Renovating vs. Building New: The Environmental Merits

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Abstract

This presentation focuses on the environmental implications of two case study projects involving extensive renovation and rehabilitation of older Canadian buildings to serve new functions. Both of the case study projects were submitted as Canadian entries to the Green Building Challenge. One deals with an old locomotive manufacturing and repair facility in Montreal that has been converted to a high tech office building. The other study deals with redevelopment of an entire city block in Winnipeg, with retention of one major building and the facades of several others. The Athena Institute assessed the environmental implications of both of these projects using its *Environmental Impact Estimator* software, the only North American software for life cycle assessment of whole buildings and building assemblies. The software allows a full life cycle assessment of the environmental effects of different design options and material mixes, and will also take account of operating energy use, including pre-combustion effects, if results are available from a separate energy simulation tool.

The paper emphasizes the process of properly crediting the retention of structural and envelope systems, which typically account for a substantial portion of the materials-related environmental footprint of a building. While it may seem intuitively obvious that retaining and renovating older buildings has environmental merit, the case is difficult to prove without access to the appropriate data and tools. It is especially difficult to convince developers, when the monetary costs of major renovations often exceed the costs of building new.

The paper will also present results from a recent Institute survey of the reasons for demolition of a large sample of buildings in a U.S. city.

1 Introduction

The Interim Report on Sustainable Use of Building Stock (SUBS) rightly emphasized the importance of existing buildings from a sustainability perspective. In addition to the fact that buildings in use today will continue to account for the major portion of the building stock for decades to come, the adaptation of existing buildings to meet evolving requirements will reduce the need for new construction. However, the monetary cost of major renovation or rehabilitation of existing buildings may be the same as, or even greater than, the cost of building new. Furthermore, the cost of rehabilitation is often uncertain because of the unknowns inherent in the process. Justifying rehabilitation may therefore be difficult, especially if the environmental gains are not quantified. That step, in turn, requires the appropriate data and tools.

The Athena Institute has had the opportunity to apply its *Environmental Impact Estimator* software in the assessment of projects that involved major renovations to existing buildings, as well as in investigative studies to determine the best approach for properly crediting the related environmental effects. I have drawn on those studies here to help address the broader questions posed by this OECD Workshop on Sustainable Buildings. In this paper I am especially focusing on how tools such as ours can be used to gauge the environmental gains of SUBS when it requires major renovation or rehabilitation of a building — a different situation from continued use of a building that does not require significant construction to prolong its life.

Before presenting the case study results, I briefly explain life cycle assessment (LCA) and the use of the LCA-based *Environmental Impact Estimator*. Section 2 then discusses the approach to assessing the environmental effects of renovation relative to new construction. Subsequent sections of the paper present the case study results. The last section presents the results of a recent survey of the reasons for demolition of about 200 buildings in the city of Saint Paul, Minnesota.

1.1 The LCA Background

Put simply, LCA is a methodology for assessing the environmental performance of a product over its full life cycle, often referred to as cradle-to-grave or cradle-to-cradle analysis. Environmental performance is generally measured in terms of a wide range of potential effects, such as the following:

- fossil fuel depletion;
- other non-renewable resource use;
- water use;
- global warming potential;
- stratospheric ozone depletion;
- ground-level ozone (smog) creation;
- nutrification/eutrophication of water bodies;
- acidification and acid deposition (dry and wet); and
- toxic releases to air, water, and land.

All of these measures are indicators of the environmental loadings that can result from the manufacture, use and disposal of a product. The indicators do not directly address the ultimate human or ecosystem health effects, a much more difficult and uncertain task, but they do provide good measures of environmental performance, given that reducing any of these effects is a step in the right direction.

In LCA, the effects associated with making, transporting, using, and disposing of products are referred to as 'embodied effects', where the word embodied refers to attribution or allocation in an accounting sense as opposed to true physical embodiment. In the building community, the tendency is to refer primarily to 'embodied energy', but there is a wide range of embodied effects, as implied by the list of indicators. All of the extractions from and releases to nature are embodied effects, and there are also embodied effects associated with the production and transportation of energy itself (known as pre-combustion effects).

In the case of buildings, the energy required to operate a building over its life greatly overshadows the energy attributed to the products used in its construction. However, for other embodied effects such as toxic releases to water, effects during the resource extraction and manufacturing stages greatly outweigh any releases associated with building operations. The essence of LCA is to cast the net wide and capture all of the relevant effects associated with a product or process over its full life cycle.

LCA is not the same as life cycle costing (LCC). The two methodologies are complementary, but LCC focuses on the dollar costs of building and maintaining a structure over its life cycle, while LCA focuses on environmental performance. Performance is measured in the units appropriate to each emission type or effect category. For example, global warming gases are characterized in terms of their heat trapping effects compared to the effects of CO2, and global warming potential is measured in equivalent tonnes of CO2.

1.2 The Athena Environmental Impact Estimator

The Environmental Impact Estimator (EIE) software was developed by the Canadian non-profit Athena Institute to make it possible for architects, engineers and researchers to assess the environmental implications of industrial, institutional, office, and residential building designs at an early stage in the project delivery process. The EIE is an LCA-based decision support tool focused at the level of whole buildings, or complete building assemblies (walls, floors and roofs, for example). It therefore captures the systems implications of product selections related to a building's structure and envelope.

The tool is regionalized — it currently covers eight specific regions for Canada, three for the U.S., and a U.S. average — and allows users to take account of the embodied effects of product manufacturing, building construction, and material maintenance and replacement over an assumed building life, distinguishing between owner-occupied and rental facilities where relevant. The building life is selected by the user and can be varied to assess relative durability effects. The software also covers the energy and emission associated with building demolition and the transport to landfills of materials that would not currently be recycled or reused.

If an energy simulation has been completed for a design, the estimated annual operating energy use by type can be entered through a simple dialogue. The EIE will then take account of operating energy emissions and pre-combustion effects (i.e., the energy and emissions associated with making and moving energy). It will also let the user compare life cycle embodied energy use to operating energy use.

The Estimator incorporates the Institute's life cycle inventory databases for generic building products, covering more than 90 structural and envelope materials. It simulates over 1,000 different assembly combinations and is capable of modeling the structure and envelope systems for about 95% of the building stock in North America.

A conceptual building design is entered in the EIE using preset building assembly dialogues. The user can then instantly see the cradle-to-grave, region-specific implications of a design in terms of a detailed list of flows from and to nature (inventory results) as well as the following summary measures:

- embodied primary energy use;
- global warming potential;
- solid waste emissions;
- pollutants to air;
- pollutants to water; and
- natural resource use.

As design data is entered using the assembly dialogues, the software builds a tree to help track entries. The tree can also display, in value or percentage terms, any one of the above summary measures. This enables the user to track the effects of each assembly addition as it is made, or to quickly pinpoint which one is causing a particular environmental effect.

Results from an individual design can be seen in summary tables and graphs by assembly group and life cycle stage. Detailed tables and graphs show individual energy use by type or form of energy, and emissions by individual substance for both the assembly group and life cycle stage breakouts. A comparison dialogue can be used to make side-by-side comparisons of as many as five alternative designs, for any one or all of the summary measures. The comparisons can be among variations on a base case, or can include completely different projects. Similar projects with different floor areas can be compared on a unit floor area basis.

For more information, please visit the Institute's web site at www.athenaSMI.ca.

2 Assessing Major Renovations

2.1 Basic Approaches

Although the EIE was developed to support decisions during the conceptual design of a new building, it can be applied to assessments of major renovations. There are two basic approaches that can be taken for this kind of assessment.

One approach is to build up a profile of the likely effects associated with demolition activities, material choices, and new construction of specific building elements. These effects can then be compared to the effects of constructing a new building, including complete demolition of the existing structure. This is a benchmarking approach in which the new building serves as the benchmark for assessing the relative merits of renovation.

A second approach is to estimate the environmental effects that are avoided by saving and rehabilitating a building. When all or part of a building is renovated, its structural system is retained, but parts of the original envelope may be demolished and replaced. To assess the environmental benefits or costs of a decision to renovate, we can define 'environmental impact avoidance scenarios' by focusing on the environmental effects of replacing those structural and envelope systems that are actually saved.

The following two avoidance scenarios define the extremes of the range of potential effects, where the range is determined by the extent of the renovation.

Minimum Avoided Impact Case
The minimum avoided environmental impact case involves saving only the structural system of an existing building, with the rest demolished and replaced. The avoided impacts equal the effects of:

demolishing a structural system + rebuilding a comparable structural system

Here the effects of demolishing the envelope are not avoided, and we can assume for analysis purposes that the environmental effects of rebuilding the envelope on an old building would be the same as constructing the envelope on a new building.

Maximum Avoided Impact Case
This case involves saving the envelope as well as the structure, with avoided impacts equal to the effects of:

demolishing a structural/envelope system + rebuilding a comparable structural/envelope system

Between these two extremes are cases where a part of the envelope is retained and the rest replaced. For example, depending on the type of construction, the exterior cladding may be retained and the windows, insulation and interior finishes replaced or augmented.

2.1.1 Selecting an Approach

The choice of approach should be dictated by the purpose of the assessment and the questions that have to be answered.

The benchmark approach is warranted when answers are needed for use in a building assessment system such as Green Globes or LEED™, or when one or more renovation scenarios is being compared to one or more new construction alternatives. In general, this approach will yield a more detailed assessment and make it easier to explore the implications of various options.

The avoided impacts approach is especially useful if the basic purpose is to decide whether a renovation offers sufficient environmental advantages to warrant probable or possible cost increases compared to building new. Avoided impacts represent the environmental effects that can be compared to the extra monetary costs that may be incurred to renovate instead of building new. In other words, the extra costs ‘buy’ the environmental gains estimated as avoided impacts.

Deciding what to include in a renovation assessment is not always as simple as implied here. The task is made especially complex when there are a variety of stakeholders, with various interests, participating in an integrated design or assessment process. We have learned by doing and along the way have made some mistakes, or at least questionable choices, as indicated in the case study discussions in Section 3.

2.2 Two Methodological Issues

In the above definition of the avoided impacts approach, I have shown the demolition of structural and/or envelope systems as an avoided impact. Demolition is also included in the benchmark approach. It could be argued, however, that these systems will eventually be demolished in any event, and that renovation simply defers demolition to some later period.

If we were dealing with monetary effects, we could account for deferral using discounting techniques. In the case of environmental effects, however, discounting is not a valid approach because it tends to undervalue the very future we are trying to protect. There is no easy answer to this issue, and we generally elect to retain demolition effects as an element of avoided impacts, making a point of showing that element separately.

The second issue is the fact that developers do not usually replace an existing structure with another that is exactly the same in terms of size and basic design. In LCA terms, it is therefore hard to maintain functional equivalence.

Again, this is a problem that has no easy solution other than to measure effects per unit of area. Doing so helps to compensate for size differences, but doesn't really solve the problem in terms of design and functionality differences. In fact, as will be noted in the case study descriptions presented in Section 3, it is often difficult to even define a suitable new building benchmark for estimating avoided effects or for use as a benchmark.

3 Case Studies

The two cases studies presented in this section used variations of the two approaches described above. Both studies represent major renovation projects assessed by the Institute as part of the Green Building Challenge (GBC) exercise, one for GBC2000 and the other for GBC2002. For scoring purposes, the assessment framework used in the GBC process requires comparisons of a building design with a benchmark. In light of the framework outlined in Section 2, we should have used the benchmark approach. However, the choices were not as clear at the time, and in the assessment for GBC2000 we used a hybrid of the two approaches with what we would now consider to be misleading results. The study for GBC2002 was more realistic, but still lacking in clarity of approach.

3.1 The Angus Technopole Building

The Angus Technopole project is a dramatic example of building renovation and re-use. The original building, a Montreal locomotive manufacturing factory from the early part of the 20th century, was converted to a commercial/industrial mall. The building has a variety of green features, but our focus here is on the elements of the original building that were retained, which include most of the structure and the envelope modifications.

The Institute's analysis was limited to initial embodied energy[1], greenhouse gas emissions (both fuel and process generated) and acid gas[2] releases. We compared the actual renovated facility to the effects of demolishing the original building and constructing a benchmark new building (structure and envelope) on the same site. We

[1] Initial embodied energy includes the direct and indirect energy associated with extraction, manufacturing and on-site construction activity stages, including all transportation within and between those three stages.

[2] Acid gas effects (SO_2, NO_2, NO, NH_3, HF and HCL) were expressed on an equivalent SO_2 basis, providing a measure of what is commonly known as acid rain potential.

used the benchmark building structure to represent the environmental effects avoided by saving the original structure. We then added in structural and envelope modifications made during the renovation.

Adding the environmental impact avoidance credit to the debits that reflected envelope additions and structural modifications yielded the results in Table 1, below. Compared to a new benchmark building, the Angus Technopole renovation apparently resulted in significant savings from an environmental perspective. In retrospect, however, we overstated the benefits of the Technopole renovation when we explicitly credited the project with the saved structural systems. The approach was modified for the Red River College project submitted to GBC2002.

Table 1
Angus Technopole Building
Comparative Embodied Environmental Effects of the Renovation
(structure and envelope)

Embodied Energy (Gj)		**Global Warming Potential** (Equivalent CO_2 tonnes)		**Acidification Potential** (Equivalent SO2 tonnes)	
Actual	Benchmark	Actual	Benchmark	Actual	Benchmark
(5,169)	13,734	(448)	1,007	(2)	7

3.2 Red River College

The Red River College Princess Street Campus project involved redevelopment of an entire city block in downtown Winnipeg. The completed project encompassed three buildings adjoined by a suspended atrium, and incorporated the reuse of an existing building, existing building facades, and a considerable number of materials reclaimed from the site. The comparative benchmark development was assumed to be a completely new single building on the site, which would provide a similar space but with a more basic generic design.

We assessed the life cycle embodied effects of the structures and envelopes assuming a 75-year life expectancy for both projects. The reuse elements included in our analysis included:

- an existing 6-storey wood and clay brick structure;
- existing heritage facades on one side of the development;
- reclaimed tyndall stone ; and
- reclaimed clay brick for the shear walls of one of the buildings.

Reuse of the existing building structure and envelope was accounted for by including its gross floor area in the total project, thereby reducing the overall environmental burden of the actual project development. This was in contrast to the use of a benchmark design to estimate and explicitly credit avoided impacts, as in the case of the Technopole project.

Reuse of the heritage facades was handled by excluding those walls from the project assessment, essentially allowing the facades to enter the model free of any environmental burdens.

Reuse of the reclaimed clay brick and tyndall stone was handled differently. The project was not charged with any embodied effects associated with production and transportation of the tyndall stone, but we did include the additional mortar and construction effects of putting the stone in place. Modelling the clay brick shear walls involved a similar approach with the project charged only with the on-site construction effects. For this element, however, we also included a credit for the shear wall material that was displaced, a debatable decision that overstates the benefits of the renovation relative to the benchmark.

Table 2 below presents the life cycle assessment results for both the benchmark building and the actual project buildings as previously described. In this case we did not estimate acid rain potential.

Table 2
Red River College Princess Street Campus
Comparative Embodied Environmental Effects of the Renovation
(structure and envelope)

Embodied Energy (Gj)		**Global Warming Potential** (Equivalent CO_2 tonnes)	
Actual	Benchmark	Actual	Benchmark
89053	69666	4585	2588

It is notable that in this case the actual project design has higher embodied effects than the benchmark. One key reason is that the benchmark building was nondescript and lacked desirable elements for the designated end-use. This is one of the methodological issues discussed in Section 2.2; as is often the case, time and budget limitations preclude developing a detailed comparative benchmark, which in turn tends to bias the assessment from an embodied effects perspective. For example, a desirable element for a school is adequate daylighting in all areas of the facility. Given the building's size, this would likely require an atrium as in the actual project, or an undulating exterior wall profile with larger windows than in the benchmark.

Another reason for the comparative results in Table 2 is that the surface area of the actual development (three buildings plus an atrium) is close to three times higher than that of the single benchmark building discussed above, which in turn results in higher embodied effects despite the reuse elements.

Despite the relative embodied effects, the actual project performs very well in terms of the full life cycle profile, including primary energy use and related emissions. Over the full 75 year expected life of the project, the actual design's total energy use and greenhouse gas releases are about half of that of the benchmark design.

4 Conclusions

There are several observations and conclusions that deserve emphasis.

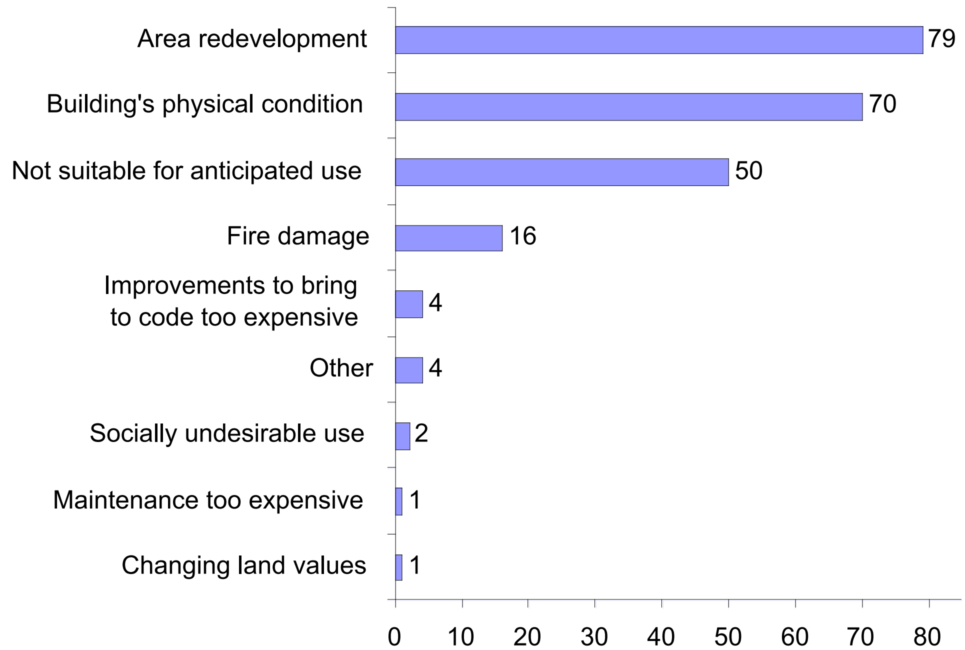
1. LCA can and should be used for renovation projects as a decision support methodology, provided the requisite data and tools are available. In North America, the EIE makes this kind of analysis possible.
2. The LCA approach should be dictated by the purpose of the analysis and the nature of the questions to be answered.
   a. The 'avoided impacts approach' is best used when the objective is to determine the likely range of environmental gains from a renovation in order to decide whether any additional monetary costs or cost uncertainties of a renovation are warranted.
   b. The 'benchmark approach' is appropriate when a renovation project is to be compared to a benchmark design for the purpose of scoring the project in a broader building assessment framework. It provides a more detailed assessment than the avoided impacts approach, and can be used to compare the estimated effects of a renovation project to other renovation or new construction options.
3. The benchmark approach involves the development of a life cycle inventory of the significant environmental effects of the renovation (e.g., any demolition activities, the production of new materials, on-site construction, use phase primary energy use and maintenance, etc.). The inventory results are then characterized to develop measures of impact potentials such as global warming.
4. **The inventory should not include negative values** (i.e., explicit credits) for reuse of all or parts of a structure or envelope. Instead, such reuse is implicitly credited to the project by registering zero manufacturing and transportation burdens for the reused elements. In comparison to a new building benchmark, the project will gain by having floor space, wall areas, or other structure/envelope assemblies that do not require the use of new materials or construction.

5 Postscript: The Reasons for Demolition

Although there is a great deal of anecdotal evidence about the reasons for building demolition, there is little in the nature of statistical data, at least for North America. Nevertheless, there is an increasing tendency to make assumptions or claims about the relative durability of different structural materials. In an attempt to bring some facts to bear on this critical aspect of SUBS, the Athena Institute has undertaken a major survey of buildings demolished in St. Paul, Minnesota, for the period from 2000 to mid-2003. While this is not the place to give a detailed presentation of the results, I would be remiss not to at least mention the survey and provide a quick overview of the results.

Covering about 230 commercial and residential properties, the survey focuses on the age of the buildings, the main structural materials, and the reasons for demolition. When the building condition was cited as a reason, the survey probed for details about specifics (e.g., state of maintenance, structural problems, etc.).

A very positive finding from a SUBS perspective is that 70% of the buildings were in the 51-100+ age category, with 51% in the 76 and over bracket. Unfortunately, the remaining 30% were all less than 50 years old, with 6% in the 0-25 category. The following chart shows the number of demolished buildings by reason for demolition.



Lack of maintenance was cited as the specific problem for 54 of the 70 buildings where physical condition was given as the reason for demolition. In only eight cases was a specific problem with structural or other materials or systems cited. All but two (one of which was of unknown age) were in the 75 and over age categories, and all eight had foundation problems along with other concerns.

Wood buildings accounted for two-thirds of the buildings in the survey, which is not surprising given the geographic region. What may be surprising, however, is that 85% of the demolished wood buildings were in the 51 and over age categories, with 49% in the 76-100 category and 18% more than 100 years old. In contrast, 63% of the structural concrete and 80% of the structural steel buildings were in the 50 and under age categories. Moreover, concrete and steel dominate the 'Area Redevelopment' and 'Not Suitable for Anticipated Use' reasons for demolition.

The survey contains a great deal of additional information and we had not yet completed our analysis of the results as of this writing. However, the complete report will be posted on the Institute's web site at www.athenaSMI.ca early in 2004. In general, we think it challenges some of the emerging conventional wisdom about durability and, perhaps more importantly, it highlights aspects of building construction and maintenance as areas of concern if we want to increase building longevity. Finally, the study tends to confirm the view of many that we should do more to develop building systems that are flexible and that can be readily deconstructed for reuse in different locations if future land use is in question for economic or other reasons.