat_idx = [0,6,2,3,4,5]
        num_idx = [1,7,8,9]


        for rec in self.obs_data:
            obs_sim = 0
            obs = self.obs_data[rec]
            for i in range(10):
                if i in cat_idx:
                    v = self.weights[i]*self.category_sim(self.test_data[i],obs[i])
                    obs_sim+=v
                else:
                    v = self.weights[i]*self.numeric_sim(self.test_data[i],obs[i])
                    obs_sim+=v
```

```
        obs_sim = (obs_sim/weight_sum) *100
        if obs_sim>self.max_sim_percent:
            self.max_sim_percent = obs_sim
            self.max_sim_id = rec

def numeric_sim(self, N, S, percent=10):
    v = abs((N-S)/S) *100
    if v<=percent:
        return 1
    else:
        return 0

def category_sim(self, N, S):
    if N==S:
        return 1
    else:
        return 0

def readData(self):
    record = 1
    for line in self.fobj:
        data = []
        line = line.split(',')
        data.append(self.getAge(line[FEATURES_IDX['AGE']].strip()))
        data.append(self.get_numeric(line[FEATURES_IDX['COB']].strip()))
        data.append(self.get_category(line[FEATURES_IDX['COMPLEX']].strip()))
        data.append(self.get_category(line[FEATURES_IDX['HAZ']].strip()))
        data.append(self.get_category(line[FEATURES_IDX['REUSE']].strip()))
        data.append(self.get_category(line[FEATURES_IDX['LOC']].strip()))
        data.append(self.get_category(line[FEATURES_IDX['SITE']].strip()))
        data.append(self.get_numeric(line[FEATURES_IDX['BAREA']].strip()))
        data.append(self.get_numeric(line[FEATURES_IDX['RECOVER']].strip()))
        data.append(self.get_numeric(line[FEATURES_IDX['FLOOR']].strip()))
```

```
                data.append(self.get_numeric(line[FEATURES_IDX['DE_COST']].strip()))
                data.append(self.get_numeric(line[FEATURES_IDX['AMT_RCR']].strip()))
                self.obs_data[record] = data
                record+=1

    def get_test_data(self):
        print 'Enter the test Data:-'
        data = []
        age = raw_input('Enter Age of building (0-100):')
        data.append(self.getAge(age.strip()))
        cob = raw_input('Enter Condition of building (Percentage):')
        data.append(self.get_numeric(cob.strip()))
        com = raw_input('Enter Complexity of Building (HIGH,MEDIUM,LOW):')
        data.append(self.get_category(com.strip()))
        haz = raw_input('Enter Hazordous Building Material (HIGH,MEDIUM,LOW):')
        data.append(self.get_category(haz.strip()))
        bmtr = raw_input('Enter Building material Reuse and Recycling Markets
(HIGH,MEDIUM,LOW):')
        data.append(self.get_category(bmtr.strip()))
        loc = raw_input('Enter Location (HIGH,MEDIUM,LOW):')
        data.append(self.get_category(loc.strip()))
        site = raw_input('Enter Site/Building Accessibility (HIGH,MEDIUM,LOW):')
        data.append(self.get_category(site.strip()))
        barea = raw_input('Enter Building Area (Numeric):')
        data.append(self.get_numeric(barea.strip()))
        recover = raw_input('Enter Amount of recoverable building material (Percentage):')
        data.append(self.get_numeric(recover.strip()))
        floor = raw_input('Enter Number of floors (1,2,3):')
        data.append(self.get_numeric(floor.strip()))
        return data

    def getAge(self, val):
        age = float(val)
```

```
        if age<=150 and age>=60:
            age = CATEGORY_VAL['HIGH']
        elif age<60 and age>=30:
            age = CATEGORY_VAL['MEDIUM']
        else:
            age = CATEGORY_VAL['LOW']
        return age

    def get_numeric(self, val):
        return float(val)

    def get_category(self, val):
        return CATEGORY_VAL[val]

if __name__=="__main__":
    obj = Driver('observation.txt')
    obj.run()
```