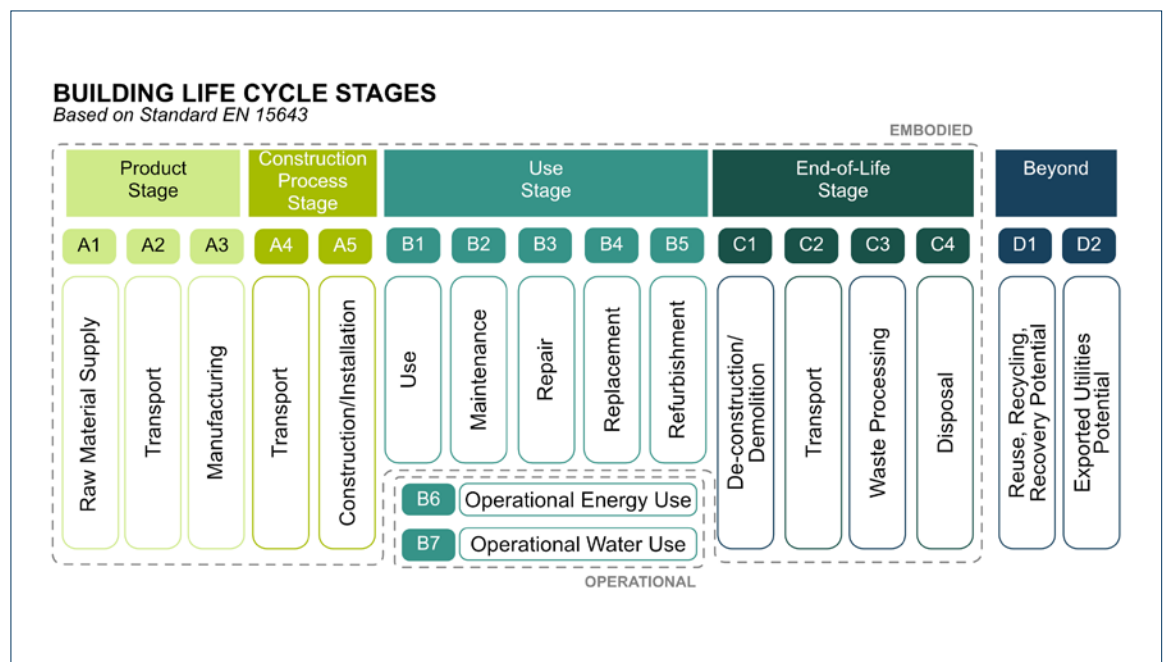


Quantifying Embodied Carbon in Preservation

LORI FERRISS

Fig. 1. Stages of the building life cycle indicating embodied and operational emissions boundaries. Graphic courtesy of the author.



The value of embodied carbon is an implicit concept in preservation. The practice of preservation is underpinned by the belief that there is embodied value—cultural, material, and historical—in the historic built environment. The embodied environmental value of a building that already exists is an extension of this thinking. However, the argument that old buildings should be preserved because of their embodied carbon is rarely grounded in data, which has hindered the uptake of preservation and building reuse more broadly as an important carbon reduction strategy in practice, planning, and policy.

Additionally, the field of preservation and conservation does not yet widely account for its own carbon footprint,

while others within the building industry are rapidly adopting this practice. Quantifying environmental impacts not only demonstrates the benefits of reusing what already exists, but it also enables the optimization of preservation practices to minimize the carbon footprint of our work in stewarding historic resources for the future.

Life cycle assessment (LCA) is the method used to quantify the cradle-to-grave environmental impacts of building design, construction, use, and end-of-life. LCA is increasingly used in design professions and required in public policies and building rating systems, and its use in the field of preservation can support the demonstration of the avoided carbon of reuse, as well as help

practitioners measure and reduce the carbon footprint of their work.

Overview of Life Cycle Assessment

LCA is a quantitative accounting methodology that predicts the environmental impacts of a material or assembly across its entire life cycle, from material extraction and manufacturing through use and end-of-life (Fig. 1). Fundamentally, a life cycle assessment takes an inventory of materials multiplied by the estimated environmental impacts of each material or process to estimate the total environmental impact of the object of study. While this article addresses embodied carbon, quantified as global warming potential, LCA can measure a wide range of environmental and even social impact categories. When this analysis is applied to many or all materials used in a building, it is referred to as whole-building life cycle assessment (WBLCA). As defined by ISO 14040, an international framework for life cycle assessment, the process of performing an LCA involves four steps:

Step 1: Goal and scope definition. Understand what the results of the assessment will be used for, and thus which materials, assemblies, and life cycle stages are important to include and to what level of detail. For example, is the goal to quantify the embodied carbon of a historical assembly, to evaluate two similar products, to assess the avoided impacts of reusing a building, or to calculate the embodied carbon of a preservation project? This stage involves defining the “functional unit.” For example, if an analysis compares a terra-cotta replacement unit with one made of glass-fiber-reinforced concrete, the functional unit would be one replacement unit rather than one kilogram of each material, because it would require different masses of each material to produce an equivalent decorative or cladding element. This step will identify the appropriate tools and data required to achieve the desired outcomes.

Step 2: Inventory analysis. Create an account of all the materials and activities that contribute to the scope defined in Step 1. This includes, but is not limited to, the bill of materials for the building or the portion of the building being evaluated. These quantities may be derived from design documents or BIM models, cost estimates, procurement documents, or other sources. This inventory may be challenging for some treatments—for example, in plaster restoration or masonry repointing, the exact quantities of materials will not be known until

the treatment is completed. However, a prediction of material quantities may be sufficient for the assessment goals defined in Step 1.

Step 3: Impact assessment. Calculate environmental impacts by applying environmental impact factors to the inventory created in Step 2. This step can be performed using tools that incorporate construction-industry life cycle impact data or manually, using open-source datasets. There are many sources of environmental impact factors for new materials. Data on historical materials and methods are less available and may require research to develop custom datasets or to approximate historical materials using contemporary data.

Step 4: Interpretation. Analyze and interpret the results to draw conclusions and address the goals defined in Step 1. This step yields the LCA findings, which will vary depending on the goal. For example, if the goal of the study was to compare alternative materials, this interpretation may involve assessing the impacts of each alternative across several environmental impact categories and incorporating this information into a larger decision-making framework that includes financial costs and other factors. If the study was meant to assess the carbon footprint of a preservation project, this step will involve reviewing the global warming potential from Step 3 and, if appropriate, identifying carbon reduction strategies.

LCA Data and Tools

An increasing number of tools are available to quantify embodied carbon in buildings. The environmental impact data underlying these tools, called life cycle inventory databases, come from three main types of sources. Publicly available embodied carbon databases, such as the Inventory of Carbon and Energy Database, enable users to manually perform LCA using the embodied carbon factors for materials within the database.¹

While these databases are not focused on preservation materials, they offer a wide range of typical construction materials that can often represent materials used in preservation work. Another source is proprietary databases held by environmental consulting or software companies. These are typically accessible only to practitioners through paid LCA tools and share similar limitations regarding data on preservation materials. The last source is Environmental Product Declarations (EPDs), which are LCAs that predict the environmental

KEY TERMINOLOGY

Embodied carbon: in the building industry, this refers to the greenhouse gas emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building materials.²

Functional unit: a description of the object of assessment defined using a set of objective criteria.³

Global warming potential (GWP): developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of the amount of energy that the emissions of 1 ton of a gas will absorb over a given period, relative to the emissions of 1 ton of carbon dioxide (CO₂).⁴

Life cycle assessment: a tool that can be used to evaluate the potential environmental impacts of a product, material, process, or activity. An LCA is a comprehensive method for assessing a range of environmental impacts across the full life cycle of a product system, from materials acquisition to manufacturing, use, and final disposition.⁵

Operational carbon: the greenhouse gas emissions due to building energy consumption.⁶

impacts of individual products or assemblies, published by manufacturers in accordance with standardized product-category rules.⁷ Data from EPDs are readily accessible, and a rapidly increasing number of products have EPDs; however, these data are available only for a subset of construction materials, and even fewer for preservation materials.

As with databases, there is a growing number of tools available to practitioners. A curated set of tools designed specifically for, or applicable to, historic buildings is presented here.

The most comprehensive tools for LCA of built structures are whole-building life cycle assessment (WBLC) software, such as Tally and One Click LCA.⁸ These tools use a bill of materials for a whole building (or specified assembly), which can be derived from a BIM model. They apply environmental impact factors to each material quantity defined in the model, enabling the capture of environmental impacts of large and complex systems, such as entire buildings. The environmental impact data come from a combination of proprietary databases and EPDs and thus share the same gaps in preservation-specific materials noted previously. Other tools, like the Embodied Carbon in Construction Calculator (EC3), use EPDs as their sole source of data.⁹

Carbon estimating tools offer a less granular approach to approximating a building project's carbon footprint. The Carbon Avoided: Retrofit Estimator, also known as the CARE Tool, is a free online tool launched in 2022 by

Architecture 2030 to estimate the total carbon emissions of reusing existing buildings compared to replacing them with new construction.¹⁰ Currently, only data for projects located in the United States are available; however, the tool can still be used to estimate emissions from projects around the world. C.Scale is a whole-life carbon platform that allows users to explore the environmental implications of a range of design decisions, including construction and sitework impacts.¹¹ These tools are most appropriate for the early design and planning stages, or to inform high-level advocacy.

STiCH, or Sustainability Tools in Cultural Heritage, is a carbon calculator and a library of case studies designed to help cultural heritage professionals make informed, sustainable choices that reduce the environmental impact of their work.¹² This calculator is unique because it focuses solely on material conservation and includes data on highly specialized materials, such as cleaning agents.

LCA in Preservation

A history of the application of life cycle assessment concepts in the field of preservation is documented in “Measuring the Capital Energy Value in Historic Structures” by Erika Hasenfus.¹³ In this thesis, the author contextualizes the argument often employed by advocates for historic preservation that the greenest building is the one that already exists. The paper identifies an important shift in discourse that has occurred in the 2000s from the concept of embodied energy, which values existing

buildings for the energy needed to create them, to the concept of avoided energy or emissions, which treats the embodied energy of existing buildings as a sunk cost and instead focuses on the extent to which future emissions can be reduced through the reuse of existing buildings.

“The Greenest Building: Quantifying the Environmental Value of Building Reuse,” published in 2012 by the National Trust for Historic Preservation Green Lab, is one of the seminal studies that uses LCA to compare the carbon emissions of historic building reuse with those of new construction.¹⁴ This approach was advanced in the study “Understanding Carbon in the Historic Environment” by Historic England in 2019.¹⁵ The concept has also gained traction with public advocacy, for example, in the surge of activism opposing the demolition of the Marks & Spencer Oxford Street store in London on the grounds of environmental and heritage impacts.¹⁶

A smaller number of discrete studies evaluate the applicability of LCA to building conservation techniques. For example, one study used LCA to assess the environmental impacts of a range of cleaning approaches commonly employed in heritage conservation in Italy, underscoring the importance of measuring the environmental impacts of preservation activities.¹⁷

While LCA of buildings is becoming more common, the practice remains biased toward new construction. Embodied carbon studies of refurbishment rely on LCA studies of new buildings and associated data, whereas refurbishment-specific LCA studies remain less common.¹⁸

There remains no single standardized approach to LCA in preservation, and data and tools remain biased toward new construction. Emerging methods from different regions propose a range of approaches that differ on several major points. Variations include whether to include impacts from enabling demolition, use-stage impacts of existing versus new materials, and end-of-life impacts for both existing and new materials, which carry a high level of uncertainty.¹⁹

Recommended Approaches to Quantifying Embodied Carbon in Preservation

The first step in calculating the embodied carbon for any project is to identify the purpose of the assessment. When applying LCA to preservation, this purpose may be to identify the embodied carbon within existing fabric; to quantify the embodied carbon of a material, treatment, assembly, or whole-building preservation approach; or

to demonstrate the avoided emissions from the reuse of existing fabric compared to replacement with new.

The first approach—quantifying the embodied carbon of existing fabric—is primarily an academic exercise because the embodied carbon in existing materials is a sunk cost. Embodied emissions have already occurred when those materials were created and installed, and no action taken now will affect those historical carbon emissions. It may, however, be instructive to understand the magnitude of these historical emissions to put past carbon investments for creating the existing built environment into perspective, or to inform low-carbon approaches in the present and future. One note is that embodied carbon data for historical and construction materials are typically not readily available; therefore, this type of analysis either requires developing such data or making assumptions about the margin of error associated with using contemporary materials information.

The second approach is useful for understanding the environmental impacts of preservation and for reducing its carbon footprint. With this approach, the assessment calculates the embodied carbon associated with the use of new materials on existing fabric. This could range from materials required for plaster repair and chemicals used to clean historic finishes to all materials, including structural elements, used in preserving a whole building. With this approach, one can both calculate the embodied carbon of the preservation approach and compare alternatives to develop less carbon-intensive alternatives.

Another parameter to define in this type of study is which life cycle stages are considered. Stages A1–A3 may be adequate if the upfront material impacts are the primary concern, for example, when comparing options for a material or a simple assembly. Alternatively, if energy use and operational emissions are important considerations for a project, a full cradle-to-grave assessment may be appropriate; this integrates use-stage carbon (results of energy modeling) with embodied carbon to understand full-life environmental impacts.

The third approach—calculating avoided emissions from reuse relative to replacement—is effective for generating data to integrate preservation into climate planning, policy, and decision-making. For this analysis, two LCAs are required: the new materials required to reuse a material, assembly, or building are analyzed and compared with those required to replace the same

system. With this approach, it is critical that the scope of what is being reused is comparable to that of what is being replaced, and that the functional unit is equivalent. This means that the existing and new buildings may not be identical, as contemporary construction standards and space-use needs may differ from those of the historic building. For example, consider a historic office building constructed of mass masonry and heavy timber with low floor-to-floor heights. If that building were modernized, it might be insulated, it would likely require structural upgrades, and it would almost certainly receive new interior finishes; the materials required for reuse would be accounted for in the LCA of the reuse. If that building were replaced with a new office building, it might have a higher floor-to-floor height and use a steel or concrete structure; the embodied carbon of all the materials that comprise this functionally equivalent contemporary building is an appropriate object of study for the comparative LCA.

Case Study: Retrospective LCA of a Campus Renovation

The recent renovation of the Alan and Sherry Leventhal Center at Boston University is a case study in applying LCA to the renewal of a historic building, demonstrating the climate benefits of preservation. The International Style building was purpose-built as a Hillel House—a center for Jewish student life—in 1953 and is in an Architectural Conservation District in Boston, Massachusetts (Fig. 2). The building was transformed into an admissions center through a rehabilitation project in 2014. While the façade was primarily preserved, the renovation included a glass addition to enhance transparency and create a connection to the river to the north, as well as a complete reconfiguration of the interior. The building envelope was upgraded by applying mineral wool insulation to the interior faces of all exterior walls, replacing all glazing with new high-performance systems, and installing new, efficient mechanical systems. Overall, the project transformed the existing building and reduced annual energy use by a predicted 70 percent while preserving 86 percent of the existing envelope and primary structure (Fig. 3).

To quantify the total carbon impacts of the renovation, a WBLCA was conducted using Tally software. Tally extracted material quantities from a BIM model of all the new materials added to the building envelope, structure, and interior through the renovation and calculated



Fig. 2.
Hillel House, Boston University, 233 Bay State Road, Boston, Massachusetts, built 1953. Photograph courtesy of Boston University, ca. 1960.



Fig. 3.
Alan and Sherry Leventhal Center, Boston University, rehabilitated admissions center, 2014. Photograph courtesy of Goody Clancy, © Anton Grassl/ESTO.

the environmental impacts using the tool's built-in proprietary database. The calculated embodied carbon footprint was just under 270,000 kgCO₂e, representing a 70 percent reduction relative to the equivalent standard new-construction baseline (Fig. 4). In other words, reusing the building rather than replacing it avoided emissions equal to driving 1.5 million miles in a passenger vehicle.²⁰

In addition to quantifying the avoided impacts of the reuse compared to replacement, the LCA is also valuable in identifying where embodied carbon reductions could have been achieved within the renovation (Fig. 5). For this project, new structure and structural reinforcing represented the single largest contribution of embodied

carbon, largely due to site work and additions. Insulation represented approximately 10 percent of the project’s carbon footprint. Further study indicated that substituting a bio-based insulation material, such as wood fiber, for the installed mineral wool could reduce the project’s overall embodied carbon by up to 11 percent through carbon storage.

While the embodied carbon savings are significant in themselves, their value is enhanced by the fact that most of these avoided emissions occur before the building is occupied, when dramatic emissions reductions are most needed. This illustrates the concept of the time value of carbon. Analysis shows that the renovation yields a four-year carbon “payback”: the carbon cost of the renovation is recouped through operating efficiencies after just four years, while the new building results in higher total carbon emissions than the renovated building through at least 2050, even with more efficient energy use (Fig. 6). Given the 2030 climate goals necessary to avoid irreparable damage to the planet, this long-term carbon payback does not serve our most critical interests as well as the more immediate benefits of existing building reuse.

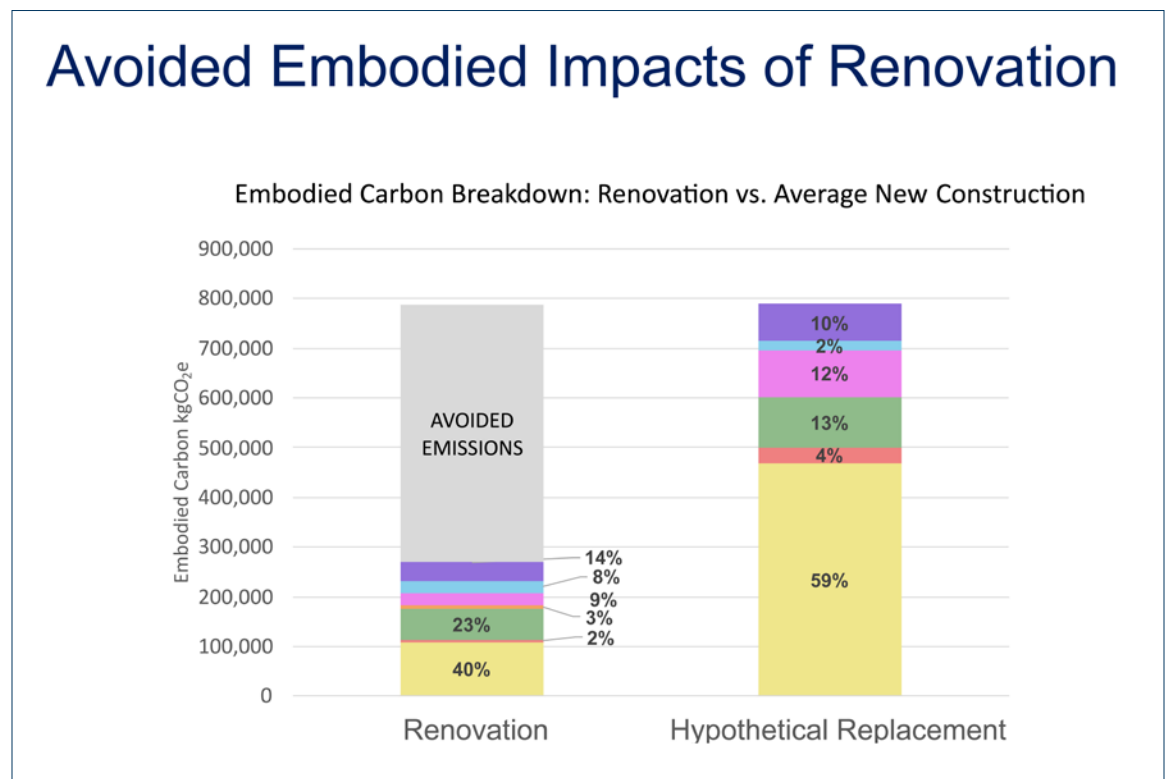
While this example was sufficiently comprehensive to yield valuable outcomes, there were gaps in the analysis of preservation treatments. For example, the embodied carbon associated with repointing and cleaning the stone masonry cladding was not included, and there remain relatively few high-quality data to support incorporating this scope into WBLCA. Collaboration between the trades, industry, and design and preservation practitioners is needed to continue the development of preservation-focused environmental impact data.

Conclusions

While significant gaps remain in LCA data and tools for existing buildings, LCA is a powerful and necessary approach for measuring and reducing the environmental impacts of preservation. The tools and datasets available are adequate for evaluating many preservation projects, and further use of LCA in preservation is needed to drive the continued development of field-specific data.

Preserving historic structures both reduces embodied carbon emissions by using less material than new construction and offers the opportunity to dramatically reduce operational emissions through improved energy

Fig. 4. Embodied carbon of the renovation compared to the embodied carbon of replacement construction based on benchmark data. The difference between the two is referred to as the avoided emissions associated with reuse. Graphic generated by the author based on Tally outputs, courtesy of Goody Clancy.



RELATIVE CARBON IMPACTS OF NEW MATERIALS

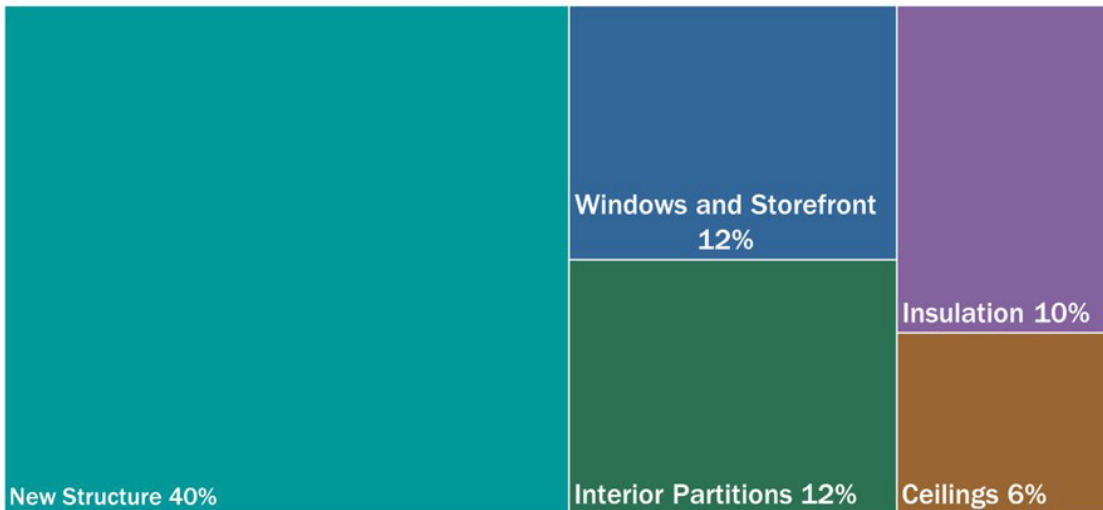


Fig. 5. Proportion of the embodied carbon contributions of different systems within the renovation. Graphic generated by the author, courtesy of Goody Clancy.

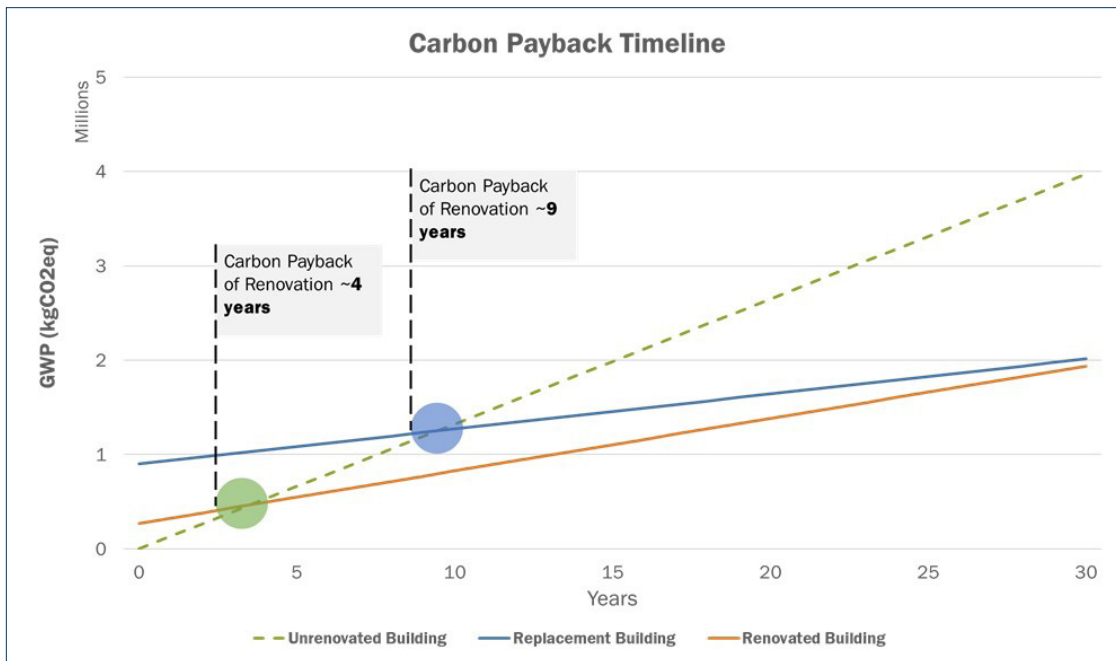


Fig. 6. Carbon payback timeline illustrating the cumulative emissions of the existing building with no intervention, the renovation as executed, and a hypothetical replacement building with 15 percent higher efficiency than the reuse. The unrenovated and renovated building lines cross at four years, indicating the earliest payback, while replacement shows higher emissions than renovation throughout the timeline. Graphic generated by the author, courtesy of Goody Clancy.

efficiency and the use of cleaner fuel sources. Additionally, the avoided emissions of reuse save carbon in the critical near term, which is the timeframe that matters as we look to mitigate the impacts of climate change. The use of life cycle assessment methods enables preservation practitioners to quantify the climate imperative of building reuse and to demonstrate the environmental value of historic buildings as a co-benefit of their cultural value, which is central to the field.

Lori Ferriss is a professional architect, structural engineer, and conservator whose work combines broad policy development with deep technical insights to promote a culturally and environmentally sustainable world through design. She is a national leader in applying whole-building life cycle assessment to quantify the environmental benefits of building reuse. Lori can be reached at lori@builtbuildings.org.

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