20 Weber Street | Kitchener

Life cycle cost analysis

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Life cycle cost analysis (LCA)

Introduction

Currently, considerable research is done in the area of integration of sustainability in construction and building information modelling (BIM). As part of their life cycle, operational and commercial performance of buildings decreases over the years until the performance fall below the expectations of owners. In consequence, the owners face the decision to finish with the life cycle of the building choosing from one of the different end of life (EoL) options. Some of the most common EoL states for building materials are direct reuse, repairing, refurbishing, remanufacturing, cannibalization, recycling, combustion with heat recovery, composting, incineration, and landfilling (Schultmann and Sunke 2007). However, the decision to choose any of these EoL options may be premature if it ignores the residual utility and value of buildings that could be optimized by "giving them new life" using the process of adaptive reuse. Because of the great impact that the building industry has in the environment, failing to optimize buildings' useful life can result in their residual lifecycle expectancy not being fully exploited and with it wasting the resources embedded.

Background Material

Life cycle cost analysis of the Region of Waterloo County Courthouse

The Region of Waterloo County Courthouse building is located at 20 Weber Street East, Kitchener, Ontario, Canada. It is a mid-20th century building built with a modern architectural style. The building is located on a two-acre parcel of land, situated on the north side of Weber Street East in the City Commercial Core Planning Community of the City of Kitchener, within the Region of Waterloo (Figure 1 left). The Region of Waterloo County Courthouse building, herein referred to as the courthouse, is recognized for its design, physical, contextual, historical and associative values (Pinard & Wade, 2012). The courthouse is a four-story structure with a basement and has a shape similar to a boomerang with a footprint area of 1,233 m2 and 5,341 m2 gross floor area. The primary structural system of the courthouse is a steel frame. The exterior is finished with precast concrete cladding. The main entrance consists of a concrete parabolic arch influenced by the Conestoga Wagon (Figure 1 right). The original courthouse was designed by the architectural firm Snider, Huget and March, and it was built in 1964. The original building replaced a previous County of Waterloo Courthouse and remained in service as a courthouse until 2013. Today it houses Region of Waterloo offices, including the Region of Waterloo Archives, as well as Provincial Offences staff offices.

Figure 1: Overhead view of the Region of Waterloo County Courthouse (left) and main entrance of courthouse (right)

The original courthouse was redeveloped using adaptive reuse from 2014 to 2015 by the architectural firm Robertson Simmons Architects Incorporated. According to the Heritage Kitchener report number CSD-12- 036 (2012), the courthouse was classified as a non-designated property of cultural heritage value. All the subsystems of the building had modifications. The modifications were principally due to the increment of loads and the complete rearrangement of the floor layouts and expanded the gross floor area by 487 m2. One of the changes included the in-filling of two large double-height courtrooms. The redeveloped courthouse has been rated as a Leadership in Energy and Environmental Design (LEED) Gold Building. The location map and the architectural drawings of the project can be found in Appendix A.

The main objective for this case file is to develop a life cycle cost analysis (LCA) based decision-making methodology for evaluating adaptive reuse of buildings. The methodology will quantify the environmental savings due to adaptive reuse for a specific class of asset, which is representative of the building stock in North America. Ultimately, the environmental savings will be monetized according to the valuation of the natural resources. Furthermore, it is desirable to project the environmental savings in the mid future to consider the effects that time have on the valuation of the natural resources. The environmental impacts that will be estimated and monetized are the Primary Energy Demand, measured in Mega Joules and the Global Warming Potential, measured in equivalent kilograms of CO_2.

The building information model (BIM) of the existing and the redeveloped subsystems required obtaining a detailed description of the building components as well as the building project (Figure 2). All building specifications relevant to the project were provided by our industrial partner Robertson Simmons Architects Incorporated. With the project information, the BIM model of the substructure was developed using the software Revit®. The software has the feature to create different phases of the project in the same BIM model. The defined phases for the purposes of this study were existing building, demolition plan, and new building. The BIM model was divided into subsets of components in order to create the breakdown structure for the environmental impacts calculated in the next steps. The component subsets established for the substructure subsystem were isolated foundation, concrete footing, concrete walls, slab-on-grade, steel columns, steel beams, and concrete slab.

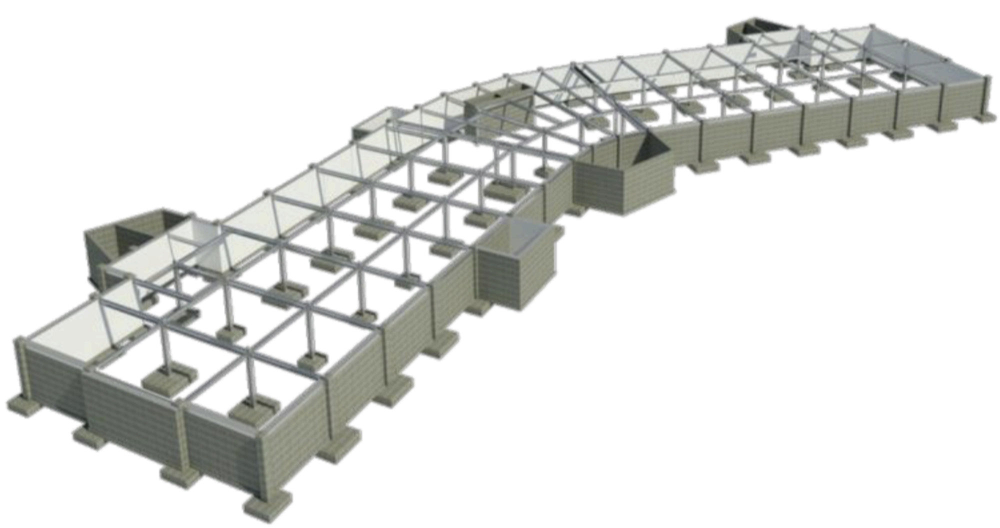

Figure 2: BIM model of Region of Waterloo County Courthouse

The LCA of the original and redeveloped subsystem under study were performed using a software called Tally®. Tally® is a plugin for Revit® that allows quantifying the life-cycle environmental impact of building materials for the analysis of the whole building as well as comparative analysis of design options. Tally® LCA modeling is conducted in accordance with the complete and science- based methodology of GaBi®, a full-range Life Cycle Impact (LCI) datasets and modeling principles (KT Innovations®, thinkstep® & Autodesk® 2015).

Methodology

The method for evaluating adaptive reuse of buildings per subsystem is shown Figure 3 which provides construction engineers and designers with a decision-making method to determine the environmental savings.

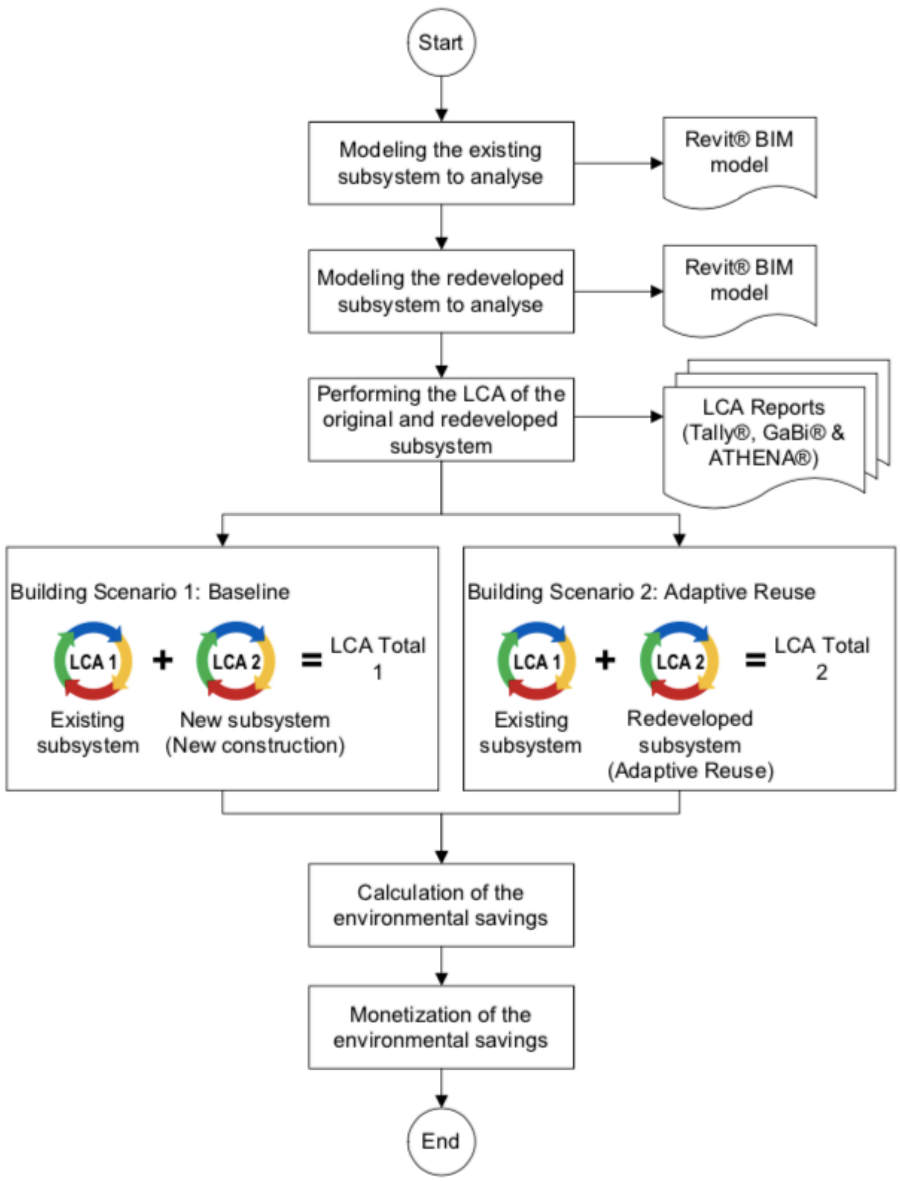

Figure 3: Life cycle cost analysis of new construction and adaptive reuse

The first scenario was the baseline case and the second scenario was the adaptive reuse case. In the first scenario, the LCA performance of two subsystems was accumulated, the existing one and the new design without adaptive reuse. Figure 4a shows the results per subset for the first scenario. The increment from 3.7 million MJ to 4.1 million MJ was due to the new extra-features of the second design. The total primary energy demand for the scenario number one was 7.9 million MJ.

In the scenario number two, it was accumulated the LCA performance of the two subsystems with the difference that the second subsystem was adaptive reused according to the specifications of the case study. Figure 4b shows the results per subset for the second scenario. The total primary energy demand for the scenario number two was 5.2 million MJ. The main difference from both scenarios was the reduction of the primary energy demand in the stages of production and construction of the new building design. The environmental savings were calculated through the difference between both scenarios.

Finally, the environmental savings for primary energy demand were monetized based on the distribution of energy consumption per source and the average fuel price rates. According to the Canadian Industrial Energy End-Use Data and Analysis Centre (IEEDAC) (2016), the energy consumption for the construction industry in Ontario for 2014 was 20% natural gas, 66% middle distillates, 4% propane, and 10% confidential. The respective prices per unit as well as the prices per Giga Joule of the referred energy products were retrieved from the public databases of the National Energy Board of Canada (2016) and Natural Resources Canada (2016). It is important to highlight the fact that the design of the new building had extra features. In general, the increase of gross floor area was around $487m^2$. This is important because even with the increment in the size of the building, adaptive reuse demonstrated to be an eco-friendlier alternative than building an entire new construction.

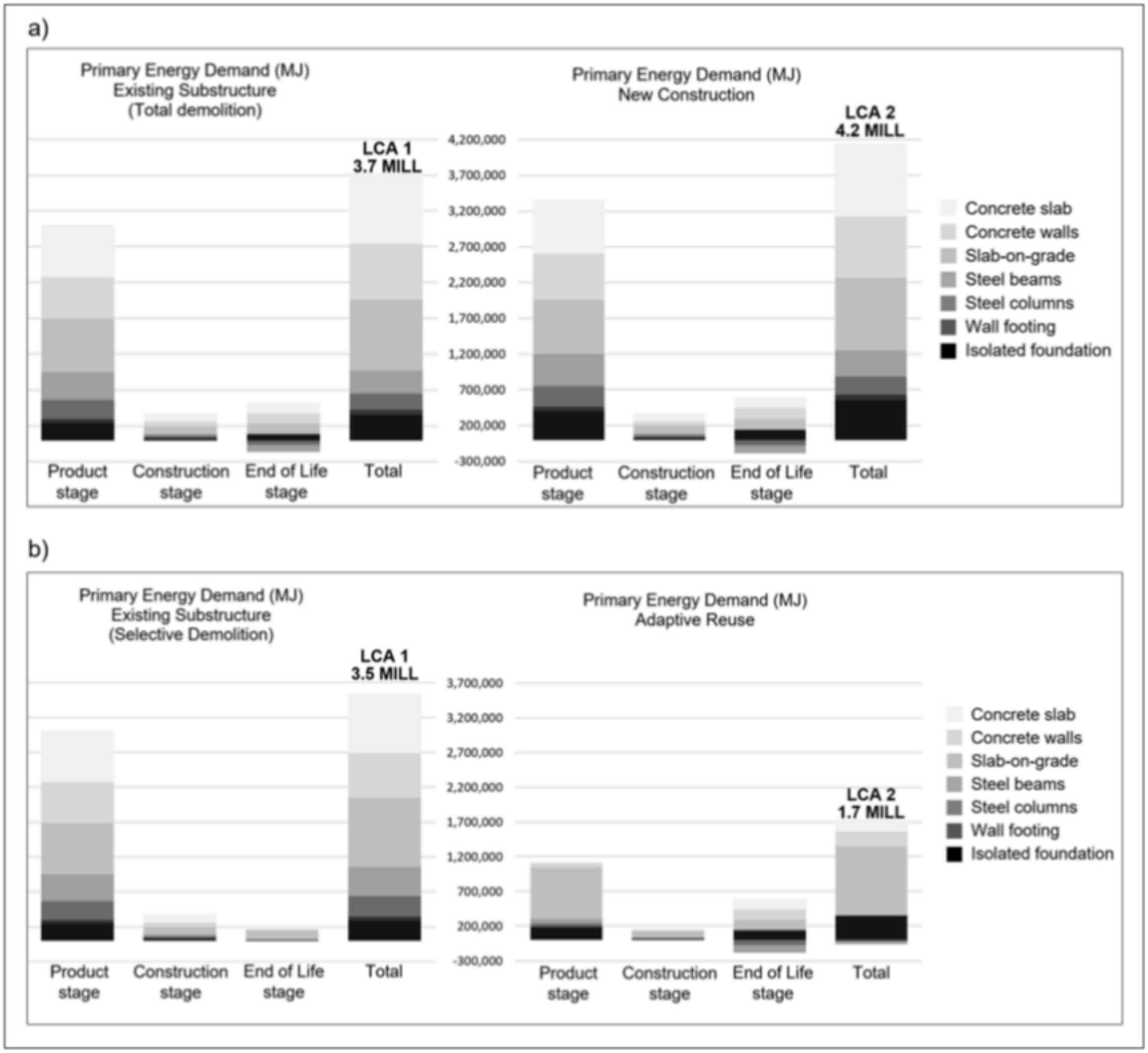

Figure 4: Primary Energy Demand for a) existing substructure and new construction and b) existing substructure and adaptive reuse

Problem Statement

The study will be performed on each building subsystem with the purpose of defining the importance according to their contribution to the total environmental impact, and to determine the convenience of extending the life of each subsystem. The subsystems under study include the substructure, structure, and building envelope. A detailed consequential LCA approach will be used to quantify the environmental impacts per subsystem. The building's operational phase will be eliminated here for simplification purposes. The environmental impact that will be estimated and monetized in this paper is the Primary Energy Demand (PED) measured in Mega Joules (MJ).

Lesson Objectives

After the lesson, students should be able to:

- Calculate the percent and the Primary Energy Demand (PED) reduction between the scenario of new construction and adaptive reuse
- Calculate the environmental savings related to the energy category for the substructure of the adaptive reuse scenario in current Canadian dollars
- Compute the PED for various materials and construction phases

Readings

**needed to complete assignment*

- *Background Material
- *Courthouse Revit model
- *"Methodology for improving the net environmental impacts of new buildings through product recovery management" by B. Sanchez and C. Haas
- *National Energy Board Commodity Prices and Trade Updates (http://one.gc.ca/nrg/ntgrtd/mrkt/prcstrdrtcl/index-eng.html?pedisable=true)

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20 Weber Street | Assignment

<u>Notes:</u>	- Complete the following calculation and discussion questions. - Always show units, and cite sources, where appropriate. - Clearly indicate final answers. - Minimum standards of neatness are expected.

Calculation Questions:

1. Calculate the percent reduction and reduction of Primary Energy Demand between the scenario of new construction and adaptive reuse.

2. Calculate the Primary Energy Demand by commodity in kWh. Adjust the percent of consumption to ignore the percent of consumption that is confidential. Percent consumption in the construction industry

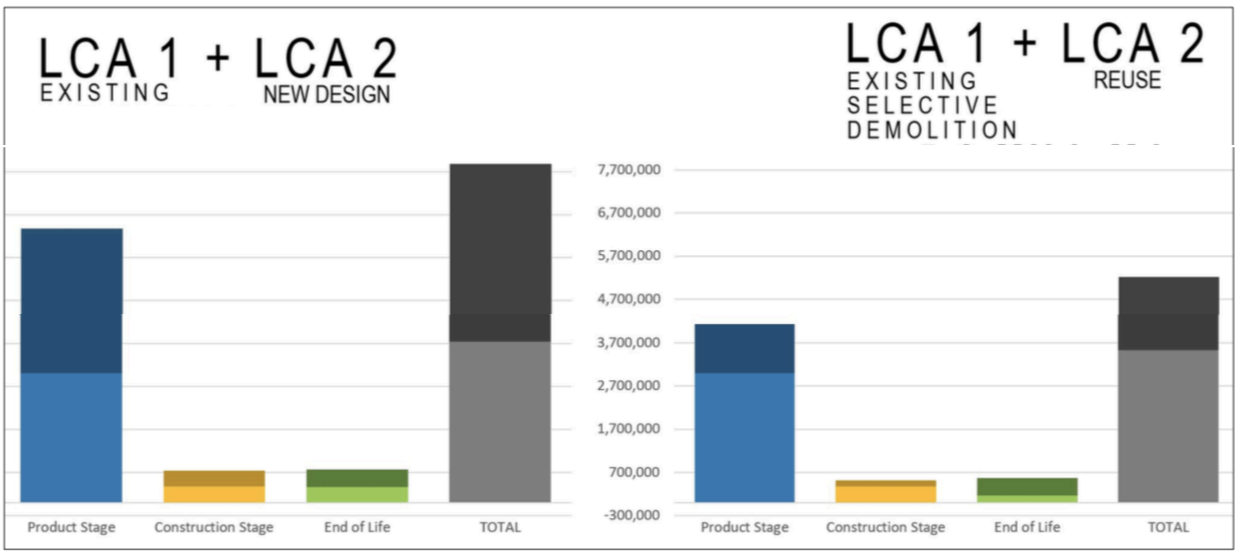
Commodity	**Percent of consumption (%)**	**Adjusted percent of consumption (%)**	**PED consumption (kWh)**
Middle distillates	66		
Natural gas	20		
Propane	4		
Confidential	10		

3. Calculate the environmental savings related to the energy category for the substructure of the adaptive reuse scenario in Canadian dollars. Refer to the National Energy Board Commodity Prices and Trade Updates for 2017. For crude oil, use the average of the prices, for natural gas refer to Dawn, ON, for propane refer to Sarnia, for electricity refer to Ontario (IESO On-Peak). In 2017, the Canadian dollar to the US dollar was on average 1.30.

Commodity	**Price (2017)**	**Calculation**	**CA$/kWh**	**Subtotal CA$**
Middle distillates				
Natural gas				
Propane				

4. Approximately what percent of the total primary energy demand of the existing substructure is attributed to concrete and what percent is attributed to steel? Which material is more of an environmental burden when recycled?

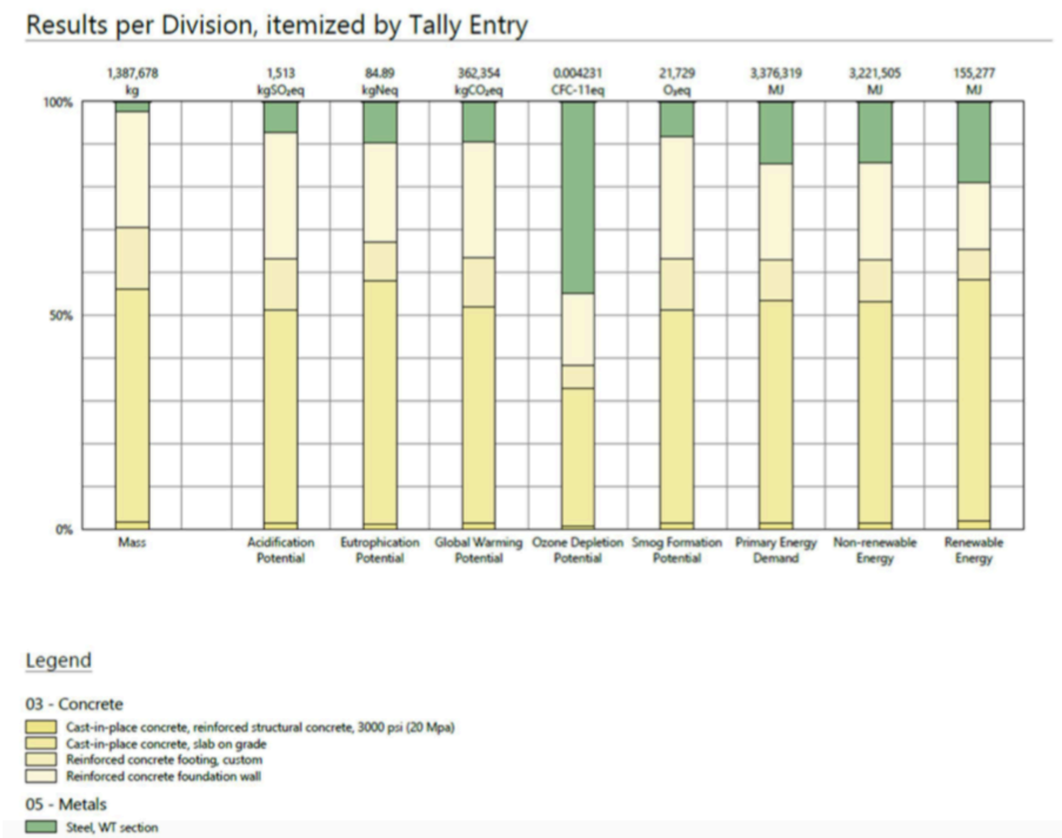
5. Below is a figure of the Primary Energy Demand by category for the scenarios choosing new construction (left) and adaptive reuse (right). LCA1 PED values are shown in a lighter colour and LCA2 PED values are shown in a darker colour for product stage, construction stage, and end of life. Calculate the percent savings (LCA2) in PED between the two scenarios for each category. Which stage benefits most (by percent savings) from adaptive reuse? Is there a stage that does not benefit from adaptive reuse and if so, which?



Discussion Questions:

1. One of the of the second design was an increase in gross area. What is the effect on the primary energy demand? What issue could it cause when presenting the alternatives to the client for decision making?

2. Below are results from Tally© from LCA1 (existing structure) per division (cast-in place structural concrete, cast-in place slab, reinforced concrete footing, reinforced concrete foundation wall, steel section). For each division, what is its biggest impact? Discuss the impact of steel on the potential and energy use within the context of this structure (refer to the mass ratio of material types).



3. Using the results from calculation question number 5 of this assignment, what points would you as an engineer highlight to a client to persuade them to choose the scenario of adaptive reuse compared with new construction?