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METHODOLOGY FOR IMPROVING THE NET ENVIRONMENTAL IMPACTS OF NEW BUILDINGS THROUGH PRODUCT RECOVERY MANAGEMENT

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Abstract: Buildings contribute significantly to the global environmental load caused by human activities. From a life cycle perspective, the building industry is responsible for about 30 per cent of global annual Greenhouse Gas (GHG) emissions and 40 per cent of energy consumption. Several studies have recognized the importance of the End-of-Life (EoL) stage in buildings, and the opportunity of their adaptive reuse as a superior alternative to new buildings in terms of sustainability. Adaptive reuse involves restoring and in some cases changing the use of existing buildings that are obsolete or are nearing their disuse stage. The aim of this study is to add a Life Cycle Assessment (LCA) perspective to the decision-making methodology for adaptive reuse in buildings. LCA accounts for the materials and energy involved in a product and then measures the associated environmental impacts along all of its life stages. The proposed methodology focuses on the LCA of the subsystems of a building and on specific classes of assets relevant to the construction industry in North America. Through a case study named "Region of Waterloo County Courthouse Renovations," the environmental savings due to adaptive reuse per subsystem is demonstrated. A detailed consequential substitution LCA was performed in order to quantitatively demonstrate the relevance of each building component, as well as their influence on the net environmental impact due to adaptive reuse. In the end, some of the environmental savings were monetized and evaluated with respect to the natural resources of the emplacement of the building.

1 INTRODUCTION

In an era of climate change mitigation and adaptation, efficient use of the earth's natural resources is considered as a practical means to increase sustainability in urban settlements. Buildings contribute significantly to the global environmental load caused by human activities. Buildings are the largest energy-consuming sector in the world. From a life cycle perspective, the building industry is responsible for about 30 per cent of global annual Greenhouse Gas (GHG) emissions and 40 per cent of energy consumption. Also, buildings are responsible for 32 per cent of world resource depletion, 12 per cent of water consumption, and 40 per cent of waste to landfill (Langston and others 2008). As such, in the last two decades there has been a growing interest in improving a building's performance over its life cycle stages (production, construction, operation, and End-of-Life [EoL]) in order to move towards a more sustainable environment in the construction industry. Buildings play an important role in the total natural resource depletion and in the production of negative environmental impacts. Therefore, there is an urgent need to mitigate these undesirable problems arising from the neglecting of the direct or indirect processes involved along the chain supply of this sector.

Several studies have recognized the importance of the EoL stage in buildings, and the opportunity of their adaptive reuse as a superior alternative to new buildings in terms of sustainability (Conejos, Langston, and Smith 2015; Schultmann and Sunke 2007; Tan, Shen, and Langston 2014). Adaptive reuse, identified as a process to improve the financial, environmental and social performance of buildings, involves restoring and in some cases changing the use of existing buildings that are obsolete or are nearing their disuse stage (Langston and others 2008; Bullen 2007). There is no doubt about the social, economic, and environmental benefits of applying adaptive reuse. As a matter of fact, the same methodologies used to quantify the social and economic benefits of new building projects have been applied to justify the feasibility of adaptive reuse. However, when proponents of these projects justify and communicate the environmental benefits to the stakeholders, they do so with a lack of objectivity. In a similar way, the lack of knowledge of monetizing environmental impacts has led to underestimating and misunderstanding the complete financial value of existing buildings. Hence, a well-known and widely accepted sustainability framework rooted in physics, can serve as the technical basis to characterize the environmental benefits of adaptive reuse in a way that would be understood by the general public and that would have a credible scientific basis. The aim of this study is to add a Life Cycle Assessment (LCA) perspective to the decision-making methodology for adaptive reuse in order to optimize its environmental and economic performance.

2 BACKGROUND

2.1 Life Cycle Assessment in Sustainable Building Design

LCA is a methodology that accounts for the materials and energy involved in a product or service along its life cycle, and then measures the associated environmental impacts. According to the International Organization for Standardization (ISO 1997) in its norm ISO-14044: “LCA is a technique for assessing the potential environmental aspects associated with a product (or service) by compiling an inventory of relevant inputs and outputs, evaluating the potential environmental impacts associated with these inputs and outputs, and interpreting the results of the inventory and impact phases in relation to the objectives of the study”. An LCA shall include definition of goal and scope, inventory analysis, impact assessment and interpretation of results (ISO 1997). LCA has been used for environmental evaluations of product development processes in different industries for a long time, but it has only been applied into the building construction sector in the last decade (Cabeza and others 2014). Through applying this methodology to the building and construction industry, it is possible to make important decisions during the design stages of a building, based in a holistic approach that involves the stakeholders of a global society. LCA represents a rational standardized approach which can evolve with the development of knowledge and it may help the stakeholders to agree upon common strategies (Peuportier 2001). Nowadays, LCA is considered as one of the main tools used to help achieve sustainability in the building industry (Jalaei 2015; Zabalza Bribian, Aranda Uson, and Scarpellini 2009; Cabeza and others 2014). When LCA is incorporated into the decision-making process for buildings, the stakeholders can scientifically asses the life cycle impacts of building systems, materials, and components, and then select the alternatives that could decrease the net environmental impact of them.

As a part of defining the goal and scope of any kind of LCA, it is necessary to define the product system to be studied as well as its boundaries (ISO1997). The system boundaries determine which unit processes of the final product shall be included within the LCA. The determination of these system boundaries depends on different factors, including the intended application of the study, the assumptions made, cut-off criteria, data and cost constraints, and the intended audience (ISO 1997). Several research (Zabalza Bribian, Aranda Uson, and Scarpellini 2009) have demonstrated the functionality of setting the system boundaries for buildings in four main stages with their respective sub processes: 1) product stage (raw materials supply, transport and manufacturing), 2) construction stage (transport and construction/installation on-site processes), 3) use stage (maintenance/replacement and operational energy use) and 4) EoL (deconstruction/demolition, transport and recycling/reuse/disposal). The environmental impact of building components or processes are evaluated on the basis of inventories. An inventory is a table of impact factors that measures the quantity of emitted or used substance per unit of the component or process (Peuportier 2001). The impact factors depend on the subject and intended use of the study. Several studies have applied LCA in construction measuring different impact factors, depending on the particular objectives of each research. Some authors (Zabalza Bribian, Aranda Uson, and Scarpellini 2009) argue that the indicators and the impact categories selected should be simple, so that architects, engineers, and end-users can easily understand the results.

2.2 Integrating Building Information Modeling and Sustainable Building Design

Building Information Modeling (BIM) is defined by international standards as “shared digital representation of physical and functional characteristics of any built object [...] which forms a reliable basis for decisions” (Volk, Stengel, and Schultmann 2014). BIM is a realistic and detailed virtual representation of buildings. BIM is accomplished with object-oriented software and consists of parametric objects representing building components that may have geometric or non-geometric attributes with functional, semantic or topologic information (Volk, Stengel, and Schultmann 2014).

Currently, considerable research is done in the area of integration of sustainability in construction and BIM. Project teams have found that synergies between green building and BIM can help to improve the accomplishment of sustainability goals (Wu, ASCE, and Issa 2015). This interdisciplinary synergy is well known with the name of “green BIM” or “6D BIM”. Researchers are still working to deliver the full potential of green BIM. The objective is to efficiently integrate the modeling systems, the specialized tools for sustainability, and the databases needed to perform a realistic simulation. Examples of BIM tools available in the market are Revit®, Bentley®, Vico®, and ArchiCAD®. In North American market Autodesk Revit® is the most prevailing BIM tool. Some of the most common modeling systems specialized in energy analysis are Ecotect®, Green Building Studio®, eQuest, EnergyPlus®, and Integrated Environmental Solutions®. Similarly, some of the most developed software for performing LCA in buildings are SimaPro®, GaBi®, Revit Plugin-Tally®, Athena Impact Estimator®, and NIST BEES®. Some researchers have pointed out that a unique software package does not exist that can provide all the needed functions at all the stages of an LCA for buildings (Wu, ASCE, and Issa 2015; Jalaei 2015). Yet, through interoperability and data exchange between applications it is possible to develop integrated green BIM tools. This is possible due to data models that have become the international standard for data exchange in the building industry (Jalaei 2015).

Finally, despite the increasing usage of all these kinds of computer tool technologies in new structures, their implementation in existing buildings is still limited. Research approaches are intensifying to harness BIM for application in existing buildings and to capture and integrate building data into BIM, as well as applications for deconstruction functionalities and reuse of materials and components (Kokkos 2014).

2.3 The Role of Adaptive Reuse in the Modern Construction

Adaptive reuse of buildings is considered by most as a superior alternative to new construction in terms of sustainability (Conejos, Langston, and Smith 2015; Douglas 2006). Adaptive reuse improves the financial, environmental and social performance of buildings. It takes existing buildings that are obsolete, restores them, and in some cases changes their use (Langston and others 2008; Bullen 2007). Adaptive reuse takes advantage of any of green design methods in order to restore and redevelop existing buildings. Green design methods are utilized to reduce environmental cost and increase economic benefits over the entire product or service lifecycle. Examples of green design methods are supply chain management and LCA.

As part of their life cycle, buildings’ operational and commercial performance 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 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.

The decision-making processes associated with the planning, design and construction of a building are diverse and dynamic, therefore to choose adaptive reuse for a building project is complex, as well. The difficulty lies in all the different aspects that have to be taken into account, such as, the physical integrity of the building, economic issues, functionality, technological retrofits, social impact, legal and political issues. For this reason, little research has been done in establishing feasible methodologies for the assessment of adaptive reuse in buildings. Some authors stress that intuition and experience are the only guides in making decisions about adaptive reuse (Highfield and Gorse 2009).

In 2008 Langston et al. (2008) developed the Adaptive Reuse Potential (ARP) model. Through the ARP model, existing buildings can be ranked based on their adaptive reuse potential over time. The ARP model predicts useful life as a function of physical life and obsolescence. In consequence, the right timing for future adaptive reuse can be predicted (Conejos, Langston, and Smith 2015). The model has generic application to all building typologies and all countries. Also, this model has been validated using a new multi-criteria decision analysis tool called iconCUR (Langston and Smith 2012; Langston 2012).

Another recent contribution in this field is the adaptSTAR model. The adaptSTAR model is a decision-making tool that aims to help the climate change adaptation of built assets (Conejos, Langston, and Smith 2014). This model provides a weighted checklist of design strategies that assists in the development of new buildings that can be adaptively reused in the future (Conejos, Langston, and Smith 2015). The approach of this model strives on the intuition and experience of the stakeholders. The adaptSTAR model was based on survey results collected from selected practitioners of the Australian architectural profession. The model is composed of 26 design criteria with weighted percentages that are organized into seven categories. The performance of any newly designed building is scored against these weighted criteria that sum to a total.

In a parallel way, technical regulations and normativity for adaptive reuse have been created in the last decade. These regulations look for making adaptive reuse of the building stock an integral part of the infill development and an affordable new building strategy under the rubric of “smart growth” and “smart codes” (Cantell 2005). “Smart codes” is the term used to describe building codes that encourage the alteration and reuse of existing buildings (DHUD 2001).

3 FRAMEWORK FOR DEVELOPING AN LCA-BASED DECISION-MAKING METHODOLOGY FOR EVALUATING ADAPTIVE REUSE

The aim of this research is to develop a decision-making methodology for adaptive reuse in buildings with a life-cycle perspective, to maximize the environmental and economic benefits of its application. Through a case study, the environmental savings due to adaptive reuse will be quantified. A detailed consequential substitution LCA will be performed in order to quantitatively demonstrate the relevance of each building component, as well as their influence on the net environmental impact due to adaptive reuse.

The proposed methodology for evaluating adaptive reuse of buildings per subsystem is shown in Figure 1. The proposed framework will provide a decision-making method to determine the environmental savings during the process of adaptive reuse of a building. 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. The preliminary results for the substructure are now available. 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).

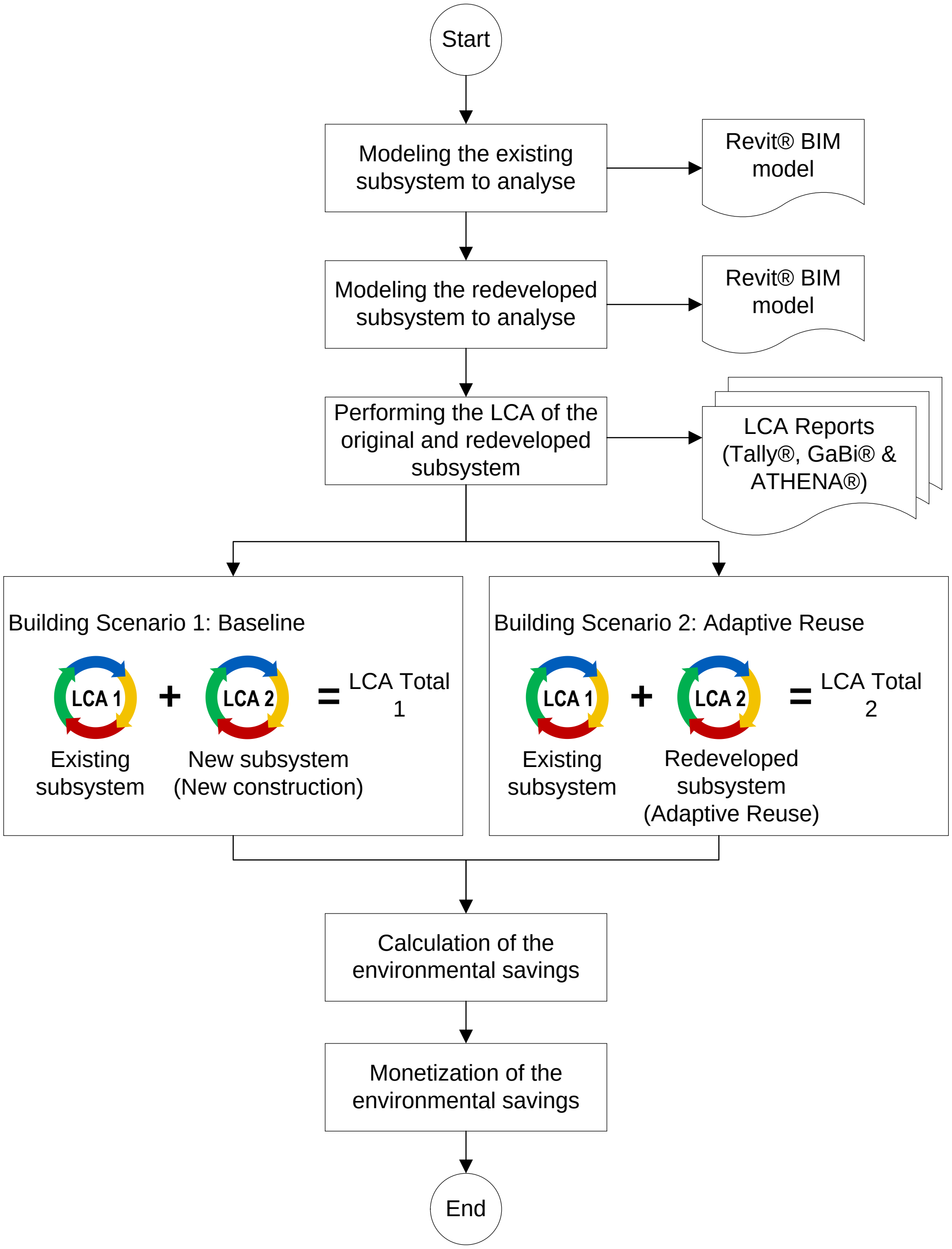

Figure 1: Proposed flow chart for evaluating adaptive reuse per subsystem

3.1 Case Study: Region of Waterloo County Courthouse Renovations

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. 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 and 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 m^2 and 5,341 m^2 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. 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.

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 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, the complete rearrangement of the floor layouts and the expansion of the gross floor area by 487 m^2. 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.

4 RESULTS

The first steps related to the BIM modeling of the existing and the redeveloped subsystems required obtaining a detailed description of the building components as well as the building project. 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 were performed using the software Revit Architecture® (see Figure 2). 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.

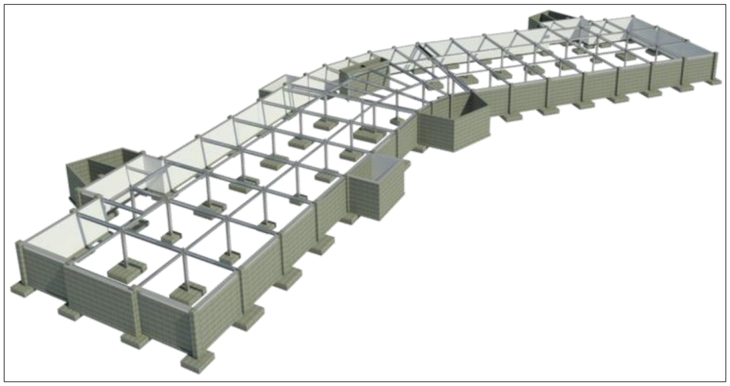

Figure 2: Region of Waterloo County Courthouse existing substructure 3D BIM model

In the next step, the LCA of the original and redeveloped subsystem under study were performed. The specialized software used for this purpose were Tally® and ATHENA®. Tally® is a plugin for Revit Architecture® 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® is a specialized software aligned to ISO 14040-14044, which are the most widely accepted and well-known, standards for LCA (KT Innovations® 2015). Tally® LCA modeling is conducted in accordance with GaBi® full-range Life Cycle Impact (LCI) datasets and modeling principles (KT Innovations®, thinkstep® & Autodesk® 2015). These datasets are a compendium of 20 years of LCA work in industrial practice (Thinkstep® 2016). They are the largest internally consistent LCI datasets available. These LCI datasets have been used in LCA models worldwide in industrial and scientific applications. GaBi® modeling principles are aligned to a complete and science-based methodology called TRACI (Thinkstep® 2016). TRACI stands for Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. TRACI is a characterization scheme and methodology developed by the United States Environmental Protection Agency, commonly used for LCA work in North America (US EPA 2016).

The LCA calculation methodology details are explained in the LCA Tally® reports. In the reports, the software displays a description for managing the LCA settings in a proper way, such as the definition of studied objects, the functional unit and reference flow, system boundaries and delimitations, and data source and quality. In this research, the studied objects were the subsets of the substructure used to compare the relative environmental impacts associated with the building components. The functional unit was the substructure. The reference flow, as well as the system boundaries, included the production, construction, and EoL stages, in agreement with the defined scope. As part of the modeling process, the most common EoL treatments for the construction materials, such as recycling, incineration, and landfilling disposal, are based on average US construction and demolition waste treatment methods and rates. Some of the main software pre-sets for the EoL stage follow. Along with processing requirements, the recycling of materials is modeled using an avoided burden approach or "consequential approach", where the burden of primary material production is allocated to the subsequent life cycle based on the quantity of recovered secondary material (KT Innovations®, thinkstep® & Autodesk® 2015). Incineration of materials includes credit for average US energy recovery rates.

In the modeling process, the production and EoL stages were calculated using Tally®. Then the construction stage was calculated with the software ATHENA®. The environmental impact categories estimated were Acidification Potential (AP), Eutrophication Potential (EP), Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Smog Formation Potential (SFP), and Primary Energy Demand (PED). However, this study focuses only on the Primary Energy Demand (PED) for illustrative purposes.

In the next step, it was necessary to calculate two comparative scenarios. 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. In other words, the baseline case represents the current trends in the construction industry of demolishing the entire subsystem in order to build another one with new characteristics. Therefore, the new subsystem was considered as a completely new construction. Figure 3a 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 3b 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. The final comparison showed a reduction of 34% of Primary Energy Demand, or 2.7 million Mega Joules.

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). The average prices were estimated for Ontario for the year of 2015. The final calculations suggest that the environmental savings related to the energy category for the substructure of the adaptive reuse scenario had a current value of $38,500 Canadian dollars.

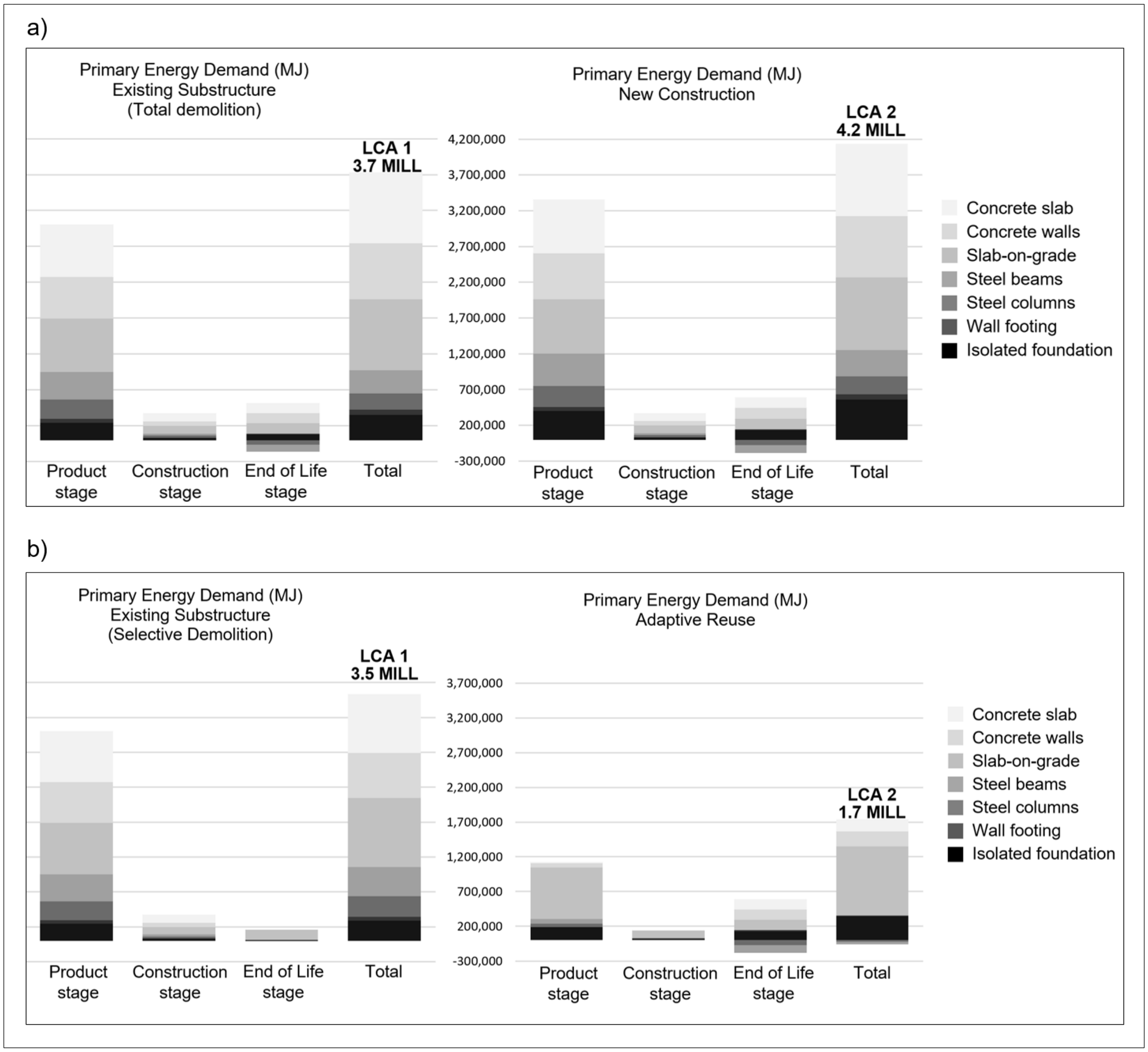

Figure 3: Comparison of substructure based on primary energy demand category: (a) scenario 1 – total demolition and (b) scenario 2 – selective demolition

5 DISCUSSION

The proposed methodology is a practical way to determine the desirability of applying adaptive reuse for building projects. With the development of a case study the technical affordability of applying the proposed method was demonstrated using the current technologies and trends in the construction industry. The breakdown structure of the LCA per subsystem and subset is a practical way for practitioners to visualize the impact of their decision-making. This methodology represents an objective approach to find an empirical stopping point for adaptive reuse projects. This means that designers and practitioners can select the necessary changes to the building project in order to increase the environmental savings and to objectively determine when the modifications in the building are creating a larger negative environmental impact than a brand new building. Therefore, it is a verifiable way to demonstrate the environmental justification of adaptive reuse projects.

In the last stage of the methodology, it is demonstrated the affordability of monetizing the environmental impacts through the current information technologies and specialized databases applied in the construction industry. From an economic standpoint, the advantages of monetizing environmental savings are meaningful, because through this kind of metric, it is much easier to compare benefits with costs and make choices across various alternatives (Viscusi 2005). Moreover, through this practices it would be possible to create the necessary framework to advance energy policy-making in Canada in regards to sustainable building management. Through the findings of these kind of studies governments will be able to create regulations to incentivize construction projects that promote adaptive reuse as the first construction option. These regulations would be based on the objective monetization of the environmental savings for the community, city, and nation. The adoption of these practices for buildings can contribute to sustainability and climate change through mitigation of negative environmental impacts.

Particularly, this case study reveals that a large amount of the environmental savings is due to avoiding the production of new construction materials, as well as the closed-loop of building components in the EoL stage. The conclusions are aligned with the literature review in regards to the distribution of the environmental impacts per building material and the opportunities for product recovery through recycling and reuse. In this matter, concrete is the main source of environmental impacts with around 56% of the total primary energy demand of the existing substructure life-cycle. Steel is the main source for environmental avoided burden when it is recycled, with around 4.8% of the total primary energy demand of the existing substructure life-cycle. 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.

Part of the future work includes completing the implementation of the proposed method for the rest of the subsystems, as well as the inclusion of the complete spectrum of the environmental impacts, such as the Global Warming Potential, Acidification Potential, Eutrophication Potential, among others. Also, it would be part of future research to discuss the actual construction cost under each of the various considered scenarios in the suggested methodology, in order to analyse the cost-effectiveness of adaptive reuse. Finally, it would be interesting to study the optimization of the deconstructive processes in order to maximize the environmental and economic performance of adaptive reuse of buildings.

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