Case Study of an Adaptive Reuse Project using Embodied Carbon Visualizations as part of a Holistic Design Process

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Abstract

This paper presents a case study of a small campus building adaptive reuse and preservation project. Embodied Carbon visualizations were used as part of a holistic design process involving undergraduate students and used in conjunction with renderings and pricing to help a college facilities department make decisions about the best pathway forward in the adaptive reuse of the building. This is a replicable process to effectively communicate embodied carbon data alongside more longstanding drawings and renderings to aid design teams and owners to make decisions that consider aesthetics and embodied carbon for a low carbon building future.

Introduction

This paper will discuss a holistic design process integrating embodied carbon calculations and visualizations alongside more traditional design tools including drawings and renderings in the decision-making process for an adaptive reuse of a small campus building. Historically, sustainability standards for the energy use of buildings focused almost exclusively on operational energy and, therefore, operational carbon emissions. As the architecture and construction industries have become better at building net zero operational energy buildings, the net impact of embodied carbon relative to operational carbon and lifecycle emissions has increased.(1) To keep global warming to a 1.5-degree Celsius limit, total emissions from the built environment must be reduced by 45% before 2030 and net-zero by 2050.(2) Understanding the speed and scale of development currently underway, reducing the up-front embodied carbon emissions becomes imperative and an important part of every design project.

The Phoenix Project

Background

The case study for this paper is the Phoenix, a small building with a significant history for Mount Holyoke College, the first of the Seven Sisters liberal arts colleges. Faced with the question of whether to demolish or renovate, the decision was made to renovate as the building has historic significance to the town and campus as the former home of the nation's first all-women's fire brigade formed in the late 1800s as part of the physical education curriculum in an effort to create a line of defense against fires. Further, in addition to this legacy, Mount Holyoke today has an ambitious sustainability goal to be a net zero campus by 2037 and this project can serve as a case study for an adaptive reuse/renovation project on the historic campus. The

Fig. 1. The Phoenix as home to the Fire Department

project team is a collaboration between an architecture professor with an active design practice who teaches at Mount Holyoke working with C & H Architects, an architecture firm practicing in the region. The college was enthusiastic about engaging students in the project and six undergraduate liberal arts architectural studies students were a part of the team. The students chosen were all third-year students in the 2023-24 academic year who would still be on campus during construction in 2024-25 and have the possibility to follow the construction process and see the project through to completion.

Fig. 2. Faculty member, 6 students and the GC Site Supervisor on site at a weekly meeting during construction

Working Process

Over the course of the 2023-24 academic year, the project team met weekly. In the fall semester, 4 students worked on aspects of the project such as archival research, selecting an appropriate carbon calculator tool, developing schematic designs, and drawing wall sections with several assembly options. In the spring semester, three students (one who continued – the other three went abroad for their junior spring) worked to develop embodied carbon Sankey diagrams for the wall and roof options, develop a carbon cost chart to help understand the carbon quantities on a more relatable level, and create renderings to help visualize the options. This paper will demonstrate how all of these components of the project came together in a presentation to the campus facilities department and Dean of Faculty office as a pathway forward for the project was decided. A more in-depth discussion of the embodied carbon calculations, Sankey diagrams, and carbon comparisons as related to the wall assembly options is currently under review. (3) This paper will focus on the selection of the roof assembly which had greater architectural and experiential implications.

Archival Research

The first phase of the project was to understand the history of the building and the people who enlivened the space. Two students went to the college archives and were able to find articles from the late 1800s extolling the virtues of the young women who were on the fire brigade with such quotes as:

> *There are 300 girls at Mount Holyoke – the prettiest, the brightest, the jolliest and the most studious of New England's daughters – also the most muscular and calmest in emergency. (4)*

This history, and such colorful writing from another era, reinforced the resolve to save the building, the first home of the fire brigade.

Quantifying Embodied Carbon

A significant portion of our research was to come up with options and make decisions based on embodied carbon alongside more typical decision drivers such as finances and aesthetics. In the past decade, a number of tools have become available for material carbon estimation calculations. Our process required a tool that was simple enough for undergraduate liberal arts architectural studies students to be able to use without extensive training. Tally (5), Beacon (6), Kaleidoscope (7), Epic (8), Care (9) and BEAM were all considered as potential tools and ultimately, we decided to work with BEAM, the Building Emissions Accounting for Materials Estimator, developed by the Builders for Climate Action. BEAM does not require a full REVIT model as Tally and Beacon do and it is more suitable to the small scale of our project than Kaleidoscope, while still allowing for a more detailed analysis of different assembly types than both EPIC and CARE enabled. BEAM allows for fine grained comparisons between different material selections and assemblies simply by inputting areas of different materials for different building components such as exterior walls, exterior wall cladding, floors or ceilings. BEAM calculates the A1-A3 "Product Phase" emissions enabling us to quantify the carbon impact of renovating instead of demolishing and rebuilding (exactly what is standing), as well as more detailed data about the carbon impacts of alternative wall and roof assemblies.

Our first step in understanding the relative carbon impacts of an adaptive reuse over a tear down and rebuild, and where we had the ability to make decisions through the design process was to first understand what parameters were set and what was open to discussion. Those set parameters we called the "Base Scope" – things that it made sense not to change such as the concrete foundation, slab and structural framing, and things that we had to update such as replacing the windows and insulating above the low slope roof of the truck bay. Beyond these givens, we identified two primary areas open to a decision-making process. The first decision was whether we keep the existing exterior siding – cedar clapboards painted and repainted over the years with multiple layers of lead paint - and just work internally, or whether we replace the existing exterior cedar siding giving us the opportunity to build a completely new assembly. This decision, while having an impact on both up-front budget and on-going maintenance costs, would not have a significant impact on the look and experience of the project. The second decision was whether to keep the drop ceiling over the historic firehouse, or open up the space for a vaulted ceiling. This decision involved differences in roof assembly and insulation type, up front construction costs, as well as a significant difference in the architectural experience of the space.

To understand the carbon impacts of these decisions, the surface areas of all of the parameters were inputted separately into BEAM. The BEAM output is a color-coded table (Figure 3) that displays the material carbon emissions by section.

MATERIAL CARBON EMISSIONS BY SECTION		
Footings & Slabs	6,747	kg CO_2e
Foundation Walls	0	kg CO_2e
Structural Elements	0	kg CO_2e
Exterior Walls	2,797	kg CO_2e
Party Walls	0	kg CO_2e
Exterior Wall Cladding	627	kg CO_2e
Windows	772	kg CO_2e
Interior Walls	0	kg CO_2e
Floors	804	kg CO_2e
Ceilings	0	kg CO_2e
Roof	2,481	kg CO_2e
Garage	0	kg CO_2e
NET TOTAL	14,228	kg CO_2e

0 MCE (kg CO_2e) 10,000

Fig. 3. BEAM output.

Visualizing Embodied Carbon

To visualize the decisions in terms of total carbon impact, we developed a summary diagram (Figure 4) clearly showing the base scope and the two decisions to be made. Immediately, it becomes clear that the decision to do an adaptive reuse project, over a tear-down and rebuild, is the most significant decision resulting in 70% reduction in carbon for the base scope. Even the most carbon intensive decisions for the wall assembly and roof are combined, only 15% of the base scope emissions impact. At this point, it is interesting to look a little deeper into the embodied carbon output for the base scope to understand why an adaptive reuse project is so much better for the environment in terms of embodied carbon.

Figure 5 is a Sankey diagram visualization of the BEAM output drawn using illustrator. The pixels of the bandwidth correlates directly with the emissions number. The bottom half of the diagram shows all of the materials that can continue to be used in the adaptive reuse project with the associated carbon emissions that would be released if the same were to be installed today. The top half of the diagram shows the emissions associated with base scope materials that will be added as part of the renovation. Color was used to group materials and to easily associate existing and added components of the same materials. For example, a light turquoise was used for all windows in the project including those that are existing as well as the new windows that will be added in the adaptive reuse. Components that cannot be reused and will be discarded transition from a color to gray to indicate waste. The original windows in the bottom half of the Sankey diagram show this transition.

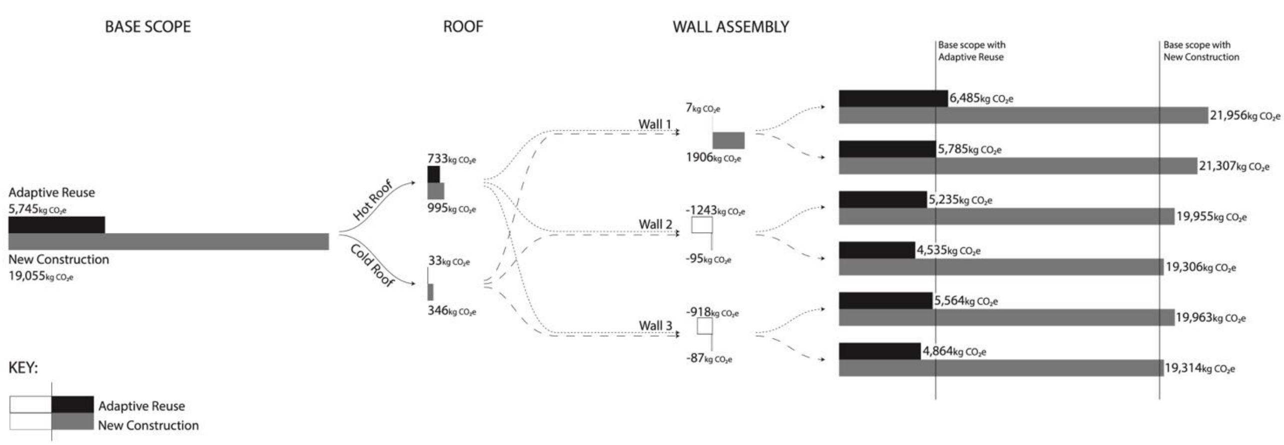

Fig. 4. Summary Diagram of embodied carbon in Base Scope and Roof and Wall options.

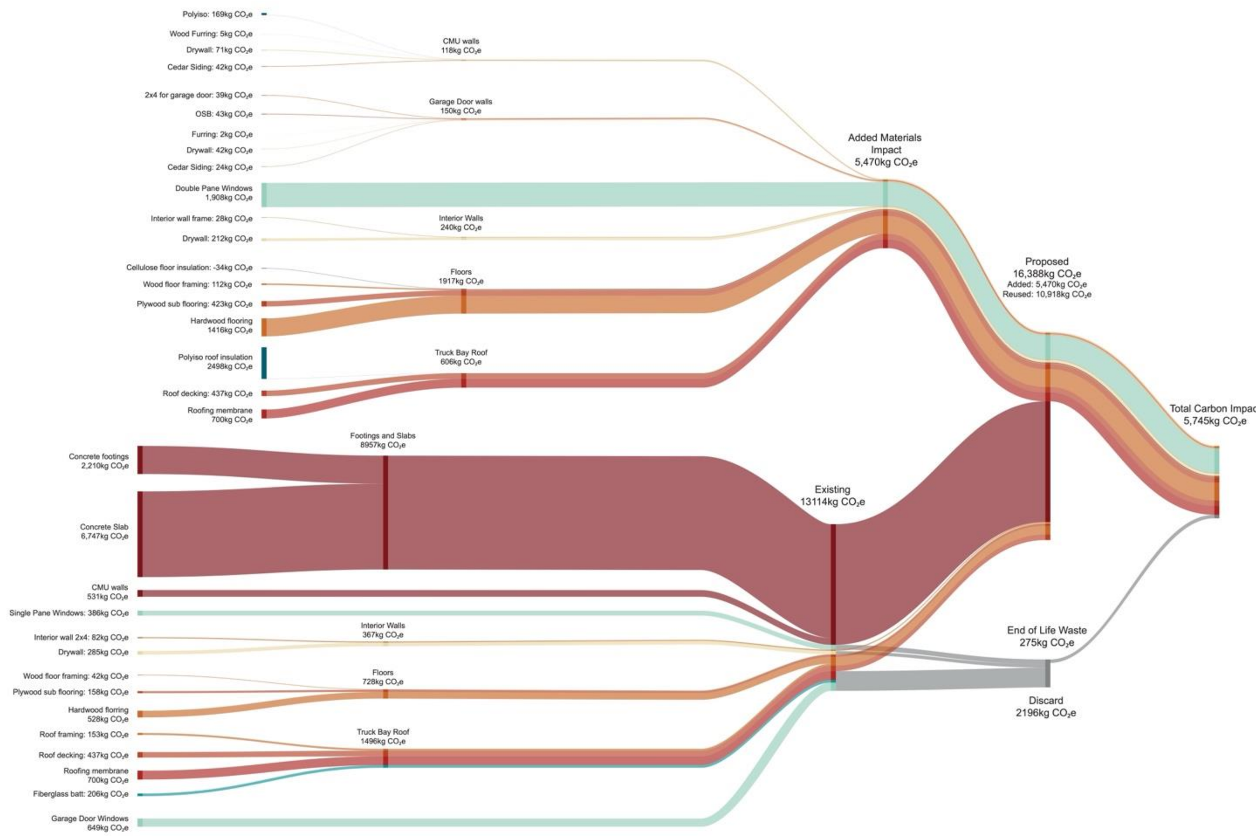

Fig. 5. Sankey Diagram of embodied carbon in the Base Scope by material – numbers taken from BEAM output

The great benefit of the adaptive reuse of the existing building is that we can continue to gain benefit from the embodied carbon in materials that were extracted over one hundred years ago. Looking more closely at the bottom half of the Sankey diagram, we can see that the emissions in brick red associated with the concrete footings, foundation, slab and CMU walls account for over 70% of the net benefit of the adaptive reuse project.

Carbon Emissions Communication

After developing the Sankey diagrams, we realized that although these clearly showed the relative impacts of the materials, without some understanding of what these numbers meant, it was still hard to interpret these diagrams. To address this, we felt that it was important to associate emissions to metrics that we can all relate to. We developed the Carbon Comparison Key in Figure 6 to address this gap in understanding. For ease of comparison, we selected relatable sources of emissions that increase by a factor of 10 – i.e. the emissions released for one hamburger is approximately 1/10 the emissions released when one drives 100 miles or 1/100 the emissions of flying from New York City to Orlando. Of course, all of these numbers are approximations – driving 100 miles in an electric car versus a car that runs solely on gasoline would be different. This assumes an average US car that gets 25 miles/gallon (10).

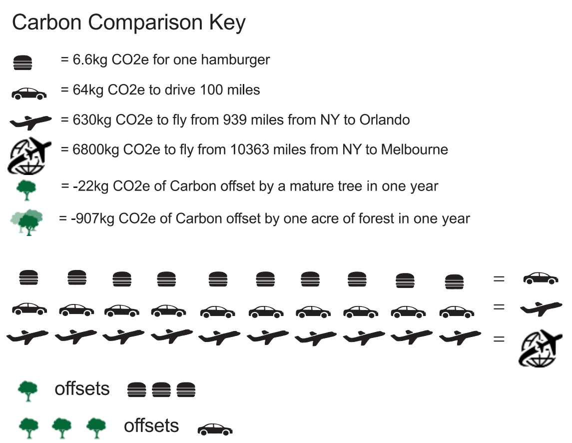

Fig. 6. Relative carbon footprint of known metrics

This key now gave us an effective way of communicating not only relative carbon impacts but also impacts relative to known metrics.

Holistic Decision Making

As previously mentioned, there were two main areas where we could make a decision – the wall assembly and the roof assembly. This paper focuses on the roof/ceiling assembly decision as this is the one that had aesthetic and experiential impacts.

Cold Roof Assembly

The existing fire house had a traditional vented cold roof with ceiling joists that tied the building together and provided a nailing surface for a finish ceiling. Maintaining such an assembly would involve installing new asphalt shingles over the existing structure. Everything could be reused with new cellulose insulation, a smart membrane and a new finish ceiling material (Fig 7).

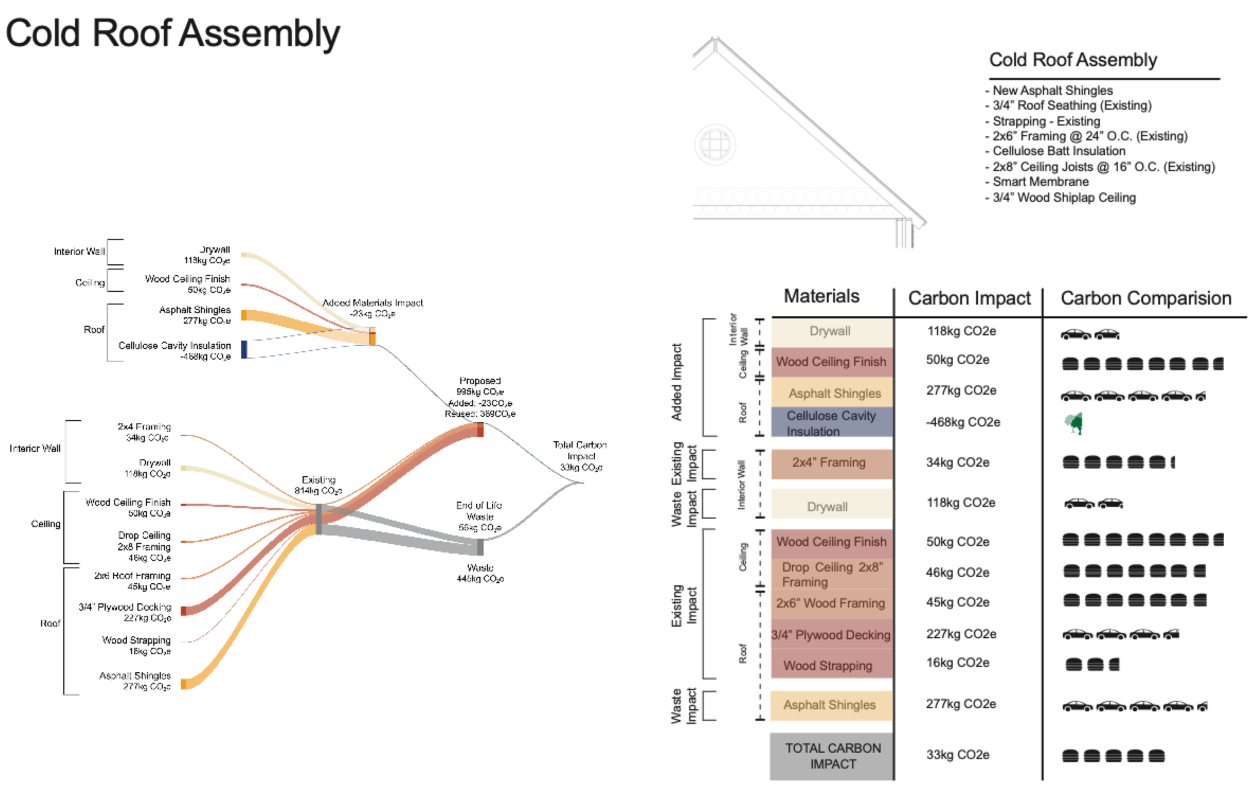

Fig. 7. Sankey Diagram, Roof Assembly and Carbon Comparison Chart for Cold Roof Assembly

With the ability to reuse the roof framing, ceiling joists, plywood decking, and strapping, and using cellulose insulation which has a negative carbon impact, the carbon cost of maintaining and renovating a cold roof with new insulation, shingles, and finish was minimal – the carbon equivalent of five hamburgers. This includes an approximation for the end-of-life C1-C4 emissions associated with the disposal of the existing asphalt shingles and drywall finish ceiling. End of life emissions were calculated at one-eighth of A1-A3 emissions based upon a RMI estimate of end-of-life emissions at 3-15% of lifecycle emissions. (11)

Hot Roof Assembly

The hot roof assembly (Fig 8) would transform the space with a vaulted ceiling. The existing wood framing, plywood decking and wood strapping would all stay – however, in lieu of cellulose insulation, a vaulted ceiling requires 3" of closed cell spray foam with an additional 8" of dense pack cellulose. The carbon impact of the spray foam is the biggest difference between the two assemblies bringing the net impact of the hot roof assembly to 733kg of material carbon emissions, the equivalent of a round-trip flight from Boston to Chicago (or a little more than a one-way flight from NYC to Orlando). At this point, other factors were considered – namely, the architectural spatial experience and cost considerations. Figure 9 shows renderings of the fire house with a drop ceiling and a vaulted ceiling - the

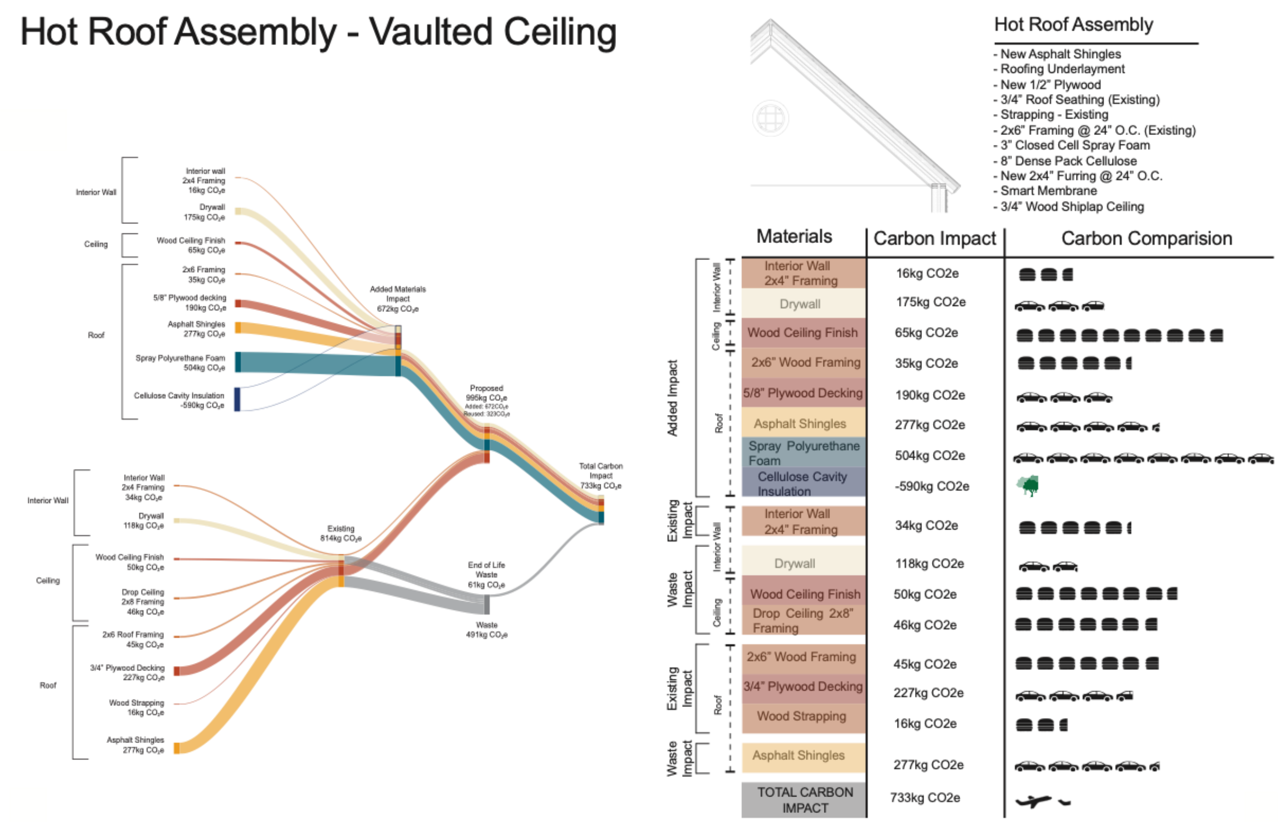

Fig. 8. Sankey Diagram, Roof Assembly and Carbon Comparison Chart for Hot Roof Assembly

Fig. 9. Renderings showing the Fire House with a cold roof and flat ceiling (L) and hot roof with vaulted ceiling (R)

difference is significant with a vaulted ceiling being preferred despite the higher carbon cost. At this point it was important to look at the ceiling decision in context of the total project. Figure 10 shows the summary diagram from Figure 4 with costs overlaid on the diagram as well as our final decision. Costs were provided by the general contractor for the project based on a pricing set issued in early April. The pricing set included the options for the wall and ceiling alternates as final costs were a necessary factor in the decision making.

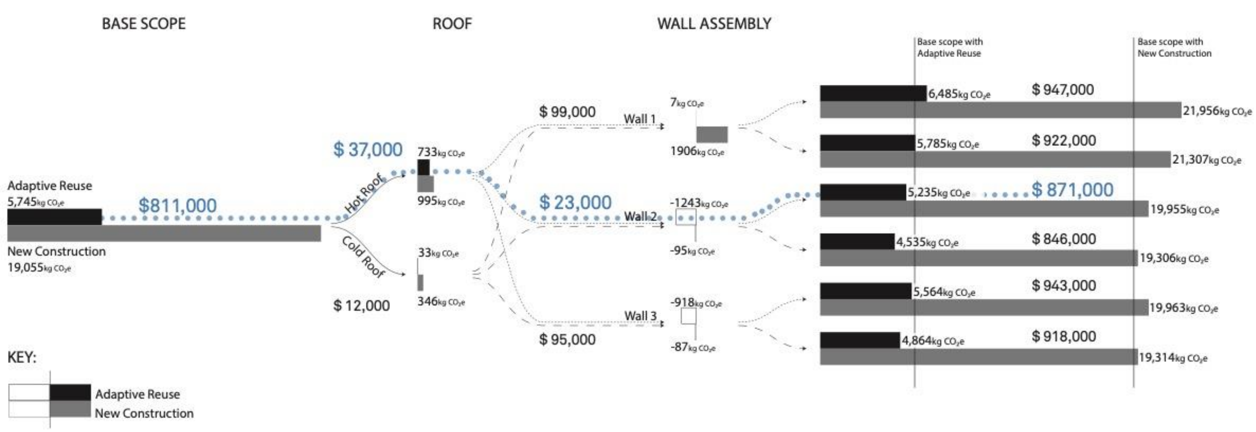

Fig. 10. Summary diagram overlaid with costs and our final decision

Final Decision

The decision was made by the Director of Facilities to proceed with a hot roof and vaulted ceiling. Although this paper did not go into the details, we also decided to proceed with wall assembly 2 which was a double stud 2x4 wall with dense pack cellulose and the only option that kept the existing cedar siding which significantly impacted up-front costs – a difference of 9% of the base cost. In contrast, the order of magnitude cost of a vaulted ceiling to a flat ceiling was less, with the difference between the two options at only 3% of the base scope cost. The renderings also played a significant role in this decision as it helped make clear the architectural benefits.

Conclusion

This has been an exciting case study for our campus on multiple levels – to address net zero energy goals, to engage students and as a model for adaptive reuse. The BEAM model, Sankey diagrams and carbon comparison key made the case very clearly for the benefits of adaptive reuse over teardown and rebuild from both an embodied carbon perspective as well as for the preservation of cultural history and memory on campus. Students were able to be directly engaged through archival research, BEAM calculations and diagramming, and developing a carbon comparison key to better communicate the impacts with the decision makers on campus. The project also reinforced the importance of visualizations such as renderings to help understand the aesthetic implications of our decisions. Having made the most impactful decision to undertake an adaptive reuse of the existing structure, we then did not proceed with every decision that was lowest carbon or lowest cost, but considered these options holistically to build a project that will serve the campus for the next 100 years while bringing delight to the occupants of the space.

The holistic design process was greatly appreciated by the Director of Facilities and the office of the Dean of Faculty has loved that students were involved in the process from design through (optional) weekly construction meetings at the project site. The college has said that this study will impact future campus growth both for better understanding the value of adaptive reuse and as a model that engages students in research for campus projects.

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Notes:

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