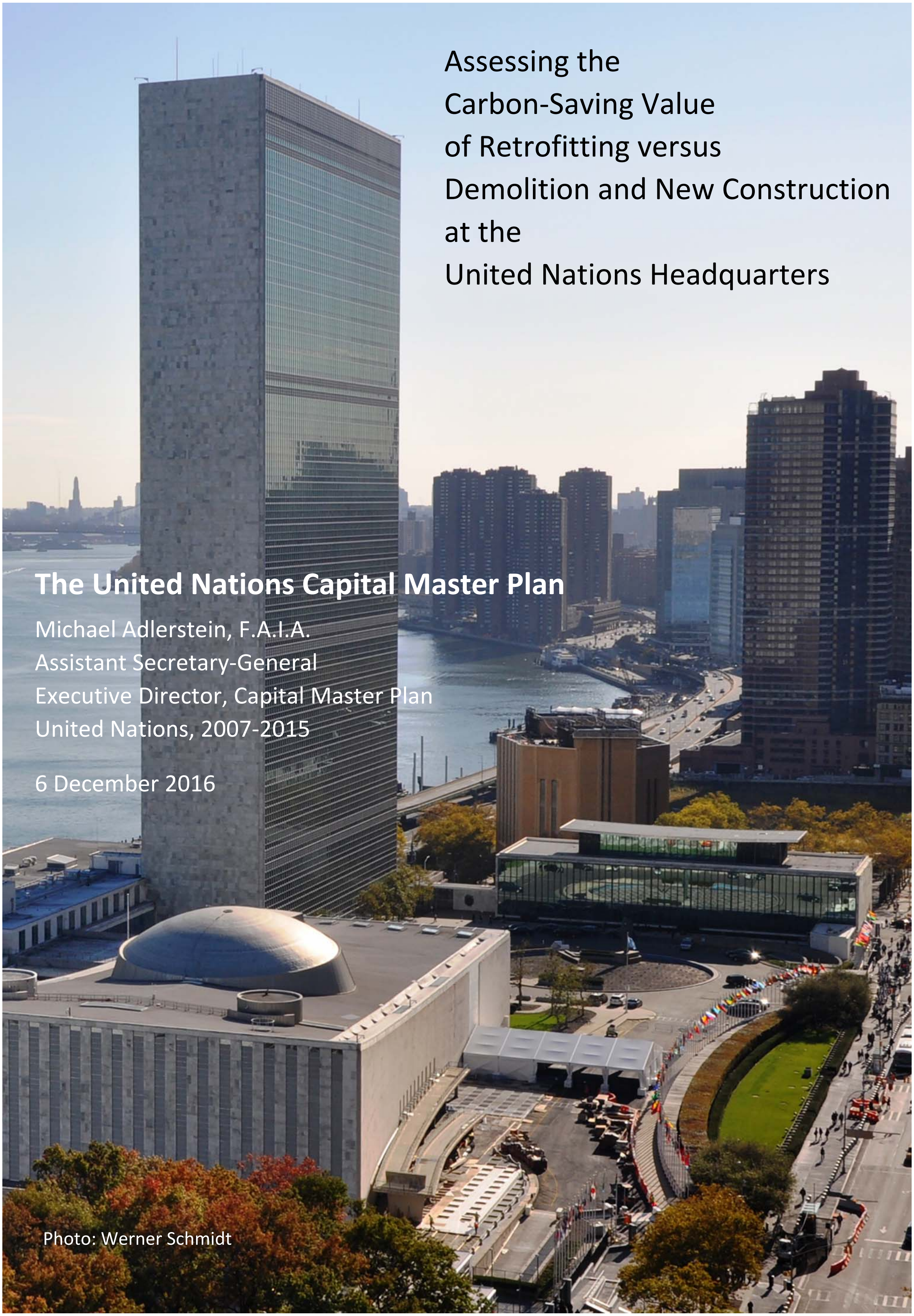

Assessing the Carbon-Saving Value of Retrofitting versus Demolition and New Construction at the United Nations Headquarters

The United Nations Capital Master Plan

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6 December 2016

Executive Summary

After almost a decade of discussion and debate, in 2007 the United Nations initiated a multi-year renovation of its New York City headquarters, the Capital Master Plan (CMP). The CMP was the most extensive renovation program for the United Nations campus since the project's initial construction in the early 1950's.

There were several drivers of the CMP including enhancing sustainability, upgrading security protection from the significantly increased scale of external threats, bringing the campus into code compliance for fire and user safety, conforming to accessibility and other international and local codes that have evolved over the decades, installing state of the art IT and mechanical/electrical infrastructure, and general improvements in conferencing and office space layouts.

Although each of these drivers were functionally critical, enhanced sustainability was, politically, the most important. For decades the UN hosted inconclusive efforts to develop a coordinated world strategy to slow the pace of climate change, including global conferences in Rio in the 1990s, Kyoto in the 2000's and Copenhagen in 2009. In more recent years, the world witnessed a far higher volume of widespread and damaging weather events. These forces of nature created a new shared sense of urgency, creating millions of refugees, which resulted in unusual cooperation and focus in Paris last year, where a climate change "commitment" was reached. The UN, led by the Secretary-General, was amongst the leaders moving the world toward action to combat climate change. With the CMP renovation, the UN demonstrated it was not just an advocate for climate change, but was ready to walk the walk.

For the CMP, sustainable design performance targets were defined in a wide range of areas: operational energy use reduction (with associated carbon emission reductions), water efficiency, use of environmentally-preferable materials, and measures to improve indoor environmental quality[1].

Among these initiatives, however, one of the most fundamental was the decision to renovate the existing campus buildings as opposed to demolishing the complex in favor of new construction. While there were clearly multiple reasons to justify renovation of our iconic, classical, mid-century modern masterpiece, the sustainability aspect of the decision has tended to be overshadowed by the historical, cultural, and architectural considerations. In large part this is because the sustainability benefits are not easily quantified, and are therefore typically acknowledged on an intuitive basis (e.g., preservation saves "many tons" of material), rather than quantitative. When reviewed in more detail, however, the benefits of renovation are substantial enough to warrant further consideration.

This report has been developed to shed more light on the magnitude of the benefits inherent in preserving of the "bones" of an existing building. At the UN complex this specifically encompasses the

[1] The project's sustainability initiatives were benchmarked using the U.S. Green Building Council's LEED rating system; overall, the campus was designed and constructed to meet the equivalent of a LEED Gold rating, while the Secretariat was individually designed and constructed to meet the equivalent of a LEED Platinum rating.

structural elements, opaque envelope assemblies (the solid exterior walls and roofs), and key interior core walls. These elements represent a large "embodied energy[2]" investment, and also carry an even larger carbon emissions burden that cannot easily be offset by new construction, even if we assume that new construction will result in more energy-efficient building operations.

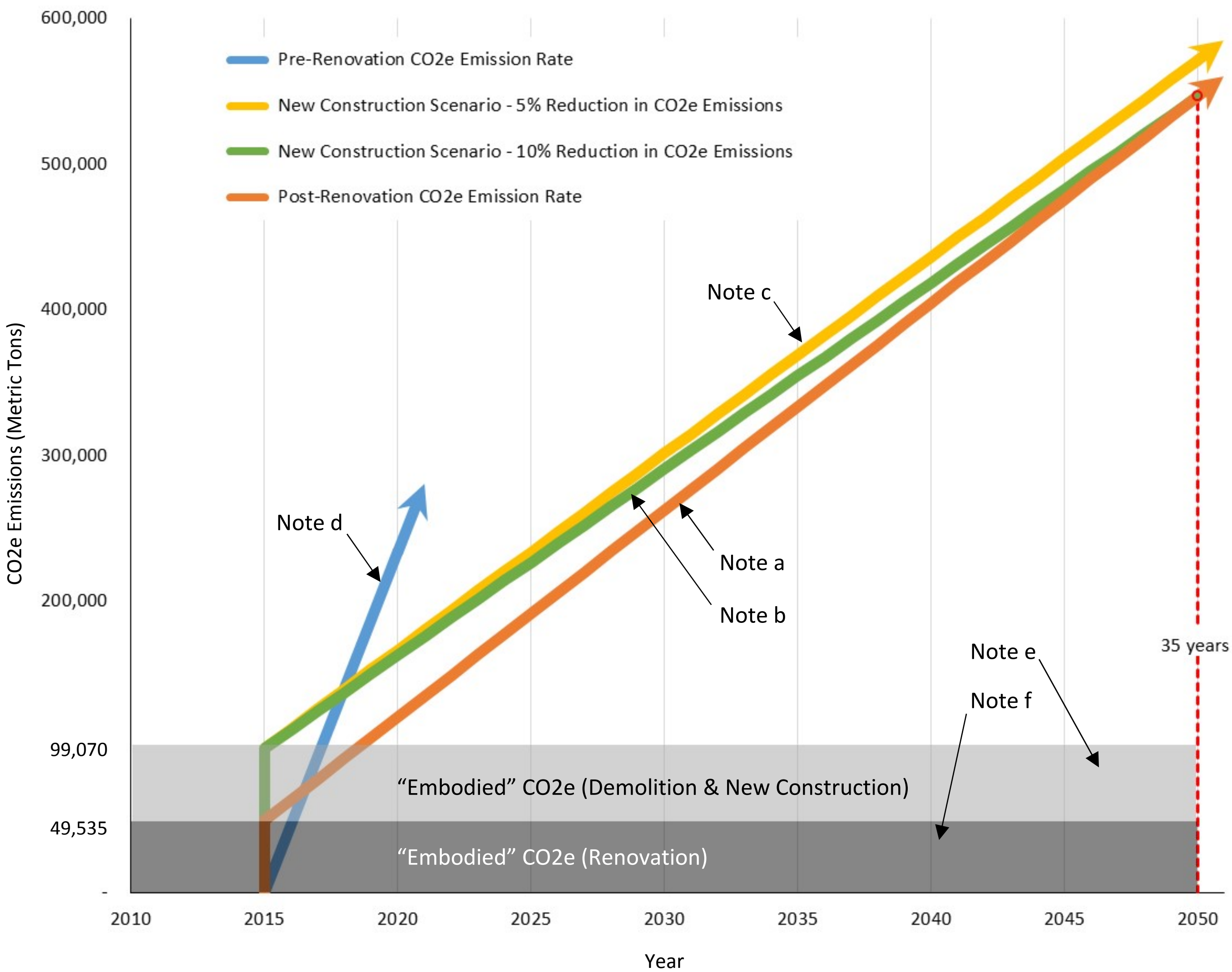
The calculations from this report indicate the following:

If the UN complex had been demolished and replaced with new construction of similar size, it would have taken between ***35 – 70 years*** *before the improved operating efficiencies of the new complex would have offset the initial outlays of carbon emissions associated with the demolition and new construction process.*

Figure 1 (next page) illustrates this relationship over a 35 year time frame.

[2] Embodied energy can generally be considered the energy required to extract and manufacture materials, transport them to the building site, and construct them into a building. Embodied energy can also be calculated for the demolition of a building.

Figure 1: Projected CO2e Emissions (Embodied and Operational) for Renovation vs. New Construction at the United Nation Campus



<u>Notes</u>:

Note a: The orange line in the graph illustrates both the initial "embodied" carbon emissions associated with the United Nations CMP renovation (the vertical portion of the line at year 2015[3]) and the annual carbon emissions associated with the ongoing campus energy consumption (sloping line projected out to 2050). The embodied carbon emissions are estimated based on the life cycle analysis calculations performed for this report (see note f below). The operational emissions are based on the modeled energy consumption of the renovated facility. The annual operational emissions have been reduced from the pre-renovation condition (blue line) by approximately 65%.

Note b: The green line in the graph represents a new construction scenario. Here it is assumed that the existing UN facility is demolished, with a brand new facility constructed in its place. As illustrated in the graph, the embodied carbon emissions for this scenario (shown at year 2015) have increased by 49,535 metric tons compared to the embodied carbon of the renovation (see note e below). In the green line scenario it is assumed that the operational carbon emissions of the new facility are 10% lower than those of the actual renovation (orange line).

[3] For simplicity, the embodied carbon is shown as a vertical line at 2015 (the end-of-construction date for the project). In actuality the embodied carbon would gradually accumulate over the 7 years of the project's renovation/construction.

As shown in the graph, it will take 35 years before the green and orange lines intersect – in other words, 35 years before the increased embodied carbon emissions are offset by the 10% reduction in operational carbon emissions.

Note c: The yellow line in the graph represents another new construction scenario. In this case the operational carbon emissions are assumed to be reduced by only 5% compared to the actual renovation. As indicated in the graph, it will take much longer (70 years, in fact) before the yellow and orange lines intersect. In other words, it will take 70 years before the increased embodied carbon emissions are offset by the 5% reduction in operational carbon emissions.

Note d: The blue line in the graph represents the annual carbon emissions of the UN facility prior to the renovation. As the graph indicates, the significant operational carbon savings achieved by the renovation (orange line) easily justifies the embodied carbon expenditure to replace the targeted systems – many of which (curtainwall, lighting, HVAC) have a direct impact on the facility's energy use. Using the assumptions of this report, the embodied carbon expenditure of the renovation is recouped within 1.5 years; however, given the approximate nature of how the embodied carbon for the renovation was derived, a more conservative approach would be to assume a recoup rate of 5 years or less.

Note e: The "embodied" carbon associated with the new construction scenarios includes the impacts from demolishing the existing UN campus and building new structure, opaque envelope (walls and roofs), and interior core walls. As explained in the body of the report, the emissions for new construction had to be approximated, since there was no new design to utilize for detailed analysis. For the purposes of this study, the new construction emissions were conservatively assumed to be the same as the emissions calculated for the equivalent building elements in the existing UN facility. The ATHENA Environmental Impact Estimator software was used to calculate the embodied energy and embodied carbon emissions of these elements. The 49,535 metric tons of CO2e allocated to the demolition and new construction is indicated in the graph as a vertical line at year 2015, and also (for graphic emphasis) through the light grey band.

Note f: The embodied carbon emissions associated with the actual CMP renovation are based on the elements of the building that were replaced. This includes curtainwall and glazings, mechanical, electrical, plumbing, fire protection, IT, vertical transportation, security systems, and interior finishes. For the purposes of this study, the embodied carbon for these elements was estimated to be, in totality, equivalent to the calculated embodied carbon of the elements that were retained – namely structure, opaque envelope, and interior core walls.[4] In the graph, this embodied carbon is shown as a vertical line at year 2015, and also (for graphic emphasis) through the dark grey band.

The results from **Figure 1** indicate that the practice of demolishing existing structures and replacing them with new construction creates a significant initial carbon burden that is typically recovered over a very long carbon "payback" period. It is even possible, if one uses typical industry assumptions of a 50-60 year useful building life, that new construction will never recoup its initial carbon outlays when compared to a quality renovation.

In this context, building renovation can be considered a fundamental strategy to reduce near-term carbon emissions as part of the national and global response to climate change.

[4] Data on the embodied energy and carbon associated with MEP systems is very limited, as most LCA software programs do not address these elements. The assumption that the building systems listed in Note f represent the equivalent embodied energy and carbon emissions as the retained structure/envelope/core elements was based on a review of available "whole building" LCA calculators, as well as the 1995 report from Cole and Kernan entitled, "Life-Cycle Energy Use in Office Buildings". It is estimated that the percentage of the total building carbon emissions associated with the renovated systems may range from 45% - 65%.

In the Paris Climate Agreement, a target was set to limit global temperature rise to no more than 2°C compared to pre-industrial levels, with a further to aim to limit the increase to 1.5°C. This upper limit was set to avoid catastrophic, irreversible climate change. To meet this goal, the Agreement expects that carbon emissions will need to peak globally "as soon as possible" (with an expectation by 2020 at the latest), and fossil fuels will need to be phased out by as early as 2050[5]. With this critical transitional timeframe defined, the implications of our UN case study become much more pronounced.

Expending significant new energy and carbon now to replace existing buildings with new construction is potentially counter-productive to our most pressing carbon reduction goals, particularly if the carbon "break-even" point is 35 – 70 years in the future. The initial bursts of new carbon into the atmosphere will have an immediate detrimental impact, at a time when society is struggling to stabilize and reduce our greenhouse gas emissions.

Current climate change imperatives involve not just a reduction in our rate of carbon emissions, but a limit to the total absolute quantity of carbon that is released. Carbon dioxide is not quickly purged or reabsorbed from the earth's atmosphere; in fact scientists estimate its atmospheric life at 100-300 years[6]. This means that the carbon burden of the original UN construction – even though it was from 65 years ago - is still in the atmosphere contributing to our current carbon dioxide intensity. Further outlays of carbon for new construction will similarly persist well beyond the life of the associated buildings.

With this perspective, there are two significant considerations for projects where renovation is an option:

- Renovation should be preferred to extend the useful life of the structure as long as feasible. This allows the structure to extend its initial carbon "burden" over as many years as possible, while avoiding the immediate increases in carbon emissions associated with demolition and new construction.

- Renovations should be performed with specific emphasis on those elements that result in substantial reductions in operational energy use and carbon emissions.

In this context, renovating existing buildings becomes an even more compelling strategy than in previous decades. Careful analyses will need to be made to determine how to best invest new embodied energy in building systems that achieve the most, and quickest, operational energy and carbon savings in return. But as the case of the UN renovation makes clear, demolishing the major mass materials of a building structure and envelope - when they still have a long potential service life - is difficult to justify in an era when serious carbon reduction is a global imperative.

These findings, we believe, represent an appropriate and often under-utilized response to the climate change challenge that can be more aggressively pursued within the development, design and construction industries – industries which are responsible for a majority of the ongoing carbon production.

[5] See, for example, "Timetables for Zero emissions and 2050 emissions reductions: State of the Science for the ADP Agreement" by Climate Analytics, http://climateanalytics.org/publications/2015/timetables-for-zero-emissions-and-2015-emissions-reductions.html

[6] See "Recent Greenhouse Gas Concentrations", April 2016, from the Carbon Dioxide Information Analysis Center, located at the U.S. Department of Energy's Oak Ridge National Laboratory, http://cdiac.ornl.gov/pns/current_ghg.html. It is the atmospheric carbon that creates the greenhouse effect associated with climate change.

I. Introduction

At the onset of the United Nations Capital Master Plan (CMP) project in 2004, a foundation of critical sustainability decisions needed to be set. In addition to establishing a comprehensive set of Sustainable Design Guidelines, which incorporated many aspects of the U.S. Green Building Council's LEED rating system and mandated a Gold level of compliance for the campus, the issue of energy efficiency was singled out as a key consideration. Upon reviewing the accomplishments of other contemporary "green" building projects, the UNCMP team decided upon a campus-wide energy efficiency target: a minimum 50% reduction (measured in energy costs) compared to the existing facility energy costs.

In establishing this goal, a question arose as to whether the proposed campus renovation would be capable of achieving this target, as opposed to pursuing a new construction approach. The design consultants determined that the renovation could likely meet the 50% target, given the extent of the energy-influencing systems that were scheduled to be replaced or refurbished, most of which had reached the end of their service lives. The renovation included replacements of the existing curtainwall and glazing systems, installation of new high-efficiency chillers, adding insulation to existing walls and roofs, and installing new lighting and controls, among other measures.

The UNCMP leadership decided that renovation would therefore be the most beneficial approach, as it would:

- Achieve the significant operational energy and carbon savings set as the project targets (which rival those of quality new construction);
- Retain the major mass materials of the original construction, and avoid the additional "embodied energy" and carbon emissions associated with new construction; and
- Preserve the symbolic, cultural, and historic capital of the original United Nations design.

As the project design progressed, and computer modeling was performed to quantify the projected operational energy savings, the UNCMP team decided that a similar investigation should be performed to quantify the embodied energy savings associated with the building preservation. In 2008, an embodied energy study was prepared, which focused on the critical high-mass structural, envelope, and interior wall materials that were retained within the UN complex. The results of these calculations established an approximate relationship between the facility's annual operational energy use and the embodied energy of the retained materials.

With recent climate change initiatives – particularly the time-based goals derived from the Paris Climate Agreement of 2015 - the UNCMP team realized there are broader and much more impactful implications to the relationship between "embodied" and "operational" energy and carbon. The goal of this report was to revisit the information that was prepared for the UN complex to more fully examine the carbon and climate change-related benefits of renovation versus an alternative of new construction.

II. Process

As noted above, the evaluation process required the use of energy modeling software, to estimate the annual energy use of the buildings, as well as life cycle assessment software, to estimate the embodied energy and carbon emissions related to the building construction.

The modeling tools used, DOE-2.2 software for the operational energy modeling, and the ATHENA Environmental Impact Estimator (v5.1) for Life Cycle Analysis, are readily available programs which are geared toward practicing engineering and architectural professionals. These tools, as used for this analysis, provide approximate results; as such we have noted assumptions and/or limitations for a number of the calculations provided.

Despite their limitations, we believe the tools provide a reasonable basis for comparing the relative magnitudes between operational and embodied energy/carbon quantities, which form the basis of our assessment. We believe that the results, while approximate, are still compelling, and reinforce similar studies that have been done by others in this general area of investigation[7].

A. Comparing Operational Energy/Carbon to Embodied Energy/Carbon

The relationship between the annual operational energy use of a facility and the embodied energy used to construct it has been a topic of consideration for many years. Surprisingly, however, there are few detailed studies to act as definitive reference points on the issue, and the stated relationship between the two quantities can vary significantly depending on the report or reporting tool being used. Much of this variation can ultimately be traced to the life cycle assessment (LCA)/embodied energy side of the analysis, as variations in the construction assemblies under consideration, and/or the capabilities and limitations of the LCA tool, can significantly influence the reported results. For the purposes of this report, we will clearly define what we have evaluated, and why.

This report reviews the relationship between operational and embodied energy/carbon in two ways:

- First, as a simple ratio that estimates the number of years of operational energy that equate to the embodied energy of the preserved building elements. A similar ratio will be established based on the operational versus embodied carbon emissions[8]. These numbers are informative in relation to other studies that have reported similar metrics, but ultimately have limited relevance to the purposes of this report.

- Secondly, following a process called the "Avoided Impacts" approach. This process is much more relevant to the UN Headquarters situation, as it more explicitly addresses the impacts of pursuing renovation versus new construction. In the Avoided Impacts approach, embodied energy and carbon are estimated for the demolition of the existing structure and for the proposed

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[7] Examples of related reports include "The Greenest Building: Quantifying the Environmental Value of Building Reuse" by the Preservation Green Lab of the National Trust for Historic Preservation, 2011, http://www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf and "The Total Carbon Study" by Ecological Building Network, Integral Group, and Siegel and Strain Architects, December 2015, http://www.siegelstrain.com/site/pdf/Total-Carbon-Study-final.pdf.

[8] The two sets of ratios (energy and carbon) need to be separately tracked – they will not typically be the same. See the Results section of this report for additional explanation on this issue.

construction of a new replacement structure[9]. This embodied energy/carbon is considered the "avoided impact" that is <u>not</u> spent if a renovation is undertaken. Under this assessment, if the new building uses less operating energy than the renovation (a reasonable assumption), a calculation can be performed to determine the number of years it takes for the new construction to "recoup" the initial embodied energy/carbon investment through its operational energy and carbon savings.

These two approaches are further reviewed in the Results section below.

Before the operational-to-embodied energy/carbon ratios can be analyzed, a description of the process to establish the two sets of numbers will be described.

B. Calculating the Operational Energy and Carbon of the Renovated Facility

As previously noted, the operational energy projections for the UNCMP complex were performed using the computer energy modeling software DOE-2.2. A detailed model was developed for the entire UN complex, including six connected buildings (General Assembly, Secretariat, Conference Building, South Annex Building, Dag Hammarskjöld Library, North Lawn Building) with a total area of approximately 2.6 million square feet.

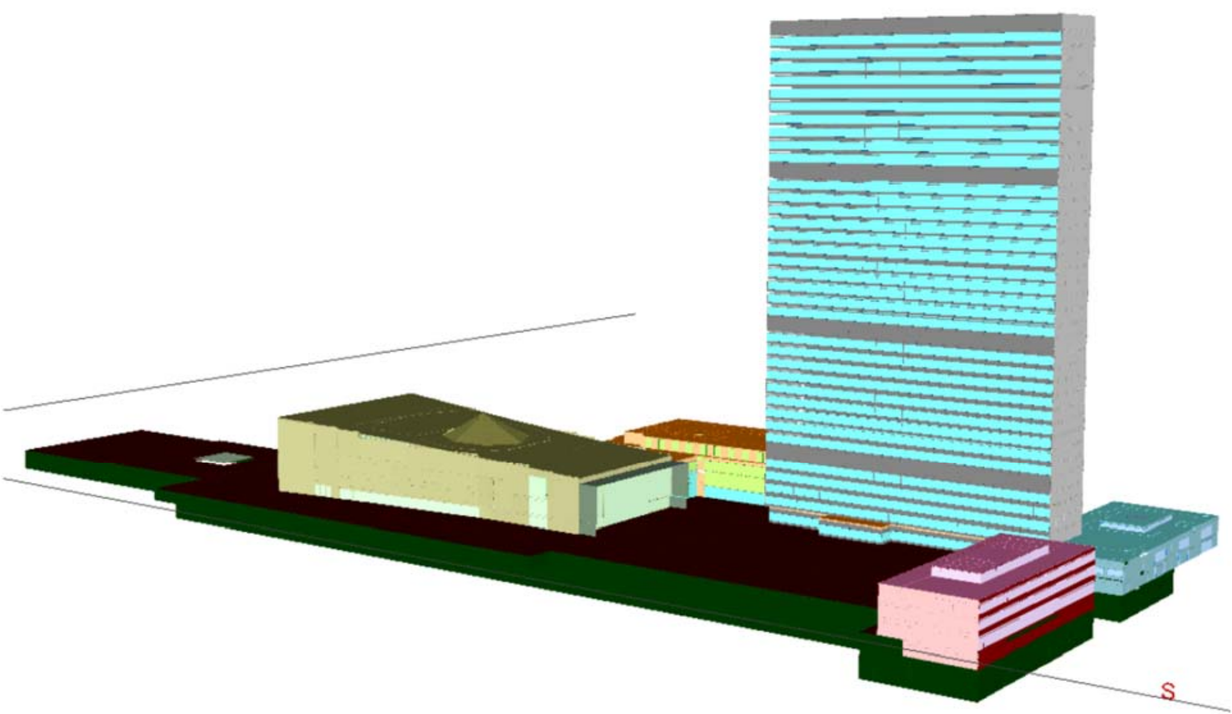


Figure 2: Image from United Nations Energy Model (Syska Hennessey Group)

While the structure and opaque envelope elements of the campus were retained, the majority of the fenestration and MEP systems were replaced, as well as fire protection, IT systems, and vertical

[9] For the UN Headquarters scenario, only the structural, opaque envelope, and interior core wall assemblies are modeled as the replacement structure. This is because new curtainwall, MEP, and interior partitions were included as part of the renovation scope; these elements are assumed to have essentially the same embodied energy impacts as the new construction.

transportation. Most of these systems had reached the end of their useful life, and were in need of replacement (some components, such as the curtainwall framing, dated back to the original 1949 construction).

Key energy efficiency measures (EEMs) implemented in the renovation included:

- New energy efficient curtainwall and storefront systems (framing and glazing) for the Secretariat, General Assembly and Conference Building.
- A new Chiller plant equipped with high efficiency electric chillers and water side economizer and variable flow chilled water and condenser water distribution.
- A new building management system with sequences of operation to maximize saving from unoccupied/occupied modes for space and night setback and temperature resets.
- Demand-controlled ventilation (using carbon dioxide sensors) to match ventilation to the occupancy requirements.
- Conversion to LED lighting for the parking garage and service drive areas.
- High efficiency lighting and lighting controls across the Campus.
- Air-side economizers incorporated into the majority of the air handling units on Campus.
- Water-side economizer coils incorporated into all computer room and telephone room cooling units.
- High efficiency electrical transformers used throughout the Campus.

The energy savings were reported using two major benchmarks. For LEED purposes (version 2.2) the "As Designed" renovations were predicted to achieve annual cost savings of 29.9% compared to the LEED baseline - standard ASHRAE 90.1-2004 (the 90.1 standard was equivalent to the New York State energy code at the time the project was designed). This was the equivalent of 8 LEED points under Energy & Atmosphere credit 1.

To meet the United Nations' project specific goals, the projected energy cost of the renovated facility had to be at least 50% lower than the measured actual operating costs of the pre-renovation facility. Using this benchmark, the modeled "As Designed" renovation demonstrated 51.7% savings versus the existing facility.

Key metrics for the facility's energy consumption, Energy Use Intensity (EUI), and carbon emissions are shown in **Table 1**, comparing the Existing Campus to the new As-Designed condition. Note that annual carbon emissions have been reduced by approximately 65%.[10]

For the purposes of this report, an additional adjustment was made to the "As Designed" energy use figures to make them more applicable to a typical office facility. The United Nations complex has two unusual "process" loads that increase its energy use over more typical offices – a very large on-site data center, and an on-site broadcasting studio. These unusually high loads, which represent approximately 6.2 million kilowatt hours of electricity use per year, have been removed from the operational energy to create a more broadly representative case study.[11]

[10] The UN has recently been tracking its actual post-renovation, post-commissioning utility bills compared to the "As Designed" projections. The actual usage is very similar to the projections; through the summer of 2016 the energy cost savings have been 51.3%, with carbon savings of 60%.

[11] Since neither the data center nor broadcasting facility loads would be impacted in a significant way by the building's architectural or structural design, they are not relevant to the operational versus embodied energy assessment of this report. Including them as part of the operational energy would, however, create an atypical situation where the operational energy was given more emphasis than in most facilities.

Table 1: Energy Consumption & Carbon Emissions at the United Nations Headquarters Facility

		Electricity	Steam	Natural Gas	Total	EUI
		kWh	1000 lbs	therms		
Units	As-Designed	35,226,636	43,878	16,202	n/a	n/a
	Existing Campus, 2006	44,532,840	399,183	16,202	n/a	n/a
		MBTU	MBTU	MBTU	MBTU	kBtu/sqft
Site Energy	As-Designed	120,193	50,196	1,620	172,010	66.4
	Existing Campus, 2006	151,946	456,665	1,620	610,232	235.4
		MBTU	MBTU	MBTU	MBTU	kBtu/sqft
Source Energy	As-Designed	382,816	83,661	1,701	468,178	180.6
	Existing Campus, 2006	483,948	761,109	1,701	1,246,758	481.0
		Lbs	Lbs	Lbs	Lbs	Lbs/sqft
Carbon	As-Designed	28,811,866	7,312,707	203,614	36,328,187	14,015
	Existing Campus, 2006	36,423,410	66,527,839	203,614	103,154,862	39,796

With the deductions noted above, the annual operational energy use for the "As Designed" renovation is as follows:

- Site: 150,960 MBTUs
- Source[12]: 401,134 MBTUs (155 kBtu/sqft)

From a carbon emissions standpoint, the total annual CO2 emissions were calculated to be:

- 31,282,224 lbs[13], or 14,189 metric tons.

[12] The Site-to-Source BTU conversions were as follows: Electricity – 3.185, Natural Gas – 1.05, Steam – 1.67.
[13] The CO2 emission conversions were as follows: Electricity – 0.818 lbs/kwh, Natural Gas – 12.567 lbs/therm, Steam – 166.66 lbs/1000 lbs steam.

C. Calculating the Operational Energy and Carbon of a Theoretical New Facility

Under the “Avoided Impacts” approach, the operational energy use of a theoretical new facility needs to be established to compare to the energy use figures modeled for the actual renovation. This is a sensitive part of this evaluation, since in the case of the United Nations Headquarters no new design was actually prepared.

While intuitively it seems that a newly constructed building would be more energy efficient than a renovated facility, the more relevant question is by how much. For the purposes of this study, the team used a combination of new energy modelling runs, team experience, and reviews of actual EUI reporting for similarly-sized high-rise commercial buildings in New York City to develop an estimate.

Energy modeling runs for the UN facility were developed to answer the following question: what energy efficiency measures were either prohibited or limited by the form, layout, or pre-existing conditions of the UN facility? These measures would likely represent the main differences between a new construction scenario and the actual renovation. The key measures identified and modeled were more limited than one might expect, and consisted of the following:

- Improved Wall Construction - Though the Secretariat curtainwall was fully replaced and far exceeds current codes, if the project had been built from scratch, many of the other wall constructions could have been improved by increasing their insulation values and reducing infiltration. For the modeling exercise it was assumed that all new constructions would meet the thresholds defined in ASHRAE 189.1.

- Fan Distribution Consolidation - The renovation attempted to consolidate air handlers and minimize ductwork, however, unlike most new buildings, most mechanical rooms were not stacked or laid out as efficiently as possible. It was assumed that new construction would lead to a reduction in duct runs and pressure loss, as well as offering better outside air distribution to the primary air handlers. It was determined that reductions of up to 20% in the total static pressure might be possible.

- Natural Gas Boilers – As a renovation, all of the infrastructure to utilize utility-provided steam was already in place; as a result, switching the heating source was not a practical option. If the project had been new construction, it was assumed that at the very least, it would have utilized high efficiency condensing boilers.

These modeling runs were aggregated and demonstrated an additional energy savings of 4.9% (source BTUs) from the already significant savings of the “As Designed” renovation.

It was also acknowledged that savings in new construction could be achieved through improved façade/glazing orientations, architectural massing, and lower window-to-wall area ratios[14]. Since a new

[14] The window-to-wall area ratio for the overall UN complex was just under 40%. Based on the team’s experience, many contemporary office/mixed use designs actually *exceed* this ratio, which would reduce their performance in this area compared to the UN design.

design was not available to demonstrate these elements, the team decided, based on experience, that these might add an additional 0-5% savings (source BTUs), depending on the design.[15]

While the above modeling represented the most controlled means of predicting additional savings, two supplementary checks were made to assess the energy performance between recently renovated buildings and new construction.

In the first check, the Vidaris team reviewed source EUI and carbon emission values from four high-rise New York City office buildings where the firm had performed energy modeling. The building sizes ranged from 1.4 million to over 2 million GSF. Two of the buildings were major renovations and two were new construction. As with the UN project, on-site data center loads were removed to prevent major variations based on significantly different process loads. The source EUIs values of the 4 buildings were as follows, ranked from lowest EUI to highest:

- Building 1 (Renovation): 113 kBtu/sqft
- Building 2 (New Construction): 166 kBtu/sqft
- Building 3 (Renovation): 179 kBtu/sqft
- Building 4 (New Construction): 186 kBtu/sqft

While there are potential variables among these buildings that would preclude making overly specific inferences, it can generally be seen that the renovations are not showing a disadvantage in energy performance compared to the new construction projects, and in some cases may even out-perform them.[16]

This general observation was also borne out by a review of actual measured EUI data submitted under New York City's Local Law 84. Twelve similarly-sized high-rise commercial buildings of varying ages were reviewed. As might be expected, this actual reported data varied considerably, since many of the key energy-impacting elements of the buildings were not normalized (e.g., the percentage of the building that is occupied, the hours of operation, the inclusion of data centers, trading floors, or other high intensity process loads). The reported EUIs ranged from 180 to 322 kBtu/sqft, with an average for the twelve of 242.

The main point of interest from this review was that of the four lowest reported EUIs among the twelve, two were pre-WWII buildings that had been renovated, and two were relatively new construction. The EUIs for these four buildings were very close, with the new construction buildings averaging a 2% lower EUI than the average of the two older renovated buildings.

While this actual reported data is not controlled enough to validate any specific inferences, it does reinforce the idea that renovated buildings, particularly of this size, tend to perform very comparably to new construction.

[15] While it is acknowledged that a theoretical new design *could* be assumed to be even more efficient, the authors decided it was more important in this study to assume current industry practices that could have been implemented at the same budget level as the actual renovation. A strategy to pursue renovations or new construction that achieves or comes close to achieving "net zero" performance is a promising approach for future consideration, but an analysis of the embodied energy and associated costs to achieve net zero is outside the scope of this report.

[16] It should also be noted that the average EUI from this group of buildings (161 kBtu/sqft) is within 4% of the source EUI (minus data center) calculated for the UN facility (155 kBtu/sqft).

Based on the above reviews it was decided that further energy use reductions of 5-10% (below the "As Designed" case) would be attributed to the theoretical new facility. The corresponding carbon reductions were also calculated from the available energy models – these were similar to the energy use reductions (although they tended to be at the lower end), and were therefore also defined as being 5 - 10% lower for new construction than for renovation.

D. Calculating the Embodied Energy and Carbon of the Renovated Facility

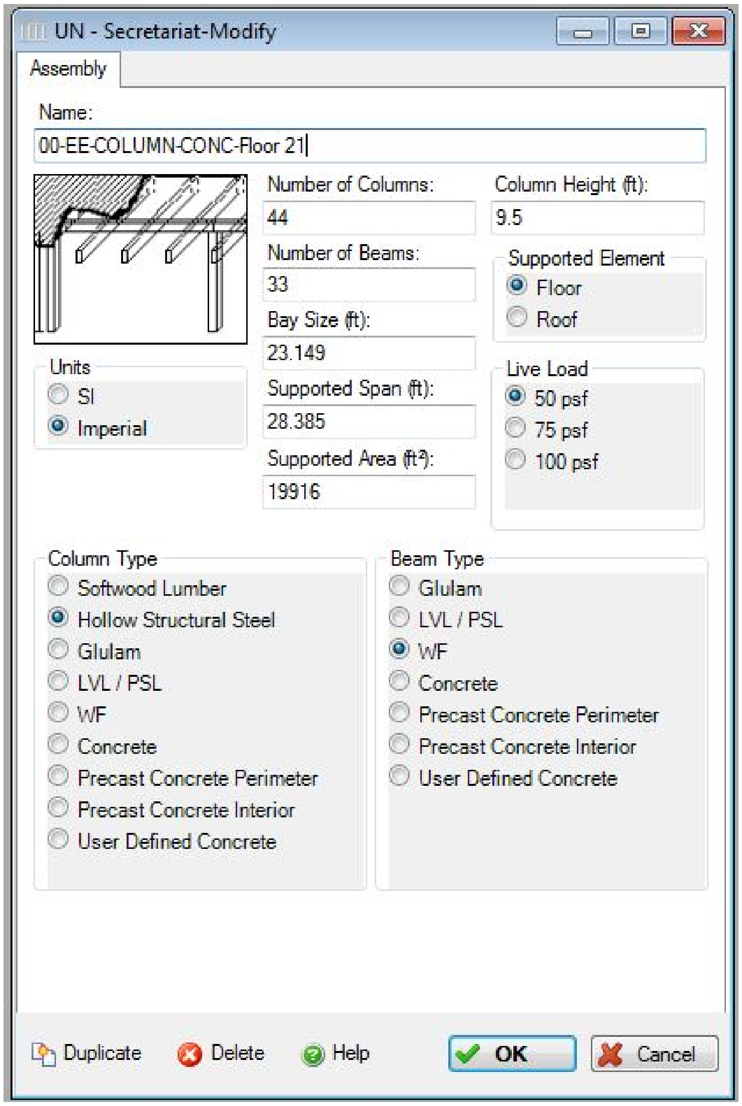
The embodied energy and carbon associated with the retained elements of the UN complex were evaluated using the ATHENA Environmental Impact Estimator software (referred to henceforth as ATHENA[17]). ATHENA allows users to "build" a simulation of their project by defining a set of structural and architectural construction assemblies[18]. The assembly types included are:

- Foundations (including footings and slabs);
- Beams and Columns;
- Floor and Roof Assemblies;
- Wall Assemblies (foundation walls, exterior walls, window or curtainwall areas, limited interior partitions); and
- Extra Basic Materials (a limited number of finishes and other basic construction materials that may need to be added to the other assemblies).

Within each basic assembly category, ATHENA defines a number of system options that represent common construction practices. The user defines the system type, the critical dimensions of the system, and a few other key characteristics to define the properties that ATHENA uses to perform its life cycle assessment. **Figure 3** below shows a sample input screen from ATHENA defining the columns and beams at a typical floor in the Secretariat building.[19]

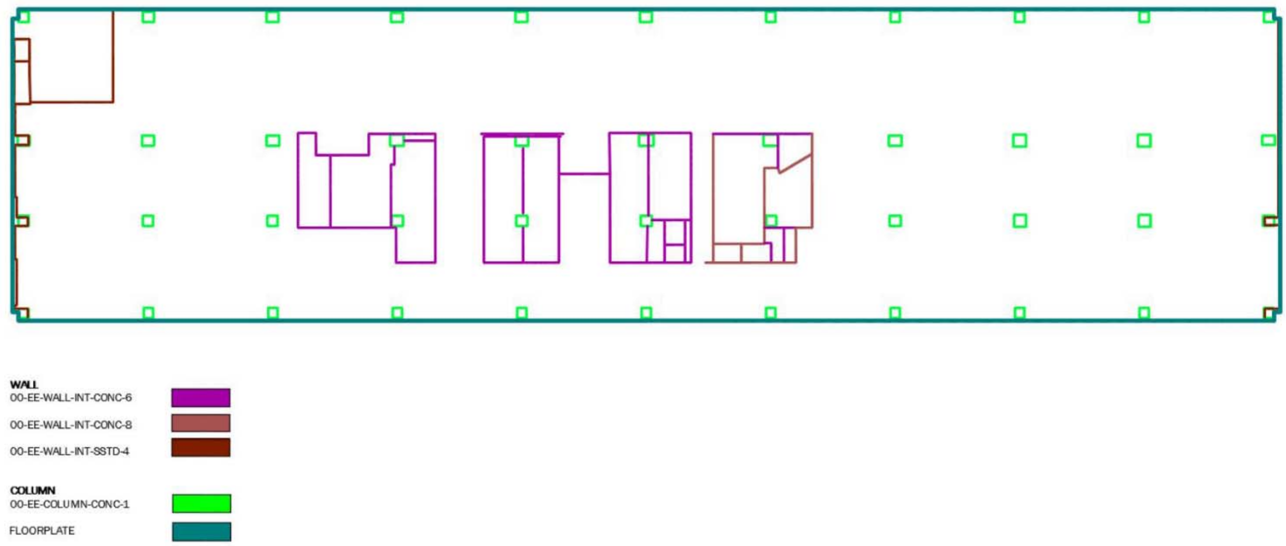
[17] The original modeling was performed in 2008 using version 3.0.3 of ATHENA. The modeling was redone as part of this report using ATHENA version 5.1, the most current version.
[18] ATHENA is limited to only structural and architectural components – mechanical, electrical, plumbing, fire protection, IT, security, and vertical transportation components are not part of the program.
[19] ATHENA was selected to perform the updated modeling as opposed to the TALLY plug-in module for AutoDesk's Revit software because BIM models were not available. At the time the UNCMP design work was performed, BIM modeling was not commonly used, and was not a project requirement.

Figure 3: Sample Floor System Entry Data for the Secretariat Building (Floor 21)



To estimate the overall embodied energy, the three largest and most diverse structures on the UN campus were modeled in detail – The Secretariat, the General Assembly, and the Basement floors (which connect the entire complex). In these structures, the preserved elements (primarily structure, core walls, and opaque envelope) were identified from the CAD plans; take-offs were calculated and entered into the ATHENA program. **Figure 4** shows a sample floor plan that highlights the elements tracked in ATHENA for a typical floor in the Secretariat.

Figure 4: Sample Floor Plan of Preserved Elements for the Secretariat Building (Floor 21)



Certain retained elements, such as egress stairways in all buildings and many of the interior partitions and finishes of the General Assembly, were not modeled due to software limitations and/or the complexities in estimating the material quantities. It was determined that these omissions were acceptable for the purposes of this report; the implication is that the embodied energy and carbon assumptions are slightly conservative.

Using the ATHENA results from the two above-grade buildings (Secretariat and General Assembly), an average was calculated for their BTU/SF and CO2e/SF impacts; these were then extrapolated for the areas of the remaining above-grade buildings in the UN complex (Conference Building, South Annex Building, and Dag Hammarskjöld Library).[20]

The results of the ATHENA modeling are summarized in **Tables 2 and 3** below:

[20] The above-grade areas of the Conference Building, South Annex Building, and Dag Hammarskjöld Library represent approximately 12% of the total campus area.

Table 2: Calculated Embodied Energy for the Preserved Elements of the UN Complex[21]

		Embodied Energy		
Building/Structure	**GSF**	**Product & Construction Process only (Stages A1 - A5) (MBTUs)**	**End of Life (Stages C1 - C4) (MBTUs)**	**TOTAL for all included Stages (MBTUs)**
Secretariat	805,225	198,465.93	11,510.33	209,976.25
General Assembly	251,560	60,865.21	3,531.58	64,396.79
Basements + Parking (entire complex)	1,231,300	216,690.61	14,562.31	231,252.91
Hammarskjold Library	60,000	14,652.71	850.00	15,502.71
South Annex Building	20,000	4,884.24	283.33	5,167.57
Conference Building	224,000	54,703.45	3,173.32	57,876.78
TOTALS	**2,592,085**	**550,262.14**	**33,910.86**	**584,173.01**

Table 3: Calculated Embodied Carbon for the Preserved Elements of the UN Complex

		Embodied Carbon Dioxide Equivalent (CO2e)		
Building/Structure	**GSF**	**Product & Construction Process only (Stages A1 - A5) (Metric tons)**	**End of Life and Beyond Building Life (Stages C1 - C4) (Metric tons)**	**TOTAL for all included Stages (Metric tons)**
Secretariat	805,225	16,256.40	830.76	17,087.16
General Assembly	251,560	5,253.20	260.36	5,513.56
Basements + Parking (entire complex)	1,231,300	19,310.80	1,067.20	20,378.00
Hammarskjold Library	60,000	1,232.13	62.00	1,294.13
South Annex Building	20,000	410.71	20.67	431.38
Conference Building	224,000	4,599.97	231.47	4,831.44
TOTALS	**2,592,085**	**47,063.21**	**2,472.46**	**49,535.67**

The implications of these numbers will be reviewed in the Results section below.

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[21] Note: All embodied energy and embodied CO2e results from ATHENA have been reduced by 8% to account for the program's use of primary energy in its reporting. Primary energy accounts for the energy required to extract, produce and transport the fuels used directly or indirectly in the various life cycle stages. The primary energy figures in ATHENA would exaggerate this report's comparison between embodied and operational energy/carbon, since the operational energy/carbon uses only source energy data. The 8% reduction was suggested by the ATHENA Sustainable Materials Institute as a reasonable correction factor.

E. Calculating the Embodied Energy and Carbon of a Theoretical New Facility

As with operational energy, it is difficult to estimate the embodied energy of a theoretical new facility, since no new design was developed. In this case, however, a relatively straightforward and conservative assumption has been made – the embodied energy and emissions that were calculated from the original UN facility design will be used to represent the new construction.

III. Results

The four sections below describe the comparisons that were targeted for this report.

Comparison 1a: Ratio of Operational Energy to Embodied Energy

The simple ratio that compares the annual operational energy of the UN complex to the embodied energy of the preserved building elements is calculated as follows:

550,262.14 MBTUs (calculated embodied energy for Product & Construction Process stages)

÷ 401,134 MBTUs/year (annual operational energy, source)

= **1.37 years**

Note that this number, on the surface, implies that operational energy dominates the comparison. While this is true as a general observation, the ratio is less relevant in assessing the merits of renovation versus new construction, as will be explained under Comparison 2 below.

Comparison 1b: Ratio of Operational CO2e to Embodied CO2e

A subsequent step in the comparison process is to address equivalent carbon dioxide (CO2e) emissions as opposed to embodied energy. The ratio of operational CO2e compared to the CO2e from the building construction will be different than the source energy ratio shown in Comparison 1a above. Some of the reasons for this are as follows:

- The emissions associated with the extraction and manufacturing stages of certain materials can be much higher than just the emissions associated with their embodied energy. Cement production, for instance, releases approximately as much CO2 to the atmosphere through calcination (a chemical reaction that occurs from heating limestone) as it releases due to its embodied energy. Since concrete is a major structural material, the impact from cement on emissions is significant.
- The electricity used for product processing and manufacturing can have a different CO2e emissions profile than the electricity purchased for the building operations. For example, per the EPA's eGrid database, the electricity produced for the New York City sub-region is primarily generated from natural gas and nuclear power plants (this is the electricity provided for the building operations). On a national basis, by comparison, over 35% of our electricity is produced from coal. Coal releases approximately 80% more CO2 per BTU of energy than natural gas. This means that materials produced in locations outside of the New York City sub-region are typically generating a higher percentage of CO2e for each kwh of electricity they consume.

- Mining and transportation of major materials involves the use of diesel-powered vehicles and equipment. Similar to coal, diesel fuels release approximately 38% more CO2 per BTU of energy than natural gas. This increases their impact in the overall operational-versus-embodied carbon analysis.

Using the data calculated from ATHENA, which accounts for the above issues, the ratio of the annual operational CO2e of the UN complex to the embodied CO2e of the preserved building elements is as follows:

47,063.21 metric tons (calculated embodied CO2e for Product & Construction Process stages)

÷ 14,189 metric tons/year (annual operational CO2e)

= **3.32 years**

Note that this ratio is over 2.4 times higher than the embodied energy ratio. While the number of years may still seem relatively low, these values will make a significant impact under the Avoided Impacts calculation shown under Comparison 2b below.

Comparison 2a: The Avoided Impacts Approach (based on Embodied Energy)

The Avoided Impacts approach provides the most relevant assessment of the merits of the United Nations campus renovation versus the approach that could have been taken – namely demolishing the complex and building new.

In the Avoided Impacts approach, the embodied energy is calculated for the demolition of the existing structure and for the proposed construction of a new replacement structure. This represents the “avoided impact” that is not spent if a renovation is undertaken.

This embodied energy value can then be compared to the potential improvement in energy efficiency obtained from building new. Ultimately, the number of years it would take for the new, more efficient building to “recoup” the embodied energy of demolition and new construction is defined.

As described in the Process section above, the relevant calculations were performed to make this comparison. When defining the level of energy efficiency improvement for a theoretical new construction, a range of between 5-10% was defined. The results are therefore presented with a range of efficiencies in **Table 4**:

Table 4: Number of Years to Recoup Demolition and New Construction Embodied Energy

Proposed Efficiency Improvement	Annual Operational Energy Savings (Source) (MBTUs)	TOTAL Demolition and New Construction Embodied Energy (MBTUs)	Years to Recoup Embodied Energy
5%	20,057	584,173.01	**29**
7%	28,079	584,173.01	**21**
10%	40,113	584,173.01	**15**

Comparison 2b: The Avoided Impacts Approach (based on CO_2e)

As noted in Comparison 1B above, the ratio of embodied carbon emissions to operational carbon emissions is significantly higher than the comparable embodied energy ratio. This results in a correspondingly longer time for the more efficient new building to recoup the initial CO_2e emissions associated with the demolition and new construction, as shown in **Table 5**:

Table 5: Number of Years to Recoup Demolition and New Construction CO_2e

Proposed Efficiency Improvement	Annual Operational CO_2e Savings (Metric Tons)	TOTAL Demolition and New Construction CO_2e (Metric Tons)	Years to Recoup CO_2e Emissions
5%	709.47	49,535.67	**70**
7%	993.26	49,535.67	**50**
10%	1,418.94	49,535.67	**35**

These calculations therefore suggest that had the United Nations decided to demolish their existing facility to build a totally new complex, it would likely have taken between **35 – 70 years** before they recouped the initial increase in CO_2e emissions they had caused. By renovating the facility instead, this large spike of almost 50,000 metric tons of carbon emissions was avoided, while the renovation still achieved 51.7% energy cost savings versus the pre-renovation facility.

IV. Conclusions

The purpose of this study was to quantify the environmental benefits inherent in the United Nation's decision to retain and renovate their existing New York City headquarters, as opposed to building a new complex. The results of this analysis present a number of timely implications, particularly in light of current climate action targets and an increased focus on reduced carbon emissions from the building sector.

Key implications from the analysis are noted as follows:

1. The carbon impact of demolishing an existing building and then replacing it with similarly-sized new construction is substantial – based on the UN example (mid-rise and high-rise commercial structures, fabricated primarily from concrete and steel) this impact is expected to be in the range of 40-45 pounds of CO_2e/GSF, and equivalent to the carbon released from approximately 3-5 years of building operations.
2. This initial CO_2e burden for new buildings works against the intent of current climate action plans, which are focused on significantly reducing total carbon emissions in the shortest practical time frame. These goals are being set at both the national level (the United States, in response to the Paris Climate Agreement, has committed to 26-28% GHG emission reductions below its 2005 level

by 2025) and at the local level (New York City has currently targeted an 80% reduction in GHG emissions below its 2005 level by 2050).

It should also be noted that “embodied” carbon emissions are often unaccounted for in municipal, state, or national carbon reduction plans and projections. Embodied energy and carbon are often considered scope 3 (or 4) emission sources that are not tracked. Having a better understanding of the embodied-versus-operational carbon emissions relationship may alter the goals, initiatives, and incentives within these plans.

3. The idea that new construction will easily recoup its initial carbon impact through more efficient operations cannot be justified in many cases. As this report indicates, unless a careful assessment has been made, it is more likely that the new construction will need three to seven decades before a balance point is achieved.

4. While renovations also have initial carbon impacts, particularly when they are substantial like the UN Headquarters renovation, these impacts can be more readily justified. Unlike building structures and some exterior wall assemblies, which can have useful lives of 50 - 100 years or more, most energy-related building systems such as glazings, HVAC equipment, lighting, electric, IT, and service hot water have much shorter service lives – typically in the range of 15 - 30 years. Replacements of this type are a necessary part of most building operations and maintenance plans, and with many of these systems the replacements provide opportunities to improve the building’s energy performance.

   In the example of the UN renovation, the energy savings due to the system replacements also represented a 65% reduction in annual CO2e emissions compared to the pre-renovation conditions. It was estimated (very approximately) that the embodied carbon emissions for the renovation work would be recouped in 5 years or less (see **Figure 1**).

5. One of the common projections in municipal, state, or national climate action plans is to increase the percentage of electricity provided through renewable energy resources, such as wind power and photovoltaics. This means it is likely over time that the carbon emissions from operational electricity will trend lower, and this will apply to all buildings, whether new construction or renovation. But while the operations-related carbon may trend down, the embodied carbon that was already spent remains a fixed, high number – with new construction having a much higher burden than renovations.

6. The additional environmental benefits of renovation are also substantial. The following list includes metrics for resource use, solid waste, air emissions, and water emissions that would have occurred had the UN decided to demolish the existing facility and building a similarly-sized new complex.[22]

   a. Resource Use: 487,800 tons
   b. Solid Waste: 97,320 tons[23]
   c. Emissions to Air: 1,030 tons
   d. Emissions to Water: 10,650 tons

[22] These numbers were generated from the ATHENA reports. The units have been converted to US tons.
[23] This number assumes significant recycling of the building demolition materials.

With all of the above implications, the impetus to preserve and renovate existing structures is demonstratively high. Undoubtedly there will be situations where new construction is warranted; however, in cases where renovation of an existing structure is feasible, a careful analysis should be performed to understand the full implications of the two options. As the example of the United Nations renovation indicates, it's more likely that new construction will require decades before it can recoup its initial carbon impacts, at a time when carbon emissions from the building sector are targeted to achieve increasingly greater reductions. In some cases the period of recoupment may even be greater than the projected service life of the new structure.

In many cases, the total investment that would be allocated to demolition and new construction (capital, materials, embodied energy, embodied carbon) may be better served if redirected to extensive energy efficiency and renewable energy measures within an existing building renovation – thereby minimizing the facility's operational energy use, carbon emissions, and operating costs. In the context of our current climate situation, this may be one of the timeliest and most important challenges for the development, design, and construction industries.