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EVALUATING THE ECONOMIC EFFECTIVENESS OF DECONSTRUCTION ACTIVITIES FOR A FACILITY: A CASE STUDY

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Abstract: Construction and demolition of buildings produce 136 million tons of debris per year in the US, with demolition alone accounting for 48% of the total construction waste stream. In the past, several researchers have reiterated the significance of 'deconstruction', a systematic disassembling of a structure, instead of demolition for reducing waste and increasing reuse. They have listed numerous environmental benefits and a cost saving of approximately £1.3 billion on haulage and landfill tax. Since deconstruction is a complex and costly process, it is important to assess the candidacy of a building for deconstruction as 'suitable'/'unsuitable' beforehand. Candidacy is assessed by considering environmental and economic factors. For this purpose, the economic viability of the entire process, consisting of expenditures, such as the cost of labor and cost of disposal, and earnings, such as resale/salvage value of the material, need to be examined before deconstruction commences. Prior research studies have compared the value of deconstruction to demolition in case studies of buildings that were not designed for deconstruction. As facilities get designed with deconstruction in mind, the impact of deconstruction activities is expected to increase.. The research described in this paper assesses the economic benefit of deconstruction as compared to demolition activities in a case study of a building designed for deconstruction. In this case study, we evaluated the economic viability of a deconstruction project based on the quantity of material recovered and different cost incurred, such as labor, material, equipment and administration costs, and explored whether the deconstruction was beneficial over demolition for the case study building. Cost-benefit analysis (i.e. total benefits - total cost) was used for evaluating the economic viability of deconstruction and it showed that deconstruction was significantly beneficial, with savings of 105%, than a demolition case scenario for the same building. This amount of saving can be attributed to the fact the facility was originally designed for deconstruction.

1 INTRODUCTION

In the recent decade, there has been unprecedented growth in research for achieving sustainable construction given its environmental and social impacts (Kibert 2016). The United States Energy Protection Agency best explains sustainable construction as the practice of creating and using healthier and more resource-efficient models in construction, renovation, operation, maintenance, and demolition (US-EPA, 2003). Based on this definition, three phases of a building's life-cycle generates waste and hence should be studied: (1) Construction, (2) Operation, and (3) End-of-life (B. Endicott, A. Fiato, S. Foster, T. Huang 2007). According to US EPA, a total of 170 million tons of construction and demolition waste was generated in 2003 in the United States. Out of that 170 million tons, 15 million tons were produced in construction, 71 million tons in the operation phase, and 84 million tons in demolition phase (US-EPA 2003). Thus, operation and demolition constituted 42% and 49% of the total waste stream of buildings (Chini 2005a). Moreover, it was reported that per capita per day (pcd) generation C&D waste has been increasing over time with 2.8

pcd, 3.2 pcd, and 4.5 pcd in 1996, 2003 and 2005 respectively. Thus, reduction of waste has become essential to support the increasing population (US-EPA 2003). Another perspective, which makes end-of-life of buildings an important research area, is that buildings in the US have a short life. The short life of building increases the volume of demolition waste stream. O'Connor reported about 50% of the demolished concrete buildings was at the age of 25-50 years and they got demolished due to various non-age related reasons like area development, change in building use, and lack of maintenance (O'connor 2004).

As a result of increasing population and short-lived buildings in the US, there is an increasing demand for virgin building material (O'connor 2004) in order to fulfill the population's needs. These demands are fulfilled by using new material for construction whereas obsolete buildings keep producing demolition waste (Guy 2006).This way of material usage has a two-fold impact: Upstream impact of material usage includes loss of forest, natural resources like fossil fuel, and consequent pollution from the manufacturing process., The downstream impacts are increased landfills, environmental degradation and economic losses (Guy 2006). Thus, in order to reduce and reuse the waste stream at the end-of-life of building, many researchers are working on implementing deconstruction instead of demolition (B. Endicott, A. Fiato, S. Foster, T. Huang 2007; Lassandro 2003).

Deconstruction is systematic disassembling of a structure instead of demolition for reducing waste and increasing reuse. The primary goal is to reduce the volume of the waste stream (Kibert et al. 2000) through increased reclamation and reuse of building materials (Thomsen, Schultmann, and Kohler 2011). Deconstruction has been studied by various researchers through case studies (Lassandro 2003; Chini 2005b), developing planning and scheduling techniques, accumulating technical capacities, and understanding and predicting the economic impacts associated with material flow management in deconstruction. However, these case studies are done for buildings, which were not designed for deconstruction. As a result, these case studies do not show the true benefits of deconstruction. Moreover, the existing research considers qualitatively environmental and social factors, introducing subjectivity in the analysis and results. Therefore, there is a need for case studies, which include buildings designed for deconstruction and provide a quantitative final estimate for comparing demolition and deconstruction. In this regard, this paper presents a case study of deconstruction of a building at Pittsburgh PA with the following two research goals in mind: (1) Development of a quantitative comparison of deconstruction and demolition, (2) Assessment of economic value of deconstruction for a building, designed for deconstruction.

2 RELATED WORK

The deconstruction is a complicated process and therefore requires extensive planning and careful execution. This section discusses various aspects of deconstruction: (1) Pre-deconstruction survey, (2) Planning and scheduling, (3) On-site execution, and (4) Material flow management. Each of them discussed in detail in the following subsections.

2.1 Pre-construction survey

Prior to any deconstruction project, a schedule of activities needs to be prepared. The activities in a deconstruction schedule changes based on site-specific factors, such as types of materials in a facility (hazardous or non- hazardous), amount of reclaimable material, and condition and type of a building. In order to quantify these factors, typically a field survey is conducted. Instead of a survey, such information can also be obtained from building drawings, but since existing drawings are typically outdated or not available for the majority of buildings, pre-deconstruction surveying becomes a necessity (Volk et al. 2018; Hurley 2003). This is also known as building audit survey. Various methods have been implemented to conduct these surveys. In current practice, surveying and on-site measurements are typically done manually. Often other resources, such as site images and checklists are used for analyses (United States Environmental Protection Agency 2015). Some efforts have also been made to generate and compile this information, to be collected by surveying, using existing BIM model or CAD drawings of the building (Volk et al. 2018; Cheng and Ma 2013).

At the end of the pre-deconstruction survey, the following information is generated: (1) Quantity takeoffs for materials, (2) Hazardous materials list, (3) Material categories by stage of recovery during deconstruction etc. (Hurley 2003), and (4) Material categories based on reuse and recycle. This information is critical in evaluating the economic feasibility of deconstruction and also generating a deconstruction plan and schedule.

2.2 Planning and Scheduling

Based on survey results, a schedule of deconstruction is prepared. A deconstruction schedule consists of two parts: (1) Process mapping and (2) Process optimization. Process mapping involves creation of a schedule with various deconstruction related activities and their durations. Deconstruction activities can be divided into the following categories: (1) Separation, (2) Crushing, (3) Sorting, and (4) Loading (Hurley 2003). Once the initial schedule is generated, it is optimized with respect to time and cost.

2.3 On-site execution

The onsite activities related to deconstruction can be broadly classified into the following:

1. Soft stripping - Dismantling of smaller elements, like windows and doors, manually by dismantling crew for salvage or reuse (Chini 2005b). This involves using hammers, crow-bars, and small hand-held machines. This process is time-consuming and labor-intensive.
2. Panelized deconstruction - Dismantling of larger building components, such as roof and wall panels, by machinery. These can involve the utilization of cranes and other larger machinery. This is faster than soft stripping and is less labor intensive (Guy 2006).
3. Separation: This involves the separation of different materials after they are removed from a facility.
4. Sorting: After the separation of all materials, they are sorted in different areas ready to be reused at a different project or sent for recycling or dumping depending upon the type of material.

2.4 Material flow management

Products obtained at the end of on-site deconstruction is classified into three categories – Reuse, Recycle and Dispose (B. Endicott, A. Fiato, S. Foster, T. Huang 2007; Lund and Yost 1997). In reuse, which is the most environmentally sustainable alternative, the products from an existing facility are used without changing its form. Materials obtained after deconstruction could be sold on-site, consigned to resellers or donated to non-profits (Geyer and Jackson 2004). Hence, reuse requires the least amount of energy. In recycling, the used materials are transformed and reintroduced in the life-cycle of a new facility (Akbarnezhad, Ong, and Chandra 2014). In disposal, the waste produced at the end of demolition is sent to landfill. Reuse and recycle make the life-cycle of a facility cyclic (cradle-to-cradle), whereas disposal is linear (cradle-to-grave).

3 ECONOMIC ASSESSMENT FOR DECONSTRUCTION

Economic analysis of deconstruction is done considering factors at two levels: (1) Regional-level – these factors capture economic factors that are universal for a region, such as availability of reuse market, involvement of the public sector in setting up recycled materials development zones, ‘buy recycled campaign’ etc. and building stock of a region as abundance of a materials affects the resale of that material (Macozoma 2002), (2) Site-level – these factors involve site-specific properties, such as building type and its size. The decision of economic feasibility is made by comparing the demolition and deconstruction techniques (Chini 2005b). In order to perform an economic evaluation of a deconstruction project, various parameters are compiled from existing studies and documentation that was done during our case study. These parameters are discussed in detail in the subsequent sections.

3.1 Economic variables

This section explains the possible benefits and costs of a deconstruction. These parameters are primarily from two sources: (1) Existing research studies, and (2) Observed and collected during the case study. As compared to demolition, deconstruction has more cost variables to be considered for economic analysis. These additional cost factors have both positive as well as negative effect on the economic value of a deconstruction project. Some of the important factors are explained below:

- Salvage value: The value earned from salvaged material reduces the overall cost of deconstruction. This value is estimated using;(1) the percentage of the retail price from the local building materials suppliers or RS means (Tatiya et al. 2018; R S Means Company 2005), (2) experience of local construction material suppliers (Guy and Mclendon 2002).
- Demolition disposal cost: This includes the cost of disposal of waste at a landfill. It is a combination of haulage cost, which is the cost of transportation of waste to landfill, and tipping cost, which is the price (per ton) charged at a landfill area. Deconstruction reduces disposal cost since lesser amount of waste needs to be disposed of at the landfill (Rubinstein 2016). Thus, reduction in the disposal cost is a benefit of deconstruction.
- Labor cost: Deconstruction being labor intensive makes labor cost an important factor for the economic assessment. This is dependent on the geographical location of a site. It is mainly obtained from RS Means data (R S Means Company 2005) and the US Department of labor data or Bureau of labor statistics (Rubinstein 2016).
- Equipment cost: Deconstruction requires careful dismantling of a building and hence incorporates different types of equipment at different stages of dismantling. Large-scale dismantling requires heavy machinery equipment. For example, cranes are used for removal of the ceiling of a building.
- Transportation cost - This is incurred as the cost required for the transport of the salvaged material to a resale market, another construction site for reuse or a reseller. It also includes the cost of disposing of C&D waste produced.
- Administration cost - As compared to demolition, deconstruction incurs increased indirect or administration cost due to increased project time. This cost covers supervision, inspections, and management cost the deconstruction process (Dwaikat and Ali 2018).
- Asbestos abatement cost - According to US EPA National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations, any residential or commercial properties with more than 4 units, needs to survey and identify hazardous material in the property before demolition or deconstruction. It also defines techniques for removal and disposal of asbestos-containing materials (Bradley Guy 2014). Thus, as per regulation, it is compulsory to treat asbestos prior to deconstruction. The cost for asbestos abatement changes depending on the size of property and the amount of asbestos-containing material to be treated.

3.2 Economic evaluation metrics

For estimating possible economic value of deconstruction, we utilized the economic metrics proposed in prior studies (Bradley Guy 2014; Zahir et al. 2016; Guy and Mclendon 2002; Akbarnezhad, Ong, and Chandra 2014; Macozoma 2002) and US EPA's deconstruction rapid assessment tool (United States Environmental Protection Agency 2015). These metrics are combined below in Equations 1 and 2.

$$[1]\ Deconstruction\ labor\ cost + equipment\ \ cost + Administration\ cost + asbestos\ abatement\ cost + transportation\ cost - Salvage\ Value = Total\ Deconstruction\ cost$$

$$[2]\ Demolition\ labor\ cost + Equipment\ cost + Disposal\ cost = \ Total\ Demolition\ Cost$$

Benefits or cost savings from deconstruction is the difference between the total demolition cost and total deconstruction cost. If the former is greater than the latter, difference gives cost savings otherwise extra cost is incurred due to deconstruction.

$$[3]\ Total\ Demolition\ cost - \ Total\ Deconstruction\ cost = \ Cost\ Saving$$

4 CASE STUDY

This section explains the economic analysis of a deconstruction case study done at Pittsburgh. Economic benefits are obtained in comparison to the demolition. In this section, we first provide an overview of the deconstruction, including building characteristics. Next, we discuss the calculation of cost incurred during deconstruction. This is followed by calculating the economic value of the project. Figure 1 shows the research methodology for the case study highlighting stages when different data is collected.

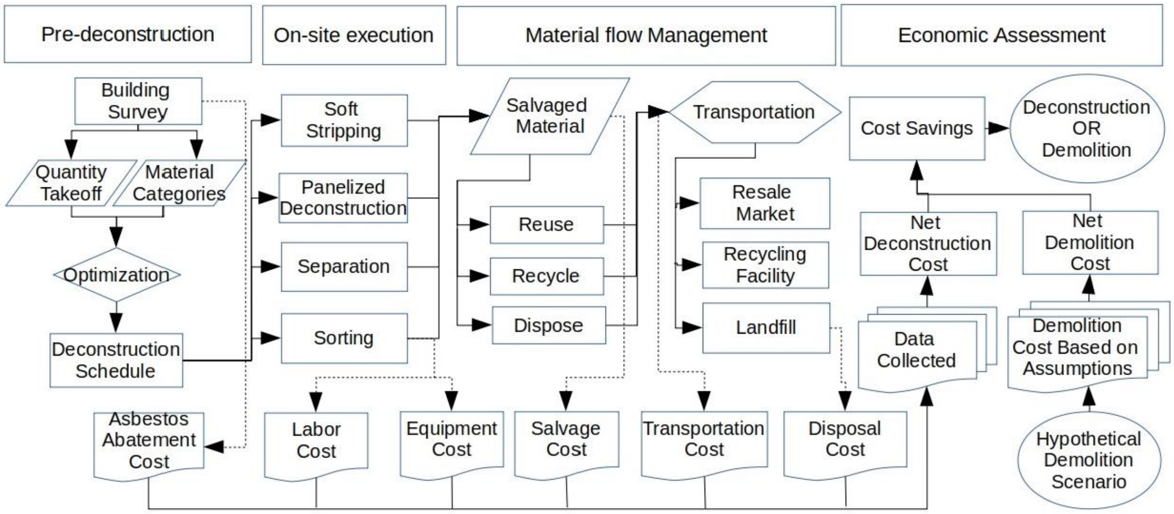

Figure 1 Research Methodology for the case study

4.1 Overview of the Site

The deconstruction was studied for a 2-story building located in Pittsburgh. The building was constructed in 2005 for Solar Decathlon competition, sponsored by US Department of Energy. The building was built with the goal of ease of disassembly and hence no adhesives or nails were used. Figure 2 shows the building and site area before deconstruction. The building was less than 4-units, therefore, no asbestos abatement was required.

Figure 2 Site

4.2 Cost calculation

The benefits and cost variables discussed in Section 3 are calculated for this site. Calculation of these variables and subsequent assumptions are described in the following subsections.

4.2.1 Labor

The labors used for deconstruction are classified in four categories – supervisor, equipment operator (skilled), skilled manpower and unskilled manpower. The amount of time spent by each category of labor was documented during deconstruction. The total calculated hours were multiplied by the respective cost per hour to obtain the total cost. The hourly pay for supervisor, equipment operator, skilled and unskilled labor was $34.92, $24.09, $21.97 and $20.04 respectively (U.S. Bureau of Labor Statistics 2018). Table 2 shows the labor cost for the deconstruction project. A part of on-site deconstruction work was done by college students as part of their coursework and no cost was incurred. In order to offset this bias of the project, labor hours of students were classified into one of the four aforementioned labor types and corresponding labor cost values were obtained.

Table 2 Labor cost

	Skilled equipment operating Manpower (hrs)	Skilled Manpower (hrs)	Unskilled Manpower (hrs)	Supervisor (hrs)
Beginning of Deconstruction	0.0	8.0	0.0	0.0
Site Staging	0.0	8.0	0.0	0.0
Safety Training and Disconnected Items Removal	0.0	8.0	170.5	6.0
Interior Deconstruction and Solar Systems Removal & Deconstruction Crew Work on Site	0.0	26.0	0.0	0.0
Interior and Exterior Deconstruction	0.0	7.0	98.5	6.0
UDBS Students and Deconstruction Crew work on Site	0.0	9.0	134.5	6.0
Deconstruction Crew work on Site	0.0	36.0	18.0	0.0
Remove the rest of furnishing	0.0	1.0	93.0	6.0
Prepare for Crane	0.0	2.0	0.0	0.0
Crane Day	9.0	3.0	43.0	6.0
Remove Frames remain	0.0	0.0	44.0	2.0
Remove Structures	0.0	2.5	0.0	0.0
Remove SIPs	0.0	8.0	0.0	0.0
Clear Site	0.0	28	0.0	0.0
Total hours	9.0	146	601	32
Cost of the respective labor per unit	$24.10	$21.97	$20.04	$34.92
Labor cost	$217	$3,222	$12,060	$1,117
Total labor cost	$16,616			

4.2.2 Material cost

The cost of the salvaged material was obtained based on the market values, based on the managers involved in deconstruction. In cases where the market value was not present, half of the market rate of new material was used (Bradley Guy 2014). The salvaged material was used for reuse and recycle and corresponding cost values were used. The results are shown in Table 3. The value of the material shown in table 3 is the actual selling cost of the material or was obtained by multiplying the quantity of salvaged material with the corresponding value of the material.

4.2.3 Equipment cost

Equipment cost was incurred for the use of cranes. A crane was used for one day at a rate of $95 per hour. A total of equipment cost of $855 was incurred in the project.

Table 3 Material cost

	Material	Landfill (%)	Salvaged Material		Value of material ($)
			Recyclable (%)	Reusable (%)	
Building enclosure	Polycarbonate	4.0	48.0	48.0	$1,072
	Cedar plank siding	1.3	21.3	57.1	$96
	Windows	0.0	0.0	100.0	$1,338.00
	Southern exposure(exterior)	0.0	0.0	100.0	$784.00
	Solar PV panels	0.0	0.0	100.0	$1,949
	Solar thermal collection	0.0	100.0	0.0	$5,372
Structure	Structurally Insulated Panels	20.0	0.0	80.0	$3,169
	PSL	0.0	0.0	100.0	$36.00
	2"x4" lumber	19.0	6.5	74.5	$117.00
	2"x6" lumber	16.0	22.7	61.3	$553.50
	Concrete	100.0	0.0	0.0	NA
	LVL	0.0	0.0	100.0	$453
MEP	Electrical equipment (box, etc.)	0.0	0.0	100.0	NA
	Plumbing equipment (water tank)		NA	NA	$250.00
	Plumbing system (pipes, etc.)	0.0	100.0	0.0	NA
	Plumbing fixtures (sink, etc.)	0.0	0.0	100.0	$187.00
	Mechanical system (a/c etc.)	0.0	0.0	100.0	$1,335.00
Interior	Interior oak cladding/roof panels	12.0	17.6	70.4	$844
	Appliances (microwave, etc.)	0.0	0.0	100.0	$120.00
	Doors (interior and exterior)	0.0	0.0	100.0	$1,800.00
Miscellaneous	Steel (l brackets, plates, etc.)	66.9	33.1	0.0	NA
	Total material cost				$19,481

Table 4 Tipping cost

Parameter	Value
Hypothetical Landfill selected	Monroeville Landfill
Travel distance (miles)	12.3
Travel time (min)	30
Tipping fee ($ / ton)	$ 36.4/ton
Material Volume (cubic feet)	1201.2
C&D waste generated (ton)	12.012
Tipping cost ($)	$ 437.00

Table 5 Haulage cost

Parameter	Value
The capacity of Standard truck trailer (CF)	2398
The capacity of Standard truck trailer (ton)	23.98
Number of haulage trips	1
The distance of traveled (miles)	24.6
Cost of haulage ($/mile)	$ 1.7/mile
Haulage cost ($)	$ 41.00

4.2.4 Demolition disposal cost

Since salvaged material was not disposed of, therefore for calculation of disposal cost following assumption was made: ‘Monroeville landfill’ was selected as the disposal area because it was closest to the construction site and allowed dumping of all the materials produced during deconstruction. The the selected landfill was at a travel distance of 12.3 miles from the deconstruction site. The tipping cost for the landfill was $36.40 per ton. Average haulage cost of trucking (Fender and Pierce 2011) was multiplied by a number of trips and miles per trip for haulage cost. The disposal cost amounts to $478, consisting of tipping cost of $437 and haulage cost of $41 shown in Tables 4 and 5 respectively.

4.2.5 Administration cost

Deconstruction requires surveying, planning, scheduling, execution, and management because of its complex nature. These activities incur a cost of administration cost. Since this project was managed by academics, therefore, no administration cost was incurred. But for removing this bias in the analysis, administration cost of 10% is assumed on the project cost, amounting to $1661 (Dwaikat and Ali 2018).

4.2.6 Cost for demolition scenario

Labor cost is calculated for the same building for the assumed demolition scenario. Demolition schedule is estimated to be 3 days, requiring 1 equipment operating labor for 16 hrs (2 days * 8 hrs per day) each. This results in 16 operating hours. Similarly, for 4 unskilled labor for 3 days (with buffer of 5 hrs), total hours sum to 95 hrs. At a rate of $24.09 per hr for equipment manpower and $20.04 per hr for unskilled labor, the total demolition labor cost adds to $2289 for the entire project. For the equipment cost, 1 cranes were estimated to be used for 2 days for 8 hours per day (that is, 2 days * 8 hours = 16 crane hours) at the cost of $95 per hour, amounting to the equipment cost of $1520.

4.3 The economic value of the project

In order to calculate the economic viability of the project, we did a cost-benefit analysis Based on the values obtained in the previous sub-sections, the final cost saving of 105% was obtained by taking the ratio of cost saving and demolition cost. The deconstruction amount was calculated to be negative $214 as shown in Table 6 using the metric defined in section 3.2, equation 1. For alternate hypothetical demolition cost, the net cost of demolition was calculated to be $4287 using the metric defined in section 3.2, equation 2. Based on the net deconstruction and demolition cost in Table 6 and Table 7 respectively and section 3.2 Equation 3, the cost saving of $4501 was realized for the entire project.

Table 6 Total Deconstruction cost

Parameter	Value($)
Labor cost	16616.00
Transportation cost	135.00
Administration cost	1661.00
Equipment cost	855.00
Salvage material income	19481.00
Total deconstruction cost	-214.00

Table 7 Total Demolition cost

Parameter	Value($)
Labor cost	2289.00
Equipment cost	1520.00
Tipping cost	437.00
Haulage cost	41.00
Total Demolition Cost	4287.00

5 RESULTS AND DISCUSSION

In this section, we discuss the results of the study. The deconstruction project discussed in Section 4, had a cost saving of 105% of the demolition cost corresponding to an actual amount of $4501. This figure shows a large cost saving potential that can be achieved through deconstruction when buildings are designed for deconstruction. In comparison to other case studies like, Chartes, Telemachus, Hamburg, and Franklin which had an extra expenditure of 77.4%, 77.9%, 9.5%, and 42.0% respectively (Denhart 2010). The result of the case study presents a larger potential of cost saving through deconstruction.

Another finding was the large value of material salvaged from the building with the salvage rate ranging from 80% to 100% for different materials, with the exception of steel at 33.1%. This salvaging rate is noteworthy in comparison to the other cases. A deconstruction study in Florida yielded a salvage rate of 60% (Guy and McLendon 2001), a project in Alabama produced 39% salvage rate (Guy 2006), and 4 houses case study in New Orleans had a salvage rate of 54.50%, 40.15%, 38.26% and 75.52% with average salvage rate of 57.82% (Denhart 2010). In this case study, the large value of salvage negated the cost of labor requirement, making deconstruction profitable. The deconstruction done for building designed for deconstruction made the results obtained different from that in the literature where deconstructed buildings were not designed for deconstruction. Thus, from the cost saving, we show that if buildings are designed for deconstruction, then end-of-life becomes an economically valuable process.

Economic assessment of deconstruction depends on factors like, (1) geographical location - vicinity to the recycling sites and landfills, and secondary material market, (2) structure characteristics - height, type, use of structure, (3) past experience of deconstructing contractor, and (4) project's time constraint and others. Thus, depending on the values of these factors the value of deconstruction can change drastically (Akbarnezhad, Ong, and Chandra 2014; Lassandro 2003). Therefore, the exact values obtained in this study do not directly apply to other buildings and study needs to be done for different cases.

6 CONCLUSION

This paper presents a case study to evaluate the economic viability of deconstruction. Through the results, we show large cost savings for deconstruction over demolition. In most of the previous research, the case studies were done for buildings that were not designed for deconstruction therefore not realizing the true value of deconstruction. In this research, the economic assessment of deconstruction was done for a building designed for deconstruction. The findings of this paper provide a strong argument for implementing a design for deconstruction for the building. In this study, social and environmental benefits of deconstruction were not considered. Since the benefits of deconstruction are not just limited to economics, therefore the next step of the study will be to incorporate social and environmental benefits in the assessment of deconstruction.

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