Life Cycle Assessment Report

Measuring Embodied Carbon in Value-Add Real Estate Investing Compared to New Construction

Johns Hopkins University 21st Century Cities
Hegemon Consulting

Sponsored by ABR Capital Partners

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Literature Review and Life Cycle Assessment Report

The present document provides a summary of the literature on the carbon footprint of multifamily renovation and reports on life cycle assessment (LCA) results of three value-add real estate investment projects that represent various types of property improvement and renovation strategies.

Building renovation can be broadly categorized into three groups: adaptive reuse, retrofitting (including deep retrofitting), and minor renovation. Adaptive reuse involves repurposing an existing building for a different new function through significant spatial transformation, along with major upgrades to the building envelope and systems. In contrast, standard and deep retrofitting focuses on building performance improvement, particularly energy efficiency, through targeted interventions in the building envelope and systems (e.g., adding insulation, replacing windows, and HVAC system upgrades), while maintaining the building's original function. Minor renovation entails limited modifications that do not change the building's function but enhance its livability and aesthetics through repainting, envelope repair, or fixture replacement. Among these, adaptive reuse generally offers the greatest potential for both embodied and operational carbon savings, while retrofitting – especially deep retrofitting – is primarily intended to reduce energy use and associated operational carbon.

1. Multifamily Sector: Housing Supply and Carbon Footprint

The increasing frequency and severity of climate change-induced natural disasters, such as hurricanes, wildfires, heatwaves, and flooding, have augmented the urgency to reduce carbon emissions across all sectors of the economy. In the building sector, the expected growth of residential and commercial floor areas, driven by population dynamics and urbanization, combined with current patterns of building energy use and greenhouse gas emissions, underscores the urgent need for decarbonization. Buildings are responsible for 37-43% of global greenhouse gas (GHG) emissions, with 28% of emissions being associated with building energy use, referred to as operational carbon, and 9-15% of GHG emissions related to building materiality and construction (e.g., building material manufacturing, construction, maintenance, demolition, and related transportation), referred to as embodied carbon [1].

The United States is currently experiencing an estimated housing shortage of 3.85 million units [2]. To address this deficit and meet the future needs driven by population growth and evolving market dynamics, it is projected that an average of 1.6 million new single-family and multifamily housing units will be initiated annually over the next decade [3]. Given the average size of a US housing unit is 1,818 square feet [4], this translates to an annual addition of roughly 2.9 billion square feet of residential space – totaling 29 billion square feet between 2024 and 2034. With multifamily housing accounting for 27% of the market share [5], approximately 7.83 billion square feet of new multifamily housing is expected to be delivered during this period through both new construction and adaptive reuse projects. This presents a strategic opportunity to reduce the carbon footprint of the residential sector, especially because multifamily is the most embodied carbon-intensive segment of the residential sector [6]. Notably, post-pandemic trends in office space downsizing have created substantial potential for converting non-residential buildings into housing. In 2023, 151,000 apartment units were under development via adaptive reuse – primarily office-to-housing conversions - marking a 24% increase over the previous year [7]. These projects now contribute approximately 10% to the projected annual housing supply, underscoring their growing role in addressing the nation's housing needs. Moreover, renovation and adaptive reuse offer a valuable pathway for reducing both embodied carbon - primarily through material conservation - and operational carbon, particularly when renovation scope extends to envelop retrofitting.

2. Energy Savings of Multifamily Renovation

Comprehensive energy-efficiency retrofits in multifamily housing across the United States present a substantial opportunity to reduce energy consumption and utility costs. Reported whole-building energy savings from multifamily retrofitting vary from 15-30% savings suggested by the American Council for an Energy-Efficient Economy (ACEEE) [8], to 22% by the New York State Energy Research and Development Authority's Multifamily Performance Program [9], 24% by the U.S. Department of Housing and Urban Development [10], and 38% by California's Low-Income Weatherization Program for Multifamily Properties [11]. In Europe, reported energy savings through multifamily retrofitting vary between 45% and 70% [12]. Liu et al [13], for instance, report 50% savings in energy use and 48% in associated carbon emissions in multifamily retrofitting in Sweden. ACEEE suggests that targeted improvements focused on space and water heating account for over 62% of potential energy savings, followed by lighting upgrades (21%), efficient air conditioning (10%), and energy-efficient appliances (6%) [14]. According to ACEEE, the energy-efficient renovation interventions in multifamily housing can result in an estimated $3 billion in utility cost savings nationwide, underscoring the economic and environmental value of investing in energy-efficient retrofits for multifamily housing [8].

3. Embodied Carbon Savings of Multifamily Renovation

The Carbon Leadership Forum (CLF) has proposed three benchmark levels for embodied carbon intensity in multifamily housing, intended to serve as reference points for future regulatory compliance. CLF recommends 520 kg CO2-eq/m2 as the maximum embodied carbon budget for new multifamily construction projects. It also establishes 390 kg CO2-eq/m2 and 320 kg CO2-eq/m2 as additional benchmarks, providing the construction industry with reference points to measure and reduce embodied carbon intensity. CLF also suggests that major renovations with new additions, on average, save 160 kg CO2-eq/m2 in embodied carbon intensity compared to new construction projects. Minor renovations' embodied carbon intensities are reported to be 60 to 210 kg CO2-eq/m2 lower than major renovations and new construction projects, respectively. Literature also documents the embodied carbon savings of adaptive reuse projects. For instance, Hasik et al. [15] reported 75% savings in embodied carbon in the adaptive reuse of a beer bottle planting facility in Philadelphia converted to an office building. Hu et al [16] suggest that the thermal envelope retrofitting and replacement of windows, floor, and roofs in an adaptive reuse of a historic school building converted into a medical facility saved 82% in embodied carbon compared to new construction.

4. Life Cycle Assessment of Three Multifamily Renovation Projects

We conducted Life Cycle Assessment (LCA) on three renovation projects owned by investment funds sponsored by ABR Capital Partners. These projects include 21st Street Lofts, The Forum Apartments, and Riverfront Village Student Housing. The scope of renovation in these projects ranged from full adaptive reuse and major conversion in the case of the 21st Street Lofts project, to window replacement, painting, and floor finishing in the Forum Apartments, to minor renovation, including repair with minor cladding replacement in the case of the Riverfront Student Housing project. For each project, we conducted the LCA under two scenarios of 25-year and 60-year service life. The LCA scope included new materials used in the project renovations. New materials were estimated based on architectural and structural drawings and other project information. The existing materials from previous projects were outside the scope of LCA as they didn't entail additional embodied carbon. A full life cycle LCA (i.e., cradle to grave and beyond) was conducted. Specifically, raw material extraction, manufacturing, construction, future demolition, potential recycling and reuse, and associated transportation across the stages were included for new materials used in these projects. Operational energy and water use were excluded from LCA. Tables 1.1, 1.2, 2.1, 2.2, 3.1, and 3.2 report project information and LCA scopes. Tables 1.5, 1.6, 2.5, and 2.6 report bill of materials included in the LCA assessment of these projects.

LCA Results: We report the results for 9 environmental impact categories, including embodied carbon, acidification potential, HH particulate matter, eutrophication potential, ozone depletion potential, smog formation potential, total primary energy (embodied), non-renewable energy, and fossil fuel consumption. A summary of results is reported in Table 1. More detailed results for both total and intensity (i.e., per square meter of floor area) values and per life stage (including product, construction, use, end-of-life, and beyond life) are reported in Tables 1.3, 1.4, 2.3, 2.4, 3.3, and 3.4. The 60-year embodied carbon intensity (per square meter of floor area) in these three projects ranges from 0.69 kg CO2-eq per m2 in the Riverfront Village Student Housing to 38 kg CO2-eq per m2 in the Forum Apartments, to 13 kg CO2-eq per m2 in the 21st Street Lofts. In addition, the 25-year embodied carbon intensity in these three projects ranges from 0.49 kg CO2-eq per m2 in the Riverfront Village Student Housing to 21 kg CO2-eq per m2 in the Forum Apartments, to 118 kg CO2-eq per m2 in the 21st Street Lofts. To put it in perspective, the Carbon Leadership Forum (CLF) suggests a median embodied carbon intensity value of 390 kg CO2-eq per square meter of floor area as a benchmark for multifamily housing new construction projects.

Table 1. Summary of LCA Results for Three Projects.

Project and Location	**Type**	**Size** (ft2)	**Scope**	**25-year Embodied Carbon Intensity** (kg CO2-eq per m2)	**60-year Embodied Carbon Intensity** (kg CO2-eq per m2)
21st Street Lofts Chicago, IL	Residential	78,477	Adaptive reuse. Conversion of the parking garage building to multifamily housing	118	132
The Forum Apartments Cincinnati, OH	Residential	284,762	Renovation including window replacement, painting, floor finishing.	21	38
Riverfront Village Tuscaloosa, AL	Residential	180,075	Renovation including replacement of 10% of cladding, and envelope repair/painting without window replacement.	0.49	0.69

Benchmarks for comparison:

- Carbon Leadership Forum (CLF) suggests a median embodied carbon intensity of 390 kg CO2-eq per square meter of floor area for multifamily housing new construction projects.
- 1 liter of gasoline that is burned emits 2.3 kg CO2-eq of emissions.

5. Conclusions

The embodied carbon associated with renovation projects can vary considerably depending on the scope and intensity of the intervention. Among the three multifamily case studies analyzed in this work, the highest embodied carbon intensity—132 kg CO2e/m2 over a 60-year lifespan—was estimated for the 21st Street Loft project. This project represents mid-rise adaptive reuse projects with a 25% floor area expansion, contributing to its relatively high embodied carbon. However, as illustrated in Figure 1, this project still achieved a 67% reduction in embodied carbon compared to the new construction benchmark defined by CLF. Although operational energy data were not available for this case, substantial reductions in operational energy use and associated emissions are anticipated relative to the building's pre-renovation condition. In contrast, the Riverfront Village Housing project exhibited the lowest embodied carbon intensity at just 0.69 kg CO2e/m2. This mid-rise renovation involved minimal interventions—primarily envelope repainting and replacement of 10% of the façade—resulting in negligible embodied carbon contributions. However, due to the limited scope of upgrades, no significant improvements in operational energy performance are expected. Finally, the Forum Apartments project represents a moderate renovation, including window replacement, painting, and floor finishing. These interventions resulted in an embodied carbon intensity of 38 kg CO2e/m2—approximately 90% lower than that of new construction. Notably, the window replacement is likely to yield meaningful operational energy savings and utility cost reductions, although specific performance data were not available.

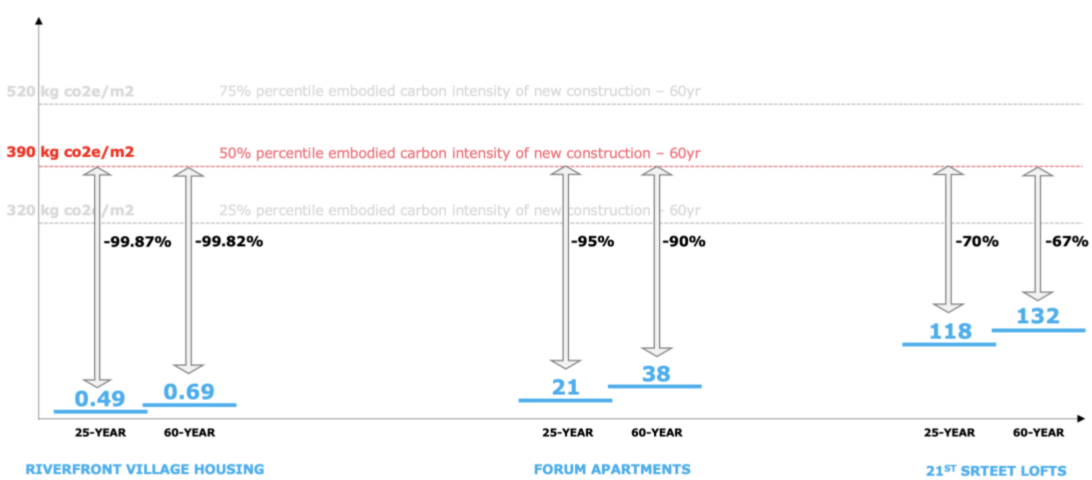

Figure 1. Savings in embodied carbon in three renovation projects.

APPENDIX A: DETAILED METHODOLOGY AND RESULTS

1. PROJECT: 21ST Street Loft Building (Chicago, IL)

In this section, we explain the details, scope, and results of Life Cycle Assessment (LCA) for the 21st Street Loft Building project in Chicago, IL. The results are presented in Section 1.2.

Table 1.1 Project information: The 21st Street Lofts.

<table>
<tr><td colspan="4">Project: 21st Street Loft Building (Chicago, IL)</td></tr>
<tr><td colspan="2">Building Use</td><td colspan="2">Multifamily Housing, Parking</td></tr>
<tr><td colspan="2">Location</td><td colspan="2">Chicago, IL</td></tr>
<tr><td>GFA – A2</td><td>78,477 Ft2 (7,290.75 m2)</td><td>No. of Floors below grade</td><td>0</td></tr>
<tr><td>GFA – H3</td><td>18,791 Ft2 (1,745.74 m2)</td><td>No. of Floors (before renovation/addition)</td><td>5</td></tr>
<tr><td>Total GFA:</td><td>97,268 Ft2 (9,036.50 m2)</td><td>No. of Floors (after renovation/addition)</td><td>6</td></tr>
<tr><td colspan="2">Type of Construction</td><td colspan="2">Adaptive reuse. Conversion of the existing 5-floor parking garage building to multifamily housing while reusing and renovation the structure and enclosure and adding a 6th floor.</td></tr>
<tr><td colspan="4">Project description: 21st Street Loft building is an adaptive reuse project that is converted from an existing 5-floor parking garage building to a multifamily housing unit. The project involves renovation and adaptive reuse of the existing building as well as addition of one floor (18,673 SF). The new exterior wall layers (from inside to outside) consist of gypsum board (2), R-13 batt insulation between metal studs, gypsum board X type, house wrap, R-5 rigid board insulation, and fiber cement hardie board siding. The renovated wall layers include (from inside to outside) consist of gypsum board (2), 6-mil vapor retarder, R-13 batt insulation between metal studs, R-5 rigid board insulation, and existing masonry.</td></tr>
<tr><td colspan="2">Project documents used for material take off and LCA assessment</td><td colspan="2">Architectural and structural drawings</td></tr>
<tr><td colspan="2">Project development stage when assessment was conducted</td><td colspan="2">☐ Schematic Design ☐ Design Development
☐ Construction Docs. ☒ Project Completed</td></tr>
<tr><td colspan="2">LCA Software</td><td colspan="2">Athena Impact Estimator for Buildings, v 5.5.0113 as the main LCA tool.
See the software's Athena IE User Manual and Transparency Document for further information on data sources.</td></tr>
<tr><td colspan="2">Life Cycle Scenarios</td><td colspan="2">Scenarios used in this assessment come from databases maintained by the Athena Sustainable Materials Institute.</td></tr>
<tr><td colspan="2">Life Cycle Inventory (LCI)</td><td colspan="2">LCI data used in this assessment is from the Athena LCI database and is compliant with ISO 14040 and ISO 14044.</td></tr>
<tr><td colspan="2">Life Cycle Impact Assessment (LCIA) method</td><td colspan="2">TRACI v2.1</td></tr>
</table>

1.1. Scope of Assessment

LCA was conducted under two scenarios of a cradle-to-site (A1-A5) and cradle-to-grave (A-C), and included the materials used for the project renovation. More details can be found below.

Table 1.2. LCA Scope: The 21st Street Lofts.

Service life	Results are reported based on two scenarios of 60- and 25-year service life.	
Construction elements included in the assessment (including renovation and new construction)		
☒ Foundations	☒ Exterior Walls	☐ Interior Doors
☐ Basement Walls	☒ Exterior windows	☒ Stair Construction
☒ Slab on Grade	☐ Exterior doors	☒ Stair Finishes (less paint)
☒ Columns and Beams	☐ Roof Coverings	☒ Wall Finishes (less paint)
☒ Floor Construction	☐ Roof Openings	☐ Floor Finishes
☒ Roof Construction	☒ Partitions	☒ Ceiling Finishes (less paint)
System boundary		
☒ A1 Raw material supply	☐ B1 Use	☒ C1 Deconstruction and demolition
☒ A2 Transportation	☒ B2 Maintenance	☒ C2 Transportation
☒ A3 Manufacturing	☐ B3 Repair	☒ C3 Waste processing
☒ A4 Transportation	☒ B4 Replacement	☒ C4 Disposal
☒ A5 Construction	☐ B5 Refurbishment	
	☐ B6 Operational energy	☒ D Beyond Life
	☐ B7 Operational water	

1.2. LCA Results

The LCA results for the 21st Street Loft project are reported in nine life cycle environmental impact categories, including embodied carbon, acidification potential, HH particulate matter, eutrophication potential, ozone depletion potential, smog formation potential, total primary energy (embodied), non-renewable energy, and fossil fuel consumption. Most importantly, the results show that the life cycle embodied carbon intensity (ECI) of the project is 132.01 kg CO2-eq per square meter of floor area, leading to a total of 962,433.69 kg CO2-eq for the project. As shown in Figure 1, the walls (including renovated and added) contributed 74.5% to the embodied carbon, followed by roofs (12%), floors (9%), and foundation (4.5%).

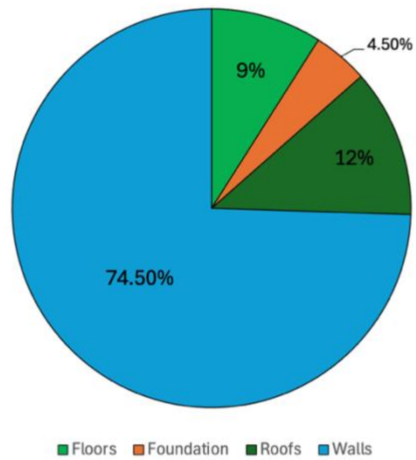

Figure 1. Breakdown of contributors to embodied carbon in the 21st Street Loft building.

Table 1.3. LCA results based on **60-year** service life, The 21st Street Lofts.

LCA Measures	**Unit**	Product (A1 to A3)	Construction (A4 & A5)	Use (B2, B4)	End-of-Life (C1-C4)	Beyond Building Life (D)	**Total** (A to C)	**Total** (A to D)	**Intensity** (A1-A5) Per square meter of floor area	**Intensity** (A-C) Per square meter of floor area
Embodied Carbon	**kg CO2 eq**	6.38E+05	1.38E+05	1.09E+05	7.80E+04	-7.04E+04	9.62E+05	8.92E+05	106.36	**132.01**
Acidification Potential	kg SO2 eq	2.69E+03	1.56E+03	7.05E+02	5.62E+02	-1.40E+02	5.51E+03	5.37E+03	0.58	**0.76**
HH Particulate	kg PM2.5 eq	4.31E+02	9.41E+01	1.30E+02	3.44E+02	-1.82E+01	9.99E+02	9.80E+02	0.07	**0.14**
Eutrophication Potential	kg N eq	7.18E+02	1.48E+02	1.24E+02	5.10E+01	-8.37E+00	1.04E+03	1.03E+03	0.12	**0.14**
Ozone Depletion Potential	kg CFC-11 eq	2.24E-02	1.94E-03	3.39E-03	2.64E-03	1.92E-09	3.04E-02	3.04E-02	3.34E-06	**4.17E-06**
Smog Potential	kg O3 eq	3.42E+04	4.79E+04	7.04E+03	1.74E+04	-1.51E+03	1.07E+05	1.05E+05	11.27	**14.62**
Total Primary Energy	MJ	8.98E+06	1.80E+06	1.94E+06	7.38E+05	-7.08E+05	1.35E+07	1.27E+07	1477.89	**1844.95**
Non-Renewable Energy	MJ	8.31E+06	1.76E+06	1.89E+06	7.34E+05	-7.36E+05	1.27E+07	1.20E+07	1382.11	**1742.40**
Fossil Fuel Consumption	MJ	7.79E+06	1.71E+06	1.65E+06	7.13E+05	-7.42E+05	1.19E+07	1.11E+07	1302.22	**1626.58**

Table 1.4. LCA results based on **25-year** service life, The 21st Street Lofts.

LCA Measures	**Unit**	Product (A1 to A3)	Construction (A4 & A5)	Use (B2, B4)	End-of-Life (C1-C4)	Beyond Building Life (D)	**Total** (A to C)	**Total** (A to D)	**Intensity** (A1-A5) Per square meter of floor area	**Intensity** (A-C) Per square meter of floor area
Embodied Carbon	**kg CO2 eq**	6.38E+05	1.38E+05	3.31E+03	7.80E+04	-7.04E+04	8.57E+05	7.86E+05	106.36	**117.52**
Acidification Potential	kg SO2 eq	2.69E+03	1.56E+03	1.19E+01	5.62E+02	-1.40E+02	4.82E+03	4.68E+03	0.58	**0.66**
HH Particulate	kg PM2.5 eq	4.31E+02	9.41E+01	7.02E+00	3.44E+02	-1.82E+01	8.76E+02	8.58E+02	0.07	**0.12**
Eutrophication Potential	kg N eq	7.18E+02	1.48E+02	1.92E+00	5.10E+01	-8.37E+00	9.19E+02	9.10E+02	0.12	**0.13**
Ozone Depletion Potential	kg CFC-11 eq	2.24E-02	1.94E-03	1.47E-05	2.64E-03	1.92E-09	2.70E-02	2.70E-02	3.34E-06	**3.71E-06**
Smog Potential	kg O3 eq	3.42E+04	4.79E+04	1.99E+02	1.74E+04	-1.51E+03	9.97E+04	9.82E+04	11.27	**13.68**
Total Primary Energy	MJ	8.98E+06	1.80E+06	1.18E+05	7.38E+05	-7.08E+05	1.16E+07	1.09E+07	1477.89	**1595.38**
Non-Renewable Energy	MJ	8.31E+06	1.76E+06	1.14E+05	7.34E+05	-7.36E+05	1.09E+07	1.02E+07	1382.11	**1498.37**
Fossil Fuel Consumption	MJ	7.79E+06	1.71E+06	1.08E+05	7.13E+05	-7.42E+05	1.03E+07	9.57E+06	1302.22	**1414.83**

Table 1.5. Bill of materials based on **60-year** service life, the 21st Street Lofts.

Materials	Quantity		Mass	
#15 Organic Felt	707.62	100sf	5.29	Tons
#30 Organic Felt	615.62	100sf	9.07	Tons
1/2" Lightweight Gypsum Board	396,570.23	Ft2	277.59	Tons
5/8" Fire-Rated Type X Gypsum Board	23,896.84	Ft2	26.10	Tons
6 mil Polyethylene	8,708.21	Ft2	0.13	Tons
8" Normal Weight Concrete Block	67,813.16	Blocks	1,287.65	Tons
Air Barrier	23,045.24	Ft2	0.14	Tons
Concrete Benchmark 4000 psi	237.02	yd3	461.60	Tons
Concrete Tile	24,267.60	Ft2	193.85	Tons
Double Glazed Hard Coated Air	18,742.98	Ft2	31.08	Tons
Fiber Cement	28,676.20	Ft2	41.09	Tons
Fiberglass Batt (low density)	335,045.77	Ft2 (1")	6.76	Tons
Fiberglass Batt (medium density)	356,468.57	Ft2 (1")	15.41	Tons
Galvanized Decking	8.44	Tons (short)	8.44	Tons
Galvanized Sheet	1.17	Tons (short)	1.17	Tons
Galvanized Studs	83.45	Tons (short)	83.45	Tons
Grout-Coarse	185.21	yd3	333.41	Tons
Joint Compound	42.97	Tons (short)	42.97	Tons
Mortar	150.63	yd3	239.68	Tons
Nails	0.62	Tons (short)	0.62	Tons
Paper Tape	0.49	Tons (short)	0.49	Tons
Polyiso Foam Board-Roof (GRF faced)	19,845.00	sf (1")	1.75	Tons
PVC Window Frame	40,420.72	lbs	20.21	Tons
Rebar, Rod, Light Sections	22.10	Tons (short)	22.10	Tons
Screws Nuts & Bolts	1.80	Tons (short)	1.80	Tons
Small Dimension Softwood Lumber	7.77	Mbfm small dimension	6.11	Tons
Softwood Plywood	86.56	msf (3/8")	40.87	Tons
TPO membrane-60 mil	63,295.10	Ft2	9.59	Tons
Water Based Latex Paint	378.51	Gallons (us)	1.18	Tons
Welded Wire Mesh / Ladder Wire	0.42	Tons (short)	0.42	Tons
Wide Flange Sections	9.21	Tons (short)	9.21	Tons

Table 1.6. Bill of materials based on **25-year** service life, the 21st Street Lofts.

Materials	Quantity		Mass	
#15 Organic Felt	294.84	100sf	2.20	Tons
#30 Organic Felt	256.51	100sf	3.78	Tons
1/2" Lightweight Gypsum Board	396,570.23	Ft2	277.59	Tons
5/8" Fire-Rated Type X Gypsum Board	23,896.84	Ft2	26.10	Tons
6 mil Polyethylene	8,708.21	Ft2	0.13	Tons
8" Normal Weight Concrete Block	67,813.16	Blocks	1,287.65	Tons
Air Barrier	23,045.24	Ft2	0.14	Tons
Concrete Benchmark 4000 psi	237.02	yd3	461.60	Tons
Concrete Tile	20,223.00	Ft2	161.54	Tons
Double Glazed Hard Coated Air	9,371.49	Ft2	15.54	Tons
Fiber Cement	23,896.84	Ft2	34.24	Tons
Fiberglass Batt (low density)	335,045.77	Ft2 (1")	6.76	Tons
Fiberglass Batt (medium density)	356,468.57	Ft2 (1")	15.41	Tons
Galvanized Decking	8.44	Tons (short)	8.44	Tons
Galvanized Sheet	1.17	Tons (short)	1.17	Tons
Galvanized Studs	83.45	Tons (short)	83.45	Tons
Grout-Coarse	185.21	yd3	333.41	Tons
Joint Compound	42.97	Tons (short)	42.97	Tons
Mortar	150.63	yd3	239.68	Tons
Nails	0.62	Tons (short)	0.62	Tons
Paper Tape	0.49	Tons (short)	0.49	Tons
Polyiso Foam Board-Roof (GRF faced)	19,845.00	Ft2 (1")	1.75	Tons
PVC Window Frame	20,210.36	lbs	10.11	Tons
Rebar, Rod, Light Sections	22.10	Tons (short)	22.10	Tons
Screws Nuts & Bolts	1.80	Tons (short)	1.80	Tons
Small Dimension Softwood Lumber	7.77	Mbfm small dimension	6.11	Tons
Softwood Plywood	86.56	msf (3/8")	40.87	Tons
TPO membrane-60 mil	26,372.96	Ft2	4.00	Tons
Water Based Latex Paint	157.71	Gallons (us)	0.49	Tons
Welded Wire Mesh / Ladder Wire	0.42	Tons (short)	0.42	Tons
Wide Flange Sections	9.21	Tons (short)	9.21	Tons

2. PROJECT: The Forum Apartments (Cincinnati, OH)

In this section, we explain the details, scope, and results of Life Cycle Assessment (LCA) for the Forum Apartments project in Cincinnati, OH. The results are presented in Section 2.2.

Table 2.1. Project information: The Forum Apartments.

<table>
<tr><td colspan="4">Project: The Forum Apartments (Cincinnati, OH)</td></tr>
<tr><td colspan="2">Building Use</td><td colspan="2">Multifamily Housing, Office</td></tr>
<tr><td colspan="2">Location</td><td colspan="2">Cincinnati, OH</td></tr>
<tr><td>Total GFA</td><td>284,762 Ft2 (26,455.25 m2)</td><td>No. of Floors</td><td>3-10</td></tr>
<tr><td colspan="2">Type of Construction</td><td colspan="2">Renovation including window replacement, painting, floor finishing.</td></tr>
<tr><td colspan="4">Project description: The Forum Apartments consist of five buildings including North building (37,576 Ft2), South building (37,576 Ft2), West building (93,950 Ft2), East building (75,160 Ft2), and Office/Club building (40,500 Ft2).</td></tr>
<tr><td colspan="2">Project documents used for material take off and LCA assessment</td><td colspan="2">Architectural and structural drawings</td></tr>
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<tr><td colspan="2">Life Cycle Impact Assessment (LCIA) method</td><td colspan="2">TRACI v2.1</td></tr>
</table>

2.1. Scope of Assessment

LCA was conducted under two scenarios of a cradle-to-site (A1-A5) and cradle-to-grave (A-C), and included the materials used for the project renovation. More details can be found below.

Table 2.2. LCA Scope: The Forum Apartments.

Service life	Results are reported based on two scenarios of 60- and 25-year service life.	
Construction elements included in the assessment (including renovation and new construction)		
☐ Foundations	☐ Exterior Walls	☐ Interior Doors
☐ Basement Walls	☒ Exterior windows	☐ Stair Construction
☐ Slab on Grade	☐ Exterior doors	☐ Stair Finishes (less paint)
☐ Columns and Beams	☐ Roof Coverings	☒ Wall Finishes
☐ Floor Construction	☐ Roof Openings	☒ Floor Finishes
☐ Roof Construction	☐ Partitions	☐ Ceiling Finishes (less paint)
System boundary		
☒ A1 Raw material supply	☐ B1 Use	☒ C1 Deconstruction and demolition
☒ A2 Transportation	☒ B2 Maintenance	☒ C2 Transportation
☒ A3 Manufacturing	☐ B3 Repair	☒ C3 Waste processing
☒ A4 Transportation	☒ B4 Replacement	☒ C4 Disposal
☒ A5 Construction	☐ B5 Refurbishment	
	☐ B6 Operational energy	☒ D Beyond Life
	☐ B7 Operational water	

2.2. LCA Results

The LCA results for the Forum Apartments project are reported in nine life cycle environmental impact categories, including embodied carbon, acidification potential, HH particulate matter, eutrophication potential, ozone depletion potential, smog formation potential, total primary energy (embodied), non-renewable energy, and fossil fuel consumption. Most importantly, the results show that the life cycle embodied carbon intensity (ECI) of the project is 37.84 kg CO2-eq per square meter of floor area, leading to a total of 1,000,967.31 kg CO2-eq for the project. The embodied carbon is driven by the windows, vinyl flooring, ceramic tiles and the paint used in the project.

Table 2.3. LCA results based on **60-year** service life, The Forum Apartments.

LCA Measures	**Unit**	Product (A1 to A3)	Construction (A4 & A5)	Use (B2, B4)	End-of-Life (C1-C4)	Beyond Building Life (D)	**Total** (A to C)	**Total** (A to D)	**Intensity** (A1-A5) Per square meter of floor area	**Intensity** (A-C) Per square meter of floor area
Embodied Carbon	**kg CO2 eq**	4.96E+05	2.71E+04	4.50E+05	2.86E+04	-1.88E+05	1.00E+06	8.12E+05	19.75	**37.84**
Acidification Potential	kg SO2 eq	3.52E+03	2.92E+02	3.23E+03	1.45E+02	-8.91E+02	7.19E+03	6.30E+03	0.14	**0.27**
HH Particulate	kg PM2.5 eq	5.51E+02	3.04E+01	6.43E+02	6.76E+01	-7.75E+01	1.29E+03	1.21E+03	0.02	**0.05**
Eutrophication Potential	kg N eq	5.35E+02	3.30E+01	4.15E+02	4.76E+00	-1.98E+01	9.88E+02	9.68E+02	0.02	**0.04**
Ozone Depletion Potential	kg CFC-11 eq	1.48E-02	5.73E-04	1.24E-02	2.63E-04	1.36E-11	2.80E-02	2.80E-02	5.81E-07	**1.06E-06**
Smog Potential	kg O3 eq	2.20E+04	6.15E+03	2.47E+04	1.98E+03	-7.33E+03	5.49E+04	4.75E+04	1.06	**2.07**
Total Primary Energy	MJ	7.25E+06	4.71E+05	6.49E+06	3.73E+05	-2.98E+06	1.46E+07	1.16E+07	291.94	**551.42**
Non-Renewable Energy	MJ	7.17E+06	4.68E+05	6.43E+06	3.70E+05	-1.75E+06	1.44E+07	1.27E+07	288.81	**545.74**
Fossil Fuel Consumption	MJ	6.13E+06	4.25E+05	5.64E+06	3.54E+05	-1.74E+06	1.25E+07	1.08E+07	247.61	**474.15**

Table 2.4. LCA results based on **25-year** service life, The Forum Apartments.

LCA Measures	**Unit**	Product (A1 to A3)	Construction (A4 & A5)	Use (B2, B4)	End-of-Life (C1-C4)	Beyond Building Life (D)	**Total** (A to C)	**Total** (A to D)	**Intensity** (A1-A5) Per square meter of floor area	**Intensity** (A-C) Per square meter of floor area
Embodied Carbon	**kg CO2 eq**	4.96E+05	2.71E+04	2.86E+03	2.86E+04	-9.42E+04	5.54E+05	4.60E+05	19.75	**20.94**
Acidification Potential	kg SO2 eq	3.52E+03	2.92E+02	1.50E+01	1.45E+02	-4.45E+02	3.98E+03	3.53E+03	0.14	**0.15**
HH Particulate	kg PM2.5 eq	5.51E+02	3.04E+01	7.59E+01	6.76E+01	-3.88E+01	7.25E+02	6.86E+02	0.02	**0.03**
Eutrophication Potential	kg N eq	5.35E+02	3.30E+01	3.10E+00	4.76E+00	-9.89E+00	5.76E+02	5.66E+02	0.02	**0.02**
Ozone Depletion Potential	kg CFC-11 eq	1.48E-02	5.73E-04	4.86E-05	2.63E-04	6.82E-12	1.57E-02	1.57E-02	5.81E-07	**5.93E-07**
Smog Potential	kg O3 eq	2.20E+04	6.15E+03	2.56E+02	1.98E+03	-3.66E+03	3.04E+04	2.67E+04	1.06	**1.15**
Total Primary Energy	MJ	7.25E+06	4.71E+05	1.23E+05	3.73E+05	-1.49E+06	8.22E+06	6.73E+06	291.94	**310.68**
Non-Renewable Energy	MJ	7.17E+06	4.68E+05	1.22E+05	3.70E+05	-8.74E+05	8.13E+06	7.26E+06	288.81	**307.41**
Fossil Fuel Consumption	MJ	6.13E+06	4.25E+05	1.17E+05	3.54E+05	-8.69E+05	7.02E+06	6.15E+06	247.61	**265.42**

Table 2.5. Bill of materials based on **60-year** service life, The Forum Apartments.

Materials	Quantity		Mass	
Aluminum Window Frame	95,371.68	lbs	47.68	Tons
Ceramic Tile	35,910.91	Ft2	187.55	Tons
Double Glazed Hard Coated Air	58,014.00	Ft2	96.20	Tons
PVC Window Frame	76,897.14	lbs	38.44	Tons
Vinyl flooring	363,179.14	Ft2	85.54	Tons
Water Based Latex Paint	4,687.92	Gallons (us)	14.67	Tons

Table 2.6. Bill of materials based on **25-year** service life, The Forum Apartments.

Materials	Quantity		Mass	
Aluminum Window Frame	47,685.93	lbs	23.8430	Tons
Ceramic Tile	29,925.76	Ft2	156.2966	Tons
Double Glazed Hard Coated Air	29,007.00	Ft2	48.1025	Tons
PVC Window Frame	38,448.57	lbs	19.2243	Tons
Vinyl Siding	211,854.50	Ft2	49.8999	Tons
Water Based Latex Paint	1,953.30	Gallons (us)	6.1129	Tons

3. PROJECT: Riverfront Village Student Housing (Tuscaloosa, AL)

In this section, we explain the details, scope, and results of Life Cycle Assessment (LCA) for the Riverfront Village Student Housing project in Tuscaloosa, AL. The results are presented in Section 3.2.

Table 3.1. Project information: Riverfront Village Student Housing.

Project: Riverfront Village Student Housing project (Tuscaloosa, AL)			
Building Use	Multifamily Housing		
Location	Tuscaloosa, AL		
Total GFA **Total GFA** (rentable)	250,282 Ft2 (23,252 m2) 180,075 Ft2 (16,729 m2)	**No. of Floors**	3
Type of Construction	Renovation including replacement of 10% of cladding, and envelope repair without window replacement.		
Project description: The Riverfront Village Student Housing project consists of three student housing buildings and a parking garage building. The buildings are steel/wood frame on slab foundations cladded with brick and fiber cement siding. The renovation project maintains 100% of building structure, 90% of cladding, and 100% of glazing.			
Project documents used for LCA assessment	Exhibit B: Scope of Work and Budget		
Project development stage when assessment was conducted	☐ Schematic Design ☐ Design Development ☐ Construction Docs. ☒ Project Completed		
LCA Software	Athena Impact Estimator for Buildings, v 5.5.0113 as the main LCA tool. See the software's Athena IE *User Manual and Transparency Document* for further information on data sources.		
Life Cycle Scenarios	Scenarios used in this assessment come from databases maintained by the Athena Sustainable Materials Institute.		
Life Cycle Inventory (LCI)	LCI data used in this assessment is from the Athena LCI database and is compliant with ISO 14040 and ISO 14044.		
Life Cycle Impact Assessment (LCIA) method	TRACI v2.1		

3.1.Scope of Assessment

LCA was conducted under two scenarios of a cradle-to-site (A1-A5) and cradle-to-grave (A-C), and included the materials used for the project renovation. Based on 3 floors and 180,075 ft2 of floor area, we estimated the wall area in this project to be 51,261 ft2. For 10% cladding replacement, we assumed 5,126 ft2 of cladding is replaced with new hardie boards. For 90% of the cladding painting, we assumed 46,139 ft2 of wall area as painted. For other materials, we assumed 0.1 kg CO_2-eq per square meter of embodied carbon, based on recommendations by the Carbon Avoided Retrofit Estimator (CARE) Tool.

Table 3.2. LCA Scope: Riverfront Village Student Housing.

Service life	Results are reported based on two scenarios of 60- and 25-year service life.	
Construction elements included in the assessment (including renovation and new construction)		
☐ Foundations	☐ Exterior Walls	☐ Interior Doors
☐ Basement Walls	☐ Exterior windows	☐ Stair Construction
☐ Slab on Grade	☐ Exterior doors	☐ Stair Finishes (less paint)
☐ Columns and Beams	☐ Roof Coverings	☒ Wall Finishes
☐ Floor Construction	☐ Roof Openings	☐ Floor Finishes
☐ Roof Construction	☐ Partitions	☐ Ceiling Finishes (less paint)
System boundary		
☒ A1 Raw material supply	☐ B1 Use	☒ C1 Deconstruction and demolition
☒ A2 Transportation	☒ B2 Maintenance	☒ C2 Transportation
☒ A3 Manufacturing	☐ B3 Repair	☒ C3 Waste processing
☒ A4 Transportation	☒ B4 Replacement	☒ C4 Disposal
☒ A5 Construction	☐ B5 Refurbishment	
	☐ B6 Operational energy	☒ D Beyond Life
	☐ B7 Operational water	

3.2. LCA Results

The LCA results for the Riverfront Village Student Housing project are reported in nine life cycle environmental impact categories, including embodied carbon, acidification potential, HH particulate matter, eutrophication potential, ozone depletion potential, smog formation potential, total primary energy (embodied), non-renewable energy, and fossil fuel consumption. Most importantly, the results show that the 60-year life cycle embodied carbon intensity (ECI) of the project is 0.69 kg CO2-eq per square meter of floor area, leading to a total of 9,800 kg CO2-eq for the project. Also, the 25-year life cycle embodied carbon intensity (ECI) of the project is 0.49 kg CO2-eq per square meter of floor area, leading to a total of 6,540 kg CO2-eq for the project.

Table 3.3. LCA results based on **60-year** service life, Riverfront Village Student Housing.

LCA Measures	**Unit**	Product (A1 to A3)	Construction (A4 & A5)	Use (B2, B4)	End-of-Life (C1-C4)	**Total** (A to C)	**Intensity** (A1-A5) Per square meter of floor area	**Intensity** (A-C) Per square meter of floor area	**Final Intensity** (A-C) Per square meter of floor area Including 0.1 for other materials
Embodied Carbon	**kg CO2 eq**	4.84E+03	6.09E+02	4.25E+03	9.60E+01	9.80E+03	0.33	**0.59**	**0.69**
Acidification Potential	kg SO2 eq	3.25E+01	4.97E+00	2.37E+01	8.89E-01	6.20E+01	2.24E-03	**3.71E-03**	-
HH Particulate	kg PM2.5 eq	2.86E+01	1.74E+00	8.97E+01	1.79E+00	1.22E+02	1.81E-03	**7.28E-03**	-
Eutrophication Potential	kg N eq	3.48E+00	4.09E-01	4.63E+00	6.52E-02	8.58E+00	2.33E-04	**5.13E-04**	-
Ozone Depletion Potential	kg CFC-11 eq	6.85E-05	6.54E-06	8.04E-05	8.12E-06	1.64E-04	4.49E-09	**9.78E-09**	-
Smog Potential	kg O3 eq	3.36E+02	9.24E+01	3.74E+02	2.77E+01	8.30E+02	0.03	**0.05**	-
Total Primary Energy	MJ	4.48E+04	4.80E+03	1.45E+05	1.41E+03	1.96E+05	2.96	**11.73**	-
Non-Renewable Energy	MJ	4.43E+04	4.76E+03	1.44E+05	1.41E+03	1.95E+05	2.93	**11.64**	-
Fossil Fuel Consumption	MJ	4.12E+04	4.52E+03	1.39E+05	1.38E+03	1.86E+05	2.73	**11.11**	-

Table 3.4. LCA results based on **25-year** service life, Riverfront Village Student Housing.

LCA Measures	**Unit**	Product (A1 to A3)	Construction (A4 & A5)	Use (B2, B4)	End-of-Life (C1-C4)	**Total** (A to C)	**Intensity** (A1-A5) Per square meter of floor area	**Intensity** (A-C) Per square meter of floor area	**Final Intensity** (A-C) Per square meter of floor area Including 0.1 for other materials
Embodied Carbon	**kg CO2 eq**	4.84E+03	6.09E+02	9.90E+02	9.60E+01	6.54E+03	0.33	**0.39**	**0.49**
Acidification Potential	kg SO2 eq	3.25E+01	4.97E+00	5.08E+00	8.89E-01	4.35E+01	2.24E-03	**2.60E-03**	-
HH Particulate	kg PM2.5 eq	2.86E+01	1.74E+00	2.61E+01	1.79E+00	5.83E+01	1.81E-03	**3.48E-03**	-
Eutrophication Potential	kg N eq	3.48E+00	4.09E-01	1.20E+00	6.52E-02	5.16E+00	2.33E-04	**3.09E-04**	-
Ozone Depletion Potential	kg CFC-11 eq	6.85E-05	6.54E-06	2.05E-05	8.12E-06	1.04E-04	4.49E-09	**6.20E-09**	-
Smog Potential	kg O3 eq	3.36E+02	9.24E+01	9.09E+01	2.77E+01	5.47E+02	0.03	**0.03**	-
Total Primary Energy	MJ	4.48E+04	4.80E+03	4.23E+04	1.41E+03	9.33E+04	2.96	**5.58**	-
Non-Renewable Energy	MJ	4.43E+04	4.76E+03	4.21E+04	1.41E+03	9.25E+04	2.93	**5.53**	-
Fossil Fuel Consumption	MJ	4.12E+04	4.52E+03	4.06E+04	1.38E+03	8.76E+04	2.73	**5.24**	-

Table 3.5. Bill of materials based on **60-year** service life, Riverfront Village Student Housing.

Materials	Quantity		Mass	
Fiber Cement Board	6,766.32	Ft2	9.69	Tons
Water Based Latex Paint	1,609.56	Gallons (us)	5.03	Tons

Table 3.6. Bill of materials based on **25-year** service life, Riverfront Village Student Housing.

Materials	Quantity		Mass	
Fiber Cement Board	5,638.60	Ft2	8.08	Tons
Water Based Latex Paint	670.65	Gallons (us)	2.09	Tons

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