Circular Economy in U.S. Building Construction: An Exploratory Triple Bottom Line Analysis

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A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Science in Construction Management

University of Washington

2026

Committee:

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Program Authorized to Offer Degree:

Department of Construction Management

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Abstract

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Circular economy (CE) in building construction promotes the reuse of materials rather than their disposal. This way, the industry is able to retain value through physical materials, cost, and reduced environmental impact. At the same time, the triple bottom line (Elkington, 1994) argues that for a sustainable strategy to be viable, it must simultaneously benefit people, the planet, and profit. This study uses environmental, economic, and social metrics as a basis for assessing CE strategies for construction projects in the United States.

Following a comprehensive literature review, this research develops an assessment method which identifies and measures circular strategies. These strategies are categorized by the 9R framework (Soliu & Migliaccio, 2024) and further refined to the assembly level. The study then uses a theoretical demonstration of the methodology to show replicability and quantitative results. Following this demonstration, the study uses interviews conducted with a small set of case studies, for a final qualitative analysis of two case studies. This way, the study shows both how to measure the potential benefits of assessing circular economy performance through a triple bottom line lens, as well as limitations in regards to project data in existing American construction projects, and qualitative trends of strategies. The assessment method uses three existing frameworks representing the triple bottom line: life cycle assessment (LCA) for "planet", cost comparison for “profit", and social life cycle assessment (S-LCA) for “people”. Data was collected through stakeholder interviews and analysis of RSMeans and CLF baseline data to quantify direct impacts.

The study finds that circular strategies may be able to deliver measurable benefits across all three dimensions of the triple bottom line, indicating their potential to support sustainable building construction in the United States. As research in circular economy is still in its early stages and fragmented, the study found challenges accessing enough quantitative data to make absolute claims on the impact of circular economy. However, the findings indicate mostly positive impacts environmentally, economically, and socially. Subsequently, recommendations for policy changes to support the formal implementation of circular economy, as well as a call for future research was made.

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List of Abbreviations

A1-A3 - The procurement stage of Life Cycle Assessment. The scope of carbon emission from this stage is defined as the point from material extraction to

C&DW - Construction and Demolition Waste

CE - Circular Economy

CFRP - Carbon Fiber Reinforced Polymer

CLF - Carbon Leadership Forum

EPD - Environmental Product Declaration

GC - General Contractor

GWP - Global Warming Potential

LBC - Living Building Challenge

LCA - Life Cycle Assessment

LCC - Life Cycle Costing

LEED - Leadership in Energy and Environmental Design

NLT - Nail-Laminated Timber

S-LCA - Social Life Cycle Assessment

TBL - Triple Bottom Line

USGBC - United States Green Building Council

Section 1: Introduction

The construction industry is a major contributor to landfill waste, resource depletion, and climate change, with an estimated 3 to 10 billion tonnes of construction and demolition waste (C&DW) generated annually, accounting for nearly 40% of solid waste from all industries (Aslam, 2020). The industry is also responsible for 37-42% of global emissions. (UNEP, 2023). Furthermore, reports from the United Nations Environmental Programme have found resource depletion to be a major and worsening concern (UNEP 2019; UNEP, 2024). As raw materials have become increasingly difficult to procure, take-make-dispose production systems are increasingly unsustainable. Landfills will become overrun with material that would have otherwise been processable or reusable, and the cost of transporting and extracting materials will rise.

Circular economy emerged as an increasingly popular sustainable building framework beginning around 2015 (Yang, 2025). Given the construction industry's significant contribution to global greenhouse gas emissions and landfill waste, CE has emerged as a critical strategy for reducing environmental impact by promoting closed-loop material systems across all project phases, including procurement, manufacturing, transport, and disposal. This offers a promising solution to waste by promoting resource efficiency, which can potentially mitigate both pollution and resource scarcity.

Reusing building structure and elements, such as lumber, is a long-standing tradition in European construction (Hein & Houk, 2008). Though it has not always been referred to as "circular economy" by name, this idea of building reuse to preserve the existing supply of finite construction resources aligns with the concept of circular economy. In the European building tradition, timber framing and construction were commonly used until the 18th century. As old-growth trees became scarce, wood was reused, and many surviving wood structures in Europe date back centuries (Domínguez-Delmás, 2023). As sustainability and material conservation became a highly visible issue, European countries began to adopt circular economy practices, which ultimately resulted in notable legislation such as the European Commission's circular economy Action Plan, further facilitating material reuse strategies in building and legitimizing circular economy as a viable strategy for sustainable construction (European Commission, 2015; Siefridt, 2026). The emergence of legislative action to support CE indicates its increasing acceptance, particularly in Europe during this period, a trend that is not yet reflected in the United States.

By contrast, the United States has yet to enact a national, CE-specific legislation or develop an action plan. (Rios, 2021). Although the United States does have ambitious sustainable building programs, such as the Living Building Challenge, which has certified over 250 projects, these programs are not as widespread as the LEED assessment framework and certification system. Although sustainability is often discussed in American construction, circular economy has not made its way into the everyday dialogue of the industry. Compared to building practices in Europe, where CE is much more widely used, the U.S. construction market is much newer. Rather than stone and reused old-growth timber construction set by early European traditions, fast-growing wood and drywall are more typically used as materials in American construction. North American old-growth decline can be seen by the changes in lumber construction techniques. Log buildings and heavy timber construction were popular prior to the 20th century, but have been replaced over time with light timber and OSB products (Wacker, 2021). As construction evolved in the United States from a context of abundant materials such as lumber, American construction projects are not typically designed for disassembly or retrofitting. Green building in the United States focuses on new and efficient building envelopes, but the reuse of existing structures was not properly considered, possibly because many buildings in North America are perceived as not having significant historic preservation value (Merlino, 2014).

LEED has long been used as the standard metric of building sustainability across the world, and is currently the most commonly used sustainability initiative in architecture and construction (USGBC). By using a mix of embodied and operational carbon strategies, the program encourages owners, contractors, and architects to use sustainable materials, build efficiently, and establish infrastructure for sustainable living in the community, such as building in densely populated areas and near public transit. When measuring impact, many LEED incentives rely on projection data for certification, and primarily focus on operational systems such as HVAC (USGBC). That being said, LEED overlaps noticeably with CE in some aspects, particularly in the materials category, but is generally more focused on reducing operational carbon rather than embodied carbon in buildings.

Demolition and landfill waste are also significant contributors to carbon emissions and take up much-needed space in an increasingly populated world. Furthermore, green initiatives have already shown a trend of decreasing operational carbon in new construction due to technological advancements in energy-efficient buildings. Operational carbon is expected to decrease from 75% to 50% of total construction emissions, and more embodied carbon reduction strategies are necessary to effectively reduce the construction industry's impact on the environment (UNEP, 2023). Many sustainable construction initiatives prioritize energy-efficient systems rather than reducing embodied carbon through reuse (Merlino, 2014). As a result, embodied carbon emissions generated throughout a building's life cycle have doubled from 20-25% to 45-50% of a building's lifecycle emissions, specifically in energy-efficient buildings (Röck et al., 2020).

For this reason, circular economy focuses primarily on halting the depletion of materials, using regenerative materials, and reducing waste. The UNEP prescribes three strategies to decarbonize buildings: avoiding unnecessary extraction and production, shifting to regenerative materials, and improving decarbonization of conventional materials. This study focuses on the first strategy (UNEP, 2023). Rather than discarding materials from existing buildings and procuring new materials in a more sustainable fashion, CE argues that the most sustainable practice is to avoid discarding those materials altogether.

Although circular economy strategies have been widely discussed conceptually, there remains limited evaluation of their direct environmental, social, and economic impacts within the context of the United States construction industry.

Section 2: Literature Review

2.1 Impact of Implementing Circular Economy Strategies

The construction industry greatly impacts the environment, the public, and the global economy. In the sphere of environmentalism and global emissions, the construction industry is commonly cited as producing between 600 million and 2 billion tons of construction and demolition waste (C&DW) per year, and contributing up to 33% to global Carbon emissions (Tafesse, 2022). In addition to pollution, the construction industry consumes materials at an unsustainable rate. Material consumption has tripled since 1970, and is projected to reach 190 billion tonnes of raw material per year if consumption norms continue in affluent and developing economies. (UNEP, 2019). This material depletion is primarily linked to the raw extraction of non-renewable construction materials such as concrete, gravel, and stone. Circular strategies can help reduce this material depletion, as materials extracted from existing structures or C&DW do not take from the earth's limited virgin resources. CE for building construction argues that materials, in this case building materials, should be reused rather than discarded, and there is value to be gained from this. The idea that there is value in reusing materials, whether that means reducing carbon emissions, saving money, or achieving social benefits, is intriguing because it aligns with the triple bottom line. This term, first used by John Elkington in 1994, holds that for a sustainable strategy to succeed, it must benefit the planet, profits, and people. (Elkington, 2004) Although not intended to be applied exclusively to the built environment, the triple bottom line remains a strong measure of success for sustainable building strategies, given existing prejudices in the industry. If implementing circular economy construction strategies can be proven to have a positive impact across all three impact categories, this presents a strong argument for why circular economy should be used as a sustainable building strategy.

Research on the actual impacts of CE strategies in building construction is fragmented but offers some promising indicators across the triple bottom line (TBL). While recycling materials like steel results in lower-impact construction than raw material extraction, reuse strategies have a far greater impact because of the high-energy processes required for recycling. Compared to typical steel production, which primarily uses recycled steel, reused steel components were shown to reduce the CO_2-eq impact by 87%. (Bartsch, 2025). Overall, reuse strategies have been shown to be the most effective circular economy strategy for profit and carbon emission reduction, both at the material and whole-building levels (Minunno et al., 2020). Although recycling construction materials in large quantities, such as structural concrete, wood, and steel, offers environmental benefits compared to raw material extraction, there are suggestions of upfront cost tradeoffs for using circular strategies, such as DFD and material reuse in new construction. That being said, the reuse of building structure shows promise as an economically viable and sustainable practice (Khadim, 2025). Refurbishment strategies were found to make projects more economically viable than new construction, as a large portion of materials can be reused in these cases (Domínguez et al., 2023). It was further demonstrated that integrated assessment frameworks combining life cycle assessment, life cycle costing, and circularity indicators are essential for evaluating the true feasibility of circular building systems at a whole-building scale (Larsen et al., 2022).

In addition to environmental and economic benefits, circular economy strategies have been found to have positive social impacts on those involved in the construction process. Circular construction methods implemented in the Living Lab Ghent case produce overall positive social impacts, particularly for workers and local communities (Kayaçetin, 2023). Benefits arise from prefabrication, reduced on-site disturbance, improved occupational learning, and the use of bio-based and locally sourced materials. Workers can benefit from improved learning and skill development in sustainable construction, and the increased coordination requirements for circular strategies can strengthen relationships between construction leadership and subcontractors (Kayaçetin et al., 2023). Recycling presents potentially harmful impacts, with studies citing unsafe working conditions, exposure to hazardous materials for workers, and low pay in material processing facilities (Bhatnagar et al., 2024). Another interesting social dimension of CE implementation in building construction is the cultural preference for new housing. Prior research has shown that building reuse is often overlooked because there is a preference for new buildings, which are seen as superior and efficient. This case is particularly strong in Japan, where building lifespan is as short as 25-30 years (Wuyts, 2019). Outside of historic preservation, there are few frameworks that advocate for building reuse, and “green building" typically refers to new construction (Merlino, 2014). Although demolition of buildings is environmentally detrimental and technically unnecessary, contractors are incentivized to demolish and rebuild buildings when demand for new construction is high, and older buildings depreciate at the same rate. This is a significant social barrier to implementing a circular economy in buildings.

2.2. Barriers to Sustainable Building Practices

The implementation of sustainable building practices, particularly circular economy, faces a range of persistent barriers across economic and cultural dimensions. Broadly, these challenges stem from the construction industry's reliance on established take-make-dispose practices, fragmented stakeholder involvement, such as in the Design-Bid-Build procurement structure, and perceived risks associated with innovation. Because CE is not yet standardized, the project requires a high level of coordination. One of the most commonly cited barriers is the higher upfront cost often associated with sustainable strategies, even when long-term economic benefits may be realized. This cost sensitivity is intensified by strict project scheduling timelines and financing structures that prioritize immediate returns over lifecycle value (Larsen et al., 2022). Additionally, limited awareness and understanding of sustainability frameworks, which is particularly strong for CE, among project stakeholders can hinder adoption, as decision-makers lack the tools or knowledge to evaluate long-term environmental and social benefits.

Another key barrier is the complexity of integrating sustainability assessment methods into practice. The use of life cycle assessment (LCA), life cycle costing (LCC), and social life cycle assessment (S-LCA) requires significant data, coordination, and technical expertise, which are not always readily available. Larsen et al. (2022) highlight that inconsistencies in methodology, data gaps, and a lack of standardization across these tools make it difficult to conduct a comprehensive quantitative assessment. Furthermore, the fragmented nature of the construction industry, where responsibilities are distributed separately among owners, designers, contractors, and subcontractors, creates challenges in aligning goals and ensuring consistent implementation of sustainable strategies in the construction projects studied.

Regulatory and institutional barriers also play a significant role. Existing building codes and contractual frameworks are often not designed to support innovative or non-traditional approaches, limiting the adoption of sustainable practices. In many cases, there is a lack of incentives or clear policy direction to encourage sustainability, which further reinforces conventional construction methods (Cruz Rios et al., 2021). Together, these factors create an environment in which sustainable strategies may be viewed as risky, complex, or economically unviable, despite their potential long-term benefits.

More specifically, the implementation of CE practices in construction introduces an additional layer of challenges. CE strategies that prioritize material reuse, adaptability, and closed-loop systems require a fundamental shift away from linear construction models. One of the primary barriers identified is the lack of established supply chains for reclaimed and reused materials. Unlike conventional materials, reused components often lack standardized specifications, consistent availability, and reliable certification processes, making their integration into projects more difficult (Salazar-Izquierdo, 2022). Although the materials may be identical to those originally used, there is no legislative guidance on how to safely select reused and reclaimed materials, leaving the contractor to assume the risk and liability for defective materials. This uncertainty can increase project teams' perceived risk and discourage adoption.

Design challenges also present significant obstacles to circular construction. Buildings are often not originally designed for disassembly or material recovery, limiting opportunities for reuse at the end of their lifecycle. (Cruz Rios et al. 2021) found that designers and engineers face difficulties in incorporating circular principles due to limited design tools, insufficient guidance on which strategies offer the most benefit, and a lack of circular precedent projects in the United States. Additionally, concerns surrounding liability, performance guarantees, and compliance with building codes further complicate the use of reclaimed or reused materials.

Finally, accessible data and reliable, replicable methods of measure remain challenges and significant barriers to advancing circular practices. Accurately quantifying the environmental, economic, and social impacts of CE strategies requires robust data on material supply chains, the reuse potential of different material types, and the building's operational lifecycle performance upon project completion. As noted by Larsen et al., the integration of LCA, LCC, and S-LCA in the context of circularity is still underdeveloped, with methodological gaps limiting the ability to fully capture the benefits of these strategies. This lack of reliable metrics makes it difficult to justify circular approaches to stakeholders and undermines confidence in their effectiveness.

While sustainable and circular building practices offer vast potential benefits, their actual implementation is constrained by a combination of economic, regulatory, and organizational barriers. Among sustainable building strategies, circular strategies, in particular, require systemic changes. Because CE and the language surrounding it are not commonly used, changes to design processes, supply chains, and stakeholder collaboration are required for a successful full implementation. Addressing these barriers is critical to enabling broader adoption and realizing the full potential of sustainability in the built environment.

2.3 Integrating the Triple Bottom Line into Circular Economy

While both sustainable construction and circular economy research reference the TBL, full integration across environmental, economic, and social dimensions remains limited. A systematic review of 86 studies found that sustainable construction research tends to overemphasize environmental performance, with significantly less attention given to economic viability and even less to social impacts, despite the importance of balancing all three dimensions for effective implementation of sustainable strategies such as circular economy (Goh et al., 2020). This imbalance suggests that, although TBL is widely acknowledged in theory, it is not cohesively measured in practice, even though it has been formulated by UNEP as life cycle sustainability assessment (LCSA) (UNEP & SEATAC, 2011).

This limitation is also evident in circular construction research, where sustainability claims are often not substantiated across all TBL dimensions. Studies must move beyond conceptual alignment with circular economy principles by demonstrating measurable benefits across environmental, economic, and social categories, including cost savings, stakeholder acceptance, and user value (Wuni, 2022). Without this comprehensive validation, circular strategies risk being positioned by stakeholders as abstractly sustainable without sufficient practical evidence.

Collectively, these findings highlight a gap in the literature: the lack of integrated frameworks that evaluate circular construction strategies across all three TBL dimensions in a consistent and comparable manner. This gap underscores the need for approaches that simultaneously assess environmental, economic, and social impacts within a unified evaluation structure.

2.4 The Triple Bottom Line Gap

The literature review process for this research was intended to identify gaps in existing studies and opportunities for a feasible study that would make a meaningful contribution. The research aims to develop a way to measure the impact of the circular economy, so that it may inform future research on the subject, policy decisions, and public visibility of the topic.

As the triple bottom line was established as a measure of "success" for a sustainable strategy, the selected literature discusses how CE, or elements of CE, have been studied for their environmental, economic, and/or social consequences. Only articles deemed relevant to the circular economy and sustainable building practices are included in this review; CE research related to manufacturing, consumer goods, and agriculture was excluded. Only the first page of results from the database was used. A subjective judgment was made on the relevance of the article, and articles intended for human health, medicine, urban planning, and new technological advances, such as machine learning, are excluded. Duplicate articles are not repeated in the source list but are noted. Finally, graphics representing the findings were created to visualize which articles mention LCC, LCA, and S-LCA, and which of the 9R strategies each article applied to.

Existing Correlations									
CE Principle	R1: Rethink	R2: reduce	R3: Reuse	R4: Repair	R5: Repurpose/ Redesign	R6: Refurbish/ Renovate	R7: Retain	R8: Recycle	R9: Recover
LCA	2,3,4,6,10,11	2,13,17	2,3,10,12,13,14,16	2	2	1,2,4,5,7,9,14,22	2,3	2,3,10,12,13,14	2,3
LCC	2,11,19,23	2	2,16,24	2	2	1,2,7	2,24	2,24	2,24

S-LCA	2,18,19,20,21	2,18	2,18,20	2	2	2,22	2,21	2,18	2

Table 1: Mapping Existing CE Literature to LCA, LCC, and S-LCA

List of Sources	
Source Number	Source Citation
1	Allacker, K., De Troyer, F., & Trigaux, D. (2014). *Cradle-to-grave life-cycle assessment within the built environment: Comparison between the refurbishment and the complete reconstruction of an office building in Belgium*. Journal of Cleaner Production, 64, 10.1016/j.jenvman.2018.02.055
2	Larsen, V. G., Tollin, N., Sattrup, P. A., Birkved, M., & Holmboe, T. (2022). What are the challenges in assessing circular economy for the built environment? A literature review on integrating LCA, LCC and S-LCA in life cycle sustainability assessment (LCSA). *Journal of Building Engineering, 50*, 104203. 10.1016/j.jobe.2022.104203
3	Sobierajewicz, P., Adamczyk, J., & Dylewski, R. (2023). *Ecological and economic assessment of the reuse of steel halls in terms of LCA*. *Applied Sciences, 13*(3), 1597. https://doi.org/10.3390/app13031597
4	Herrmann, F., Pürschel, H., Wörner, J., Blasius, J., Lahiri, L., Böhme, M., & Hartmann, V. (2022). *Restructure, repurpose, extend: Design strategies for future-oriented building and for strengthening the potential of the existing building fabric*. *IOP Conference Series: Earth and Environmental Science, 1078*(1), 012014. https://doi.org/10.1088/1755-1315/1078/1/012014
5	Cardinale, N., Negro, E., & Selicati, V. (2022). *Energy audit of 1900s buildings for sustainable renovation*. *Journal of Physics: Conference Series, 2385*(1), 012010. https://doi.org/10.1088/1742-6596/2385/1/012010
6	Decorte, Y., De Meyer, S., & Steeman, M. (2021). *The environmental impact of prefabricated renovation systems: A worthy alternative to on-site renovation? IOP Conference Series: Earth and Environmental Science, 855*(1), Article 012007. https://doi.org/10.1088/1755-1315/855/1/012007
7	Marique, A.-F., & Rossi, B. (2018). *Cradle-to-grave life-cycle assessment within the built environment: Comparison between the refurbishment and the complete reconstruction of an office building in Belgium*. *Journal of Environmental Management, 224*, 396–405. https://doi-org.offcampus.lib.washington.edu/10.1016/j.jenvman.2018.02.055
8	Schwartz, Y., Raslan, R., & Mumovic, D. (2022). *Refurbish or replace? The life cycle*

	carbon footprint and life cycle cost of refurbished and new residential archetype buildings in London. Energy, 248, 123585. https://doi-org.offcampus.lib.washington.edu/10.1016/j.energy.2022.123585
9	Domínguez, C., Kakkos, E., Gross, D., Hischier, R., & Orehounig, K. (2023). Renovated or replaced? Finding the optimal solution for an existing building considering cumulative CO_2 emissions, energy consumption and costs—A case study. Energy and Buildings, 303, 113807. 10.1016/j.enbuild.2023.113767
10	Minunno, R., O'Grady, T., Morrison, G. M., & Gruner, R. L. (2020). Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building. Resources, Conservation and Recycling, 160, 104855. https://doi-org.offcampus.lib.washington.edu/10.1016/j.resconrec.2020.104855
11	Khadim, N., Agliata, R., & Mollo, L. (2025). Circling towards profit: A circular life cycle approach to evaluate the economic and environmental feasibility of buildings and construction. In R. Corrao, T. Campisi, S. Colajanni, M. Saeli, & C. Vinci (Eds.), Lecture Notes in Civil Engineering (Vol. 612, pp. 454–470). Springer. https://doi.org/10.1007/978-3-031-71867-0_31
12	Feng, H., García de Soto, B., & Adey, B. T. (2022). *Using BIM and LCA to evaluate material circularity: Contributions to building design improvements*. In *Proceedings of the 39th International Symposium on Automation and Robotics in Construction (ISARC 2022)* (pp. 26–33). International Association for Automation and Robotics in Construction. https://doi.org/10.22260/ISARC2022/0004
13	Quéheille, E., Taillandier, F., Saiyouri, N., Cherradi, T., & Fernandez, C. (2024). *A many-objective optimization model for the end-of-life of buildings*. *Environment Systems and Decisions, 44*(4), 946–965. https://doi.org/10.1007/s10669-024-09984-9
14	Sandanayake, M., Zhang, G., & Setunge, S. (2018). Consequential LCA modelling of building refurbishment in New Zealand: An evaluation of resource and waste management scenarios. Journal of Cleaner Production, 197, 1296–1306. 10.1016/j.jclepro.2017.07.099
15	Akanbi, L. A., Oyedele, L. O., Akinade, O. O., Ajayi, A. O., Davila Delgado, J. M., Bilal, M., & Bello, S. A. (2018). *Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator*. *Resources, Conservation and Recycling, 129*, 175–186. https://doi.org/10.1016/j.resconrec.2017.10.026
16	Alejandrino, C., Mercante, I. T., & Bovea, M. D. (2022). *Combining O-LCA and O-LCC to support circular economy strategies in organizations: Methodology and case study*. *Journal of Cleaner Production, 336*, Article 130365.

	https://doi.org/10.1016/j.jclepro.2022.130365
17	Rabbat, C., Awad, S., Villot, A., Rollet, D., & Andrès, Y. (2022). *Sustainability of biomass-based insulation materials in buildings: Current status in France, end-of-life projections and energy recovery potentials*. *Renewable and Sustainable Energy Reviews, 156*, Article 111962. https://doi.org/10.1016/j.rser.2021.111962
18	Bhatnagar, A., Härri, A., Levänen, J., & Niinimäki, K. (2024) Exploring the role of social life cycle assessment in transition to circular economy: A systematic review Resources, Conservation & Recycling, 207, 107702 https://doi.org/10.1016/j.resconrec.2024.107702
19	Ghisellini, P., Ripa, M., & Ulgiati, S. (2018). *Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector: A literature review*. *Journal of Cleaner Production, 178*, 618–643. https://doi.org/10.1016/j.jclepro.2017.11.207
20	Kayaçetin, N. C., Piccardo, C., & Versele, A. (2023). Social impact assessment of circular construction: Case of Living Lab Ghent. In Proceedings of the 40th International Symposium on Automation and Robotics in Construction (ISARC 2023). International Association for Automation and Robotics in Construction (IAARC). https://www-mdpi-com.offcampus.lib.washington.edu/2071-1050/15/1/721
21	Wuyts, W., Miatto, A., Sedlitzky, R., & Tanikawa, H. (2019). Extending or ending the life of residential buildings in Japan: A social circular economy approach to the problem of short-lived constructions. Journal of Cleaner Production, 231, 660–670. https://doi.org/10.1016/j.jclepro.2019.05.258
22	Mohaddes Khorassani, S., Ferrari, A.M., Pini, M. et al. Environmental and social impact assessment of cultural heritage restoration and its application to the Uncastillo Fortress. Int J Life Cycle Assess **24**, 1297–1318 (2019). https://doi.org/10.1007/s11367-018-1493-1
23	AlJaber, A., Alasmari, E., Martinez-Vazquez, P., & Baniotopoulos, C. (2023). Life cycle cost in circular economy of buildings by applying Building Information Modeling (BIM): A state of the art. Buildings, 13(7), Article 1858. https://doi.org/10.3390/buildings13071858
24	Balasbaneh, A.T., Sher, W. & Li, J. A systematic review of the life cycle cost estimation of upgrading buildings for sustainability. *Environ Sci Pollut Res* **32**, 19649–19671 (2025). https://doi.org/10.1007/s11356-025-36757-x

Table 2: Literature Review Source List

Through this screening, connections were visualized in existing literature between CE in construction and three tools for measuring the triple bottom line: LCA, LCC, and S-LCA (Table

1). Through this screening process, several gaps were identified in TBL related CE research for building construction. The majority of case studies were conducted in Europe, with studies based in Denmark, Finland, the Netherlands, Austria, and Germany being the most frequently studied locations. Many studies also come from eastern and southeastern Asia. There is a significant gap of studies conducted in and/or about circular economy systems in the United States. Another significant gap was found in the scope of research. These findings are further supported by previous meta-analysis research, which found that, when looking at CE research in building construction globally, over 70% of studies are cradle-to-gate, over 80% study only embodied carbon, and 64% of studies were conducted in Europe (Anderson et al., 2022). Case studies measuring whole-building carbon impacts of CE strategies through LCA (Allacker, 2014; Dominguez, 2023), as well as measuring cost impacts (Schwartz, 2022), were present, but they use theoretical digital buildings rather than actual costs and environmental impacts. This phase of the literature review was used for identifying existing patterns in CE research, and additional sources were ultimately explored in addition to those identified in Table 2.

Given these gaps, the goal of this study is to add to the existing quantitative and qualitative research on construction-based circular economy practices in the United States. This research is expected to yield an assessment method for promoting circular construction practices in the United States. The anticipated outputs include a deeper understanding of the economic, social, and environmental benefits of CE adoption, a set of actionable recommendations for policymakers and industry stakeholders, and a model for overcoming the identified barriers. Ultimately, this research aims to contribute to a more sustainable and resilient construction industry in the United States.

2.5 Need for this Study

Accurately assessing the value of circular economy strategies requires reliable methods of measurement. After conducting a broad literature review, several gaps were identified: Most existing research does not quantify its impacts on specific buildings. As stated previously, many studies estimate hypothetical benefits of theoretical buildings, or draw conclusions from broad literature reviews and meta-analyses. Few case studies of completed projects measuring the upfront and/or operational impact of implementing CE strategies are present in the data set. Even newer studies on the reuse of buildings rely on digital modeling or estimated material quantities rather than on real-world projects with detailed material and financial data (Domínguez, 2023; Kayaçetin, 2023; Schwartz, 2022). More data is needed on existing projects in order to understand the impact circular economy strategies when implemented in practice. If impact cannot be fully measured, information barriers in case study projects can guide needed changes in project data organization, documentation best practices, and policy.

Additionally, the geographic distribution of existing research is disproportionate, with Scandinavian countries producing the largest volume of circular economy case studies, followed by broader Europe and parts of Asia (Anderson et al., 2022; Bhatnagar, 2024). Research in North America appears to be extremely underdeveloped by comparison, partly because regional procurement systems, policies, and construction practices differ considerably from those in Europe and Asia. As a result, strategies that work well in those regions cannot always be translated directly to U.S. projects. This region, like every global region, has its own environmental regulations, typical construction practices, material profiles, and end-of-life resources. An investigation into barriers and data on construction projects in the United States will provide valuable insights into the viability of the circular economy as a sustainable building strategy and into how best to proceed in the industry and in future research on the topic.

Another notable gap is the limited integration of all triple bottom line elements in existing CE studies: environmental, economic, and social considerations (USBCG, 2009). Much of the current research is fragmented, addressing only one or two of these dimensions, which points to a need for more holistic evaluations that reflect the complexity of decision-making in the construction sector. Although CE was created for the purpose of addressing and mitigating environmental concerns, financial feasibility and social impact on workers and the local community are major considerations for project stakeholders and cannot be ignored (Larsen, 2022). Tradeoffs may exist, but for project owners and contractors to adopt a new sustainable strategy, there should be documented benefits across all three TBL dimensions. A holistic approach to assessing a given CE framework should therefore address all three dimensions of construction sustainability. This study addresses the discussed research gaps and proposes an assessment method intended to answer the following research questions:

RQ1: How can the triple-bottom-line effects of implementing circular economy strategies be measured in a standardized and replicable way?

RQ2: How are circular economy strategies currently manifested within American construction projects?

RQ3: What environmental, economic, and social benefits and tradeoffs are associated with circular economy strategies for building construction in the United States?

Section 3: Methodology

3.1 Study Overview

This study uses a two-part approach consisting of a quantitative, theoretical demonstration of the methodology and qualitative case study analysis to evaluate circular economy (CE) strategies in building construction. The research adapts the principles of Life Cycle Sustainability Assessment (LCSA), an existing sustainability assessment approach, into a practical assessment method for evaluating CE strategies through environmental, economic, and social metrics aligned with the triple bottom line (Larsen et al., 2022). To support this objective, the study combines a theoretical demonstration of the assessment method with a small set of construction project case studies in the United States that have implemented several of the 9R circular strategies for building construction (Soliu & Migliaccio, 2024).

The selected case studies were chosen based on established relationships between project stakeholders and the University of Washington, increasing the likelihood of obtaining project information and access to key personnel. Initial interviews were conducted with project team members to identify circular strategies implemented within each project, confirm project scope, and evaluate the applicability of the assessment method within existing construction practice. Through these interviews, project strategies were categorized according to the 9R framework and further broken down into individual measurable interventions at the assembly level. While some strategies could reasonably fit multiple categories, each strategy was assigned to a primary category based on its dominant function and measurability. Across the selected projects, the majority of measurable strategies involved material retention and reuse, including the salvage and reuse of building components and materials.

Following the initial interviews, a data request form was developed to support consistent data collection. The form was designed to gather information necessary for environmental, economic, and social assessment while recognizing that project teams may not possess all information required for a comprehensive evaluation. Data requests included project documentation, material quantities, cost information, and other information relevant to the selected circular strategies.

In order to account for variable availability and quality of case study project data, a theoretical assessment demonstration was conducted to illustrate the complete application of the proposed assessment method in the environmental and economic portions of the assessment. Using a hypothetical but realistic building scenario, the demonstration provided a guided example of how circular strategies can be identified, categorized, and quantified using CLF baseline embodied carbon data and RSMeans cost information. This approach reduced reliance on incomplete project data while demonstrating the replicability of the assessment method and its ability to generate measurable environmental and economic outcomes.

Once project information was collected, environmental, economic, and social assessments were performed for each identified strategy using the procedures described in the following sections. Figure 1 illustrates the process of conducting the study so that sufficient data could be collected to report meaningful results.

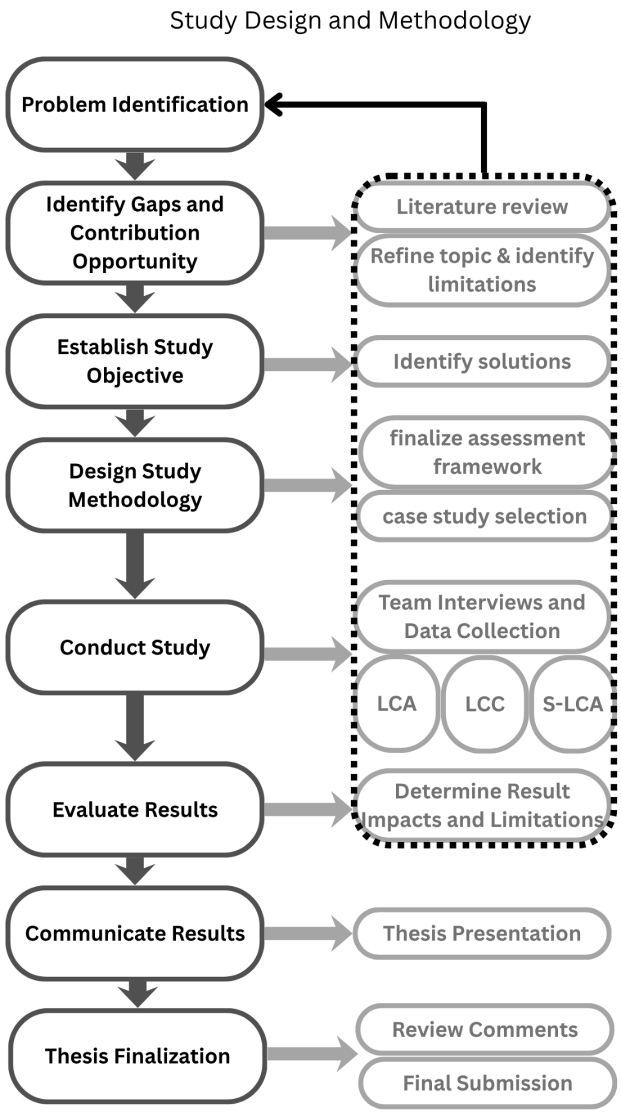

Figure 1: Study Design Overview Diagram

3.2 The 9R Framework

One of the most well-known methods to conceptualize circular economy strategies is the 9R framework developed by Potting et al. (2017). This framework is widely referenced in both LCA- and LCC-based analyses and outlines a hierarchy of strategies that retain value, prolong product life, or avoid unnecessary resource consumption. However, the original framework was written for a manufacturing context and contains elements that do not translate well to construction. For example, the R0, or “Refuse” strategy, assumes the possibility of eliminating the need for a product altogether. a concept that does not align with the fundamental necessity of housing and buildings. There is no digital alternative to a physical building. One can only find ways to build that are less demanding on resource pools and the environment as a whole.

To address this gap, a construction-specific adaptation of the 9R framework was used, maintaining the logic of the original 9R hierarchy while focusing on strategies that can realistically be applied to building construction. This framework was ultimately chosen to serve as a guide for the evaluation of circular economy strategies in the selected case study (Soliu & Migliaccio, 2024).

9R Framework for Building Construction

1. **Rethink:** Develop innovative designs and strategies to maximize efficiency, e.g., adopt modular design and prefabrication of building elements, using mechanical connections to facilitate building disassembly.
2. **Reduce:** Minimize the amount of energy used and waste generation by increasing material efficiency while minimizing consumption. e.g., divert waste from landfills by reusing reclaimed building materials and components such as concrete, doors, windows, lumber, steel, etc.
3. **Reuse:** Reusing materials and components for the same purpose after the first cycle of usage to extend their life while maintaining their original functions, e.g., reusing stone cladding, façade, or structural steel in another building.
4. **Repair**: Fixing damaged or deteriorating building components instead of replacing them, e.g., repairing a damaged HVAC system instead of completely replacing it.
5. **Repurpose/Redesign:** Using damaged products or parts of defective products to produce new ones with a different function, e.g., repurposing untreated wood from the façade and interior walls for furniture, or using demolished concrete elements as aggregate.

6. **Refurbish/Renovate:** Upgrading or restoring an existing building to improve functionality, aesthetics, or performance without entirely replacing it, e.g., changing the floor layout or altering the interior walls to meet new demand.
7. **Retain:** Preserving existing buildings, components, or materials in their original form and function for as long as possible. It involves adaptive reuse, repurposing, or reconfiguring structures to serve new functions without demolition or major material transformation.
8. **Recycle**: An operation by which waste materials are reprocessed to create new ones with the same higher (upcycle) or lower (downcycle) qualities, e.g., using concrete for aggregate, or recycling metal for a second use.
9. **Recover:** Process of retrieving used products/materials at the end of their life through disassembly, sorting, and cleaning for utilization, e.g., salvaging structural steel, roof elements, or floor tiles instead of demolition.
   https://www.researchgate.net/profile/Idris-Soliu/research

Figure 2: 9R Framework for Building Construction

When looking at a project, any circular strategy used by a contractor can fall into one or more of these 9 categories; however, when breaking down strategies into material components to measure upfront impacts.

The goal of implementing circular economy is to "generate more value and economic opportunity while designing out waste and using fewer resources that can be reused" (Rios, 2021), which is what this assessment method aims to capture. The first strategy, rethink, while the most difficult to measure directly, is the most central to the idea and intent of circular economy, which is to change the way the construction industry approaches buildings. Case study findings indicate that existing buildings may already implement circular strategies on some level, but standardized terminology and frameworks are not yet sufficient to make circular economy strategies common practice.

Together, the 9Rs encompass all the project actions that can be taken by a contractor to make a building that is more circular. In other words, if a building component falls into one of these definitions, even if by coincidence, the project is considered to have some amount of circularity. These definitions will be used in the absence of formal legislative definitions for circular economy in building construction in the United States.

9 possible definitions were mapped alongside existing research on LCA, LCC, and S-LCA to gather additional information on possible studies on measuring circular economy against the triple bottom line as a measure of success.

3.3 Environmental Metric: Life Cycle Assessment (LCA)

The first metric used in this study to evaluate the impact of implementing circular economy strategies is the LCA method, which evaluates environmental impact. LCA is a commonly used metric for assessing environmental impact, and is used in this study as a material-focused approach. The life cycle assessment (LCA) methodology follows the framework established by ISO 14040 and ISO 14044. Material quantities were identified for each building scenario and assessed for their embodied environmental impacts using cradle-to-gate environmental product declaration (EPD) data. The assessment approach aligns with the LCA requirements of ASHRAE Standard 189.1 and was used in the quantitative framework demonstration, while case study findings were evaluated qualitatively using the same environmental impact categories and circular economy principles. The LCA scope covers A1-A3 impacts for specific material categories, and does not address operational carbon. This was deemed appropriate as case study findings could not identify change in building lifespan or operational performance resulting from material reuse strategies.

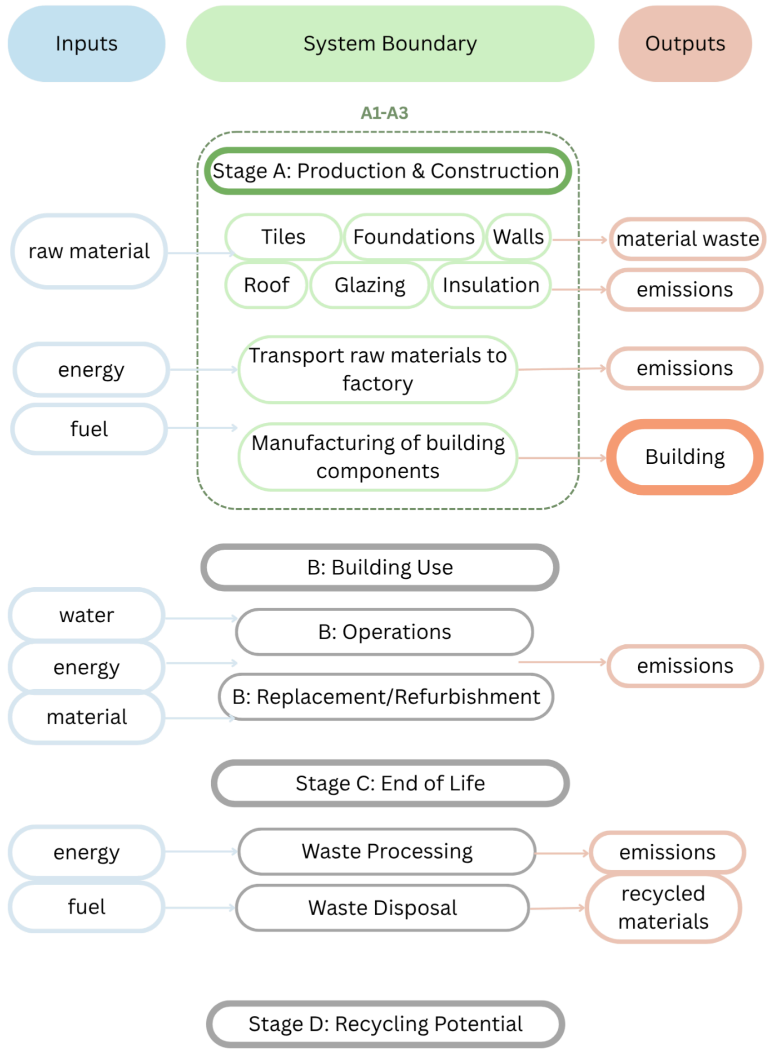

Figure 3: LCA System Boundary Definition

The process of conducting this LCA is as follows: The system boundary of the study must first be identified, which in this case is a cradle-to-gate, or A1-A3 impact study. To be precise, this analysis scope includes material extraction, manufacturing, transportation, and construction. The study scope excludes use, maintenance, and demolition/disassembly. For components that are reused, recycled, or designed for disassembly, end-of-life alternatives will be considered, and the boundary will include credits for avoided impacts (Figure 3). Once the precise study parameters are determined, meetings with the project team will be needed to confirm material specifications, quantities, and procurement routes. This includes identifying which components were reused, which were sourced as reclaimed, and which were newly manufactured.

Following interviews, impacts will be quantified using Environmental Product Declarations (EPDs), which provide standardized data on global warming potential (GWP) and other impact categories. The LCA analysis will be conducted through guidelines provided by the Carbon Leadership Forum (CLF) alongside the CLF 2025 material baseline data set.

To assess the environmental value of circular strategies, the "circular scenario" and the conventional alternative "non-circular scenario" must be established, which will vary depending on the project. Examples include: a full demolition and new construction scenario instead of renovation, traditional procurement instead of modular construction, or conventional material sourcing instead of reclaimed components.

3.3.1 Scope Reduction Justification

The study was initially designed to apply a cradle-to-grave LCA, LCC, and S-LCA framework in order to evaluate the TBL impacts of real construction projects. At the outset, this approach was conceptually appropriate because these methods are among the most commonly used metrics for assessing sustainable strategies within the built environment. In particular, circular economy is inherently linked to the life cycle of buildings and materials. CE strategies seek to extend the useful life of individual materials, building components, or the building as a whole through reuse, adaptation, and waste reduction. Because CE directly addresses end-of-life waste and seeks to minimize disposal impacts, a cradle-to-grave LCA was initially proposed, as this appeared initially to be the most suitable environmental assessment method. Likewise, if environmental impacts were to be evaluated across the full building life cycle, it was reasonable to propose LCC as the corresponding economic measure, capturing costs incurred over the same long-term period.

As the research progressed, however, practical constraints and the realities of available project data necessitated a refinement of scope. The environmental assessment component was ultimately reduced from cradle-to-grave to cradle-to-gate. One primary reason for this adjustment was the nature of available data sources. Environmental Product Declarations (EPDs), which are commonly used to quantify embodied environmental impacts in construction materials, are generally cradle-to-gate documents. They provide data associated with raw material extraction, manufacturing, and transportation to the project boundary, but do not typically include building operation, maintenance, replacement cycles, or demolition stages. Extending the analysis beyond this boundary would therefore require substantial supplementary assumptions or additional performance data that were not consistently available.

A second limitation involved the operational phase of the buildings studied. To complete a cradle-to-grave assessment, reliable estimates or monitored performance data would be required for systems such as insulation, glazing, lighting, water use, and MEP systems. Collecting this information was not feasible within the study's timeframe. In many cases, the selected projects involved older existing buildings, where historical performance records were incomplete, unavailable, or not organized in a manner suitable for life-cycle modeling. Attempting to project long-term operational performance under such conditions introduces a high degree of uncertainty and potentially weakens the validity of the findings.

In addition, many of the CE strategies examined in this study were focused on material retention and adaptive reuse rather than operational efficiency improvements. For example, the reuse of an existing structural frame, floor slab, or enclosure system can significantly reduce embodied carbon and construction waste, yet these strategies may not substantially alter operational energy performance over the building's remaining life, as noted by case study responses. As a result, emphasizing cradle-to-grave operational impacts risked shifting attention away from the central CE actions under investigation, specifically, preserving materials already in place and avoiding the impacts associated with new material production and demolition waste. For this reason, a cradle-to-gate system boundary was more aligned with the study's objective of evaluating material-reuse centered circular strategies. Operational carbon in buildings has been extensively studied, and modern sustainability initiatives are often prioritized at the cost of implementing embodied carbon strategies. Because of this need for embodied carbon reduction strategies and the emphasis that CE places on material retention and waste reduction strategies, an embodied carbon emphasis was chosen.

Similar reasoning led to the reduction of the economic assessment from full life cycle costing to upfront cost evaluation. Although LCC is valuable for understanding costs over a building's entire service life, practitioners involved in construction delivery often place greater emphasis on immediate capital costs, budget certainty, and initial financial feasibility during early project decision-making. This was particularly relevant in the case studies, where stakeholders were more familiar with first costs than with long-range maintenance or replacement projections. Reliable long-term cost forecasting would also require assumptions regarding future labor rates, energy prices, maintenance schedules, and inflation, all of which introduce additional uncertainty.

Therefore, narrowing the economic scope to upfront cost impacts improved both the practicality and relevance of the analysis. It allowed the study to evaluate financial considerations that more directly influence whether CE strategies are adopted during project planning and construction.

When combined with cradle-to-gate LCA and qualitative social considerations, this revised assessment method remained consistent with the TBL intent of the study while improving methodological feasibility and reducing dependence on speculative long-term assumptions.

Ultimately, the reduction in scope should not be viewed as a limitation alone, but as a strategic refinement. By focusing on measurable upfront environmental and economic impacts, the study is better positioned to assess the current viability of CE strategies in existing construction projects, where data availability, stakeholder priorities, and project timelines often constrain the use of more expansive life-cycle methods such as a Cradle-to-Grave LCA and LCC assessment.

3.4 Economic Metric: Comparative Cost Analysis

The second component of this study is an economic assessment conducted alongside the environmental analysis. Because the environmental assessment is limited to the cradle-to-gate (A1–A3) lifecycle stages, the economic assessment similarly focuses on direct upfront cost impacts associated with circular and non-circular alternatives. Unlike the Life Cycle Costing (LCC) approach proposed by Larsen et al. (2022), which evaluates costs across the full building lifecycle, this study uses a comparative cost assessment to examine the immediate economic implications of circular strategies at the assembly level. By aligning the economic and environmental boundaries, the assessment allows for a direct comparison of the financial and embodied carbon impacts associated with individual design and material retention decisions. A 2023 study identifies poor stakeholder engagement as one of the key barriers to implementing circular economy in construction. Because owners in construction projects are primarily motivated by cost and schedule performance, rather than sustainability alone. There is often the notion that implementing an environmental strategy in a construction project comes at a financial cost, which owners are not willing to incur (Salazar-Izquierdo, 2022). The process for conducting the comparative cost analysis for this study is as follows:

- First, the cost boundary must be determined. Costs may include the initial cost of work performed, operational and maintenance expenses, repair cycles, replacement intervals, and end-of-life considerations for both the circular and baseline scenarios. In this study, the cost boundary is defined as upfront so that the cost scope matches the A1-A3 environmental scope.
- Close coordination with the chosen project team is required to obtain accurate figures, including procurement costs for reused or modular components, additional labor associated with deconstruction or refurbishment, and savings from avoided material purchases or reduced demolition.

Some circular strategies can also influence maintenance cycles. For example, modular components may reduce repair costs, while reclaimed materials may require more frequent inspection. In the case of an analysis scope that exceeds A1-A3, scenarios are to be compared over the building's life span. The goal of this cost comparison methodology is to compare upfront cost between a circular and non-circular scenario when broken down at the assembly level.

3.5 Social Metric: Social Life Cycle Assessment (S-LCA)

Social Life Cycle Assessment can be used to quantify the social impact of sustainable strategies. When looking at studies about S-LCA, not all of the 9Rs of circular economy are applicable to construction, but some are. Stakeholders are typically industry workers, product users, and/or community members affected by production.

The S-LCA portion of this study follows the general assessment structure established by ISO 14040 and ISO 14044, which are the parameters that define LCA, while utilizing the UNEP/SETAC Guidelines for Social Life Cycle Assessment of Products and Organizations to identify stakeholder groups, social impact categories, and assessment indicators (UNEP, 2020).

Among the three assessment types discussed in this study, S-LCA is the least frequently used and least standardized methodology for measuring impact, but it can still be used in order to address any additional and project-specific concerns. There is no universally accepted set of standardized S-LCA metrics equivalent to kg CO2e in LCA. Instead, UNEP/SETAC guidelines provide stakeholder categories and subcategories. Once stakeholders are decided, one must also determine the positive or negative impact that this may cause people/communities. Can only determine whether an action had a positive or negative impact, the magnitude of how much is not as quantifiable (Bhatnagar, 2024). However, in the context of specific projects, additional concerns can be addressed. The S-LCA analysis will be used in order to evaluate potential questions, such as how any practice will impact workplace accidents, employee health, and disease in those industries.

- ➔ How will the project team be impacted through strategies that expose them to potentially dangerous chemicals in the recycling/recovery process?
- ➔ What cultural benefit is there to renovating a historic building, as opposed to new construction?
- ➔ How will changes in the affordability of the project impact rent? (in the case of a residential project)

For this process, stakeholders must first be identified in the project, which may include construction workers, building users, surrounding community members, and local organizations influenced by renovation or demolition decisions.

Because S-LCA lacks universal metrics, categories will be developed based on issues most relevant to the project. These impact categories are related to human well-being before, during, and after the project. Interviews, surveys, and discussions with project team members and stakeholders will provide insight into perceived risks, benefits, and social outcomes.

As stated previously, S-LCA cannot precisely quantify magnitude, unlike LCA or LCC, but it can determine the direction and nature of social effects, highlighting trade-offs or concerns of CE strategies. The analysis will explain how social outcomes support or challenge the viability of circular strategies and whether they align with the broader aims of sustainability in the built environment.

Although environmental benefit is a major objective of circular economy and other sustainable frameworks, sustainable construction projects must also address feasibility concerns such as financial constraints and social impacts, which are major concerns for project owners and investors.

Section 4: Assessment Methodology Demonstration

The purpose of the demonstration is to show, step-by-step, how the proposed TBL assessment method can compare competing construction strategies using measurable environmental, economic, and social criteria. To achieve this, a hypothetical project scenario is used: the conversion of an existing 25,000 square foot urban office building into residential housing. This is contrasted with the demolition and subsequent new construction of a multifamily residential building of the same footprint and similar structural and exterior characteristics.

This project type was selected because it reflects contemporary market conditions in many United States cities. Demand for housing remains high, while office vacancy rates have increased substantially in the post-pandemic period. In dense urban areas, where undeveloped land is limited and sprawl reduction is a planning priority, redevelopment frequently occurs on parcels that already contain existing buildings. As a result, stakeholders are increasingly faced with two primary options. Scenario 1 consists of full demolition followed by new construction, whereas scenario 2 involves partial demolition with adaptive reuse and retrofit of the existing structure.

Although full demolition and replacement may be logistically straightforward from a design and construction management perspective, it often represents the most resource-intensive pathway. Demolition of structurally sound buildings generates significant construction and demolition waste, increases landfill burden, and discards embodied carbon already embedded in the existing structure. New construction further requires large quantities of virgin materials, particularly for concrete foundations and steel structural systems. The extraction, manufacturing, and transportation of these materials creates considerable and avoidable environmental impacts.

By contrast, adaptive reuse strategies preserve existing embodied resources while reducing waste generation and material demand. These projects may require greater early-stage coordination among project stakeholders such as owners, designers, and contractors, particularly when integrating new program requirements into the project scope. However, such complexity may be offset by lower environmental impacts, reduced disposal costs, shorter construction timelines in some cases, as discussed in Section 8 of this study, and broader social benefits associated with sustainable urban redevelopment.

4.1 Assessment Overview

This assessment method demonstration compares the following two scenarios for the same 25,000 square foot building:

- Scenario A describes a full demolition and new multifamily residential construction project with the same building footprint as the existing commercial building. The existing office building is completely demolished, including structural systems and interior components, and replaced with a newly constructed residential building of equivalent size. This is the previously described take-make-dispose strategy, which is often used rather than retrofitting existing buildings.
- Scenario B describes the partial demolition and subsequent multifamily residential retrofit of the same 25,000 sq ft office building described in the first scenario. The existing building's structural frame, core and shell, facade, and access components, such as stairwells, are retained. In this scenario, interior framing, partitions, and finishes are removed and replaced to accommodate residential layouts. Mechanical, electrical, and plumbing (MEP) systems are assumed to be fully redone in order to accommodate the occupancy increase between a commercial and residential building. Approximately 50% of glazing is replaced to provide operable windows suitable for residential occupancy. The second scenario reflects the preferred circular construction strategy examined in this thesis. It retains major structural assets while allowing sufficient intervention to support functional conversion.

This simplified project is intentionally uniform in scope: all floors are assumed to receive equivalent renovation treatment, and the building geometry is kept basic to improve analytical clarity. The case, therefore, serves as a demonstration of how the proposed assessment method can quantify and compare the tradeoffs of demolition versus reuse under realistic conditions across the selected environmental, economic, and social metrics of this study.

Once circular and non-circular baseline scenarios have been established, an LCA and cost comparison can be made in order to evaluate the environmental, social, and economic impact of the scenarios. Ideally, for the most accurate representation of data, the actual cost and specification of materials can be acquired. This requires knowledge on the manufacturer level because materials can vary significantly in cost and environmental impact. This impact may be smaller for line items such as paint and hardware, but when considering the carbon impact of concrete structural elements or glazing systems, the manufacturer matters.

As this is an estimated run-through in order to build understanding of how the assessment method operates in practice, Carbon Leadership Forum (CLF) baselines were used as industry averages. The CLF baseline report is a set of average embodied carbon values (kg CO2e per declared unit) for common building materials like concrete, steel, wood, and finishes. These values are derived from industry data such as EPDs, which have been aggregated to form average values by category in the Pacific Northwest, and represent average or “baseline” impacts rather than project-specific ones. If manufacturer specifications can be provided by the project, the global warming potential (GWP), or kg CO2e section of an EPD should be used as values. This is particularly relevant for hardware and tile, which can vary significantly in the manufacturing process. The system boundary scope of the circular and non-circular scenario can be adjusted by adding estimated carbon during installation of the materials, refurbishment over time, or operational impact over time, but this must be specified and accounted for equally and fairly in both the circular and non-circular scenario.

Several assumptions were made in this analysis. Because the CLF baseline relies on EPD data, which accounts for A1-A3 impacts only, this will be the scope of the environmental and cost assessment. Reused materials are assumed to have a negligible A1-A3 carbon impact. Carbon and costs associated with on-site construction work, labor, and machinery are not accounted for in this assessment, although it would be beneficial to consider in future assessments. The building is assumed to be 40% glazing and 60% opaque, which is the widely used "rule of thumb" for optimal commercial building performance (Marceau & Hoffman, 2013). As the residential retrofit scenario leaves major structural building elements untouched, this split will remain the same in both scenarios.

The foundation system is assumed to be a shallow reinforced concrete mat or spread footing system typical of mid-rise construction in urban conditions. As foundations are measured in terms of a building's footprint rather than total floor area, the foundation footprint is assumed to be 5,000 SQF. In order to accommodate operable windows in residential units, 50% of glazing is replaced. To maintain consistency across both environmental and economic comparisons, CLF baseline data were used in conjunction with industry-standard cost data derived from RSMeans Construction Cost Data. This alignment ensures that both carbon and cost calculations are based on standardized, comparable datasets. However, this methodological decision also constrains the scope of the analysis. Only material categories that can be clearly mapped to CLF baseline values and RSMeans data were used, leading to the exclusion of MEP systems, finishes, and sitework. Carbon fiber reinforced polymer (CFRP) was added as a material category with supplemental EPD and cost data as an acknowledgment that older buildings may require structural reinforcement, which adds to logistical, cost, and environmental considerations. The results from this demonstration should be interpreted as deltas in the environmental, economic, and social metrics of selected material and assembly categories. Given these assumptions, Table 3 breaks down the described assumptions into assembly categories and quantities.

Material Category	**Declared Unit**	**Non-Circular Qty (Declared Unit)**	**Circular Qty (Declared Unit)**
Concrete foundation	m^3	139.45	0
Foundation rebar	metric ton	13.94	0
Structural concrete	m^3	384.39	0
Structural rebar	metric ton	38.32	0
Glazing	metric ton	7.88	3.94
Exterior envelope / cladding	100 m^2	7.88	0
Interior framing	metric ton	10.21	10.21
Drywall	1000 ft^2	55	55
Insulation	m^2	2081.13	2081.13
Roof	m^2	464.52	464.52
Flooring	m^2	2,322.58	2322.58
CFRP strengthening	m^2	0	92.9

Table 3: Materials and Quantities for Assessment Method Demonstration

4.2 Cradle to Gate LCA Assessment Method

The environmental assessment portion of the theoretical assessment demonstration consists of a cradle to gate, or A1-A3, life cycle assessment (LCA). Embodied carbon impacts are calculated using the Carbon Leadership Forum (CLF) North American Material Baseline Report 2025, which provides average global warming potential (GWP) values for common building materials. These values are derived from aggregated EPD data and represent typical industry conditions rather than project-specific performance (Waldman, 2025).

For this demonstration, the system boundary is limited to A1–A3 (cradle-to-gate) impacts, consistent with the scope of CLF baseline data. As a result, carbon associated with construction activities, transportation, installation, and operational use is excluded. The general calculations are as follows:

Embodied Carbon = (Material Quantity x Declared Unit) x (CLF Baseline kg CO2e / Declared Unit)

Carbon Savings = Baseline Scenario - Circular Scenario

In an applicable case study scenario, CLF Baseline for the specified material category is replaced with kgCO2e of the specified material EPD. An example of this is illustrated with retained wooden doors in a building.

Volume per door: 0.06 m^3
Number of Doors: 45
Total Volume in Strategy: 2.7 m^3
2.7 m^3 × 250 = 675 kg CO2e

Material quantities (QTO) were developed based on building geometry and typical construction assumptions. Foundation systems scale with building footprint rather than total floor area. Reinforcing steel quantities are estimated based on standard ratios per cubic meter of concrete. Structural concrete volumes are derived using typical mid-rise construction benchmarks.

Summary Metric	Value	Unit
Total non-circular GWP	312,510.46	kg CO_2e
Total circular GWP	90,220.80	kg CO_2e
Total carbon savings	222,289.66	kg CO_2e
Percent reduction	71.1%	%

Table 4: Example of Assessment Method LCA Results

The environmental results compare total embodied carbon between the circular and non-circular scenarios across all included material categories.

The analysis demonstrates that the non-circular scenario, which relies on complete demolition and reconstruction, results in significantly higher embodied carbon due to the production of new structural materials. By contrast, the circular scenario achieves substantial reductions by retaining the existing structure and minimizing the need for new material inputs. For a more complete future analysis, databases in addition to the 2025 CLF North American Baselines Report and RSMeans Construction Cost Insights Report: Q1 2025 should be aggregated.

4.3 Project Cost Demonstration

Cost estimates were developed using unit pricing derived from industry-standard construction cost data. These values represent installed costs, including both material and labor components, and were normalized to align with the material categories used in the assessment method. The scope and calculation method for the comparative cost assessment portion of this analysis align with the methods used in the environmental assessment. Costs were calculated per unit using RSMeans typical values for the described materials. In cases where a range of values is provided, the average cost value was used. Calculations follow the same format of environmental assessment calculations:

Total Material Cost = Quantity x (Cost/Unit)

Cost Savings = Baseline Scenario - Circular Scenario

In a practical case study scenario using EPDs of the specified material, either total cost of material + labor for the specified activity, or cost/unit + labor. If reported costs are unavailable, typical RSMeans values can be used.

It is important to emphasize that the cost analysis presented in this demonstration does not represent total project cost. Instead, it reflects selected material and assembly categories included in the assessment method, allowing for a direct comparison between circular and non-circular strategies. Sitework and demolition, MEP systems, soft costs such as permits and design fees, and profit were excluded from the cost scope, as they are not relevant to material reuse.

As a result, the cost totals presented should be interpreted as partial construction costs, rather than full project budgets. This distinction is critical, as total project costs for similar developments are typically significantly higher.

Summary Metric	Value	Unit
Total non-circular cost	$2,747,452.20	USD
Total circular cost	$1,708,644.01	USD
Total cost savings	$1,038,808.19	USD
Percent reduction	37.8%	%

Table 5: Example of Assessment Method Economic Results

These results highlight the importance of structural retention as a primary driver of embodied carbon reduction in adaptive reuse projects. In the demonstrated scenario, retaining significant portions of the existing concrete and steel structure resulted in proportionally greater environmental benefits than economic benefits, suggesting that structural retention strategies may have a particularly strong influence on embodied carbon reduction. The analysis also demonstrates that environmental and economic objectives can align under certain conditions, as the circular scenario achieved reductions in both embodied carbon and upfront costs when compared to the non-circular alternative (Figure 4), even when accounting for additional interventions such as CFRP structural reinforcement.

It is important to note that these findings are specific to the demonstrated scenario and should not be interpreted as evidence that all circular economy strategies will produce simultaneous environmental and economic benefits. Rather, the purpose of this analysis is to illustrate a replicable process for quantifying and comparing the environmental and economic impacts of circular and non-circular alternatives. By establishing a consistent basis for comparison, the assessment method provides a framework for evaluating the potential benefits and tradeoffs of circular strategies in future studies and construction projects.

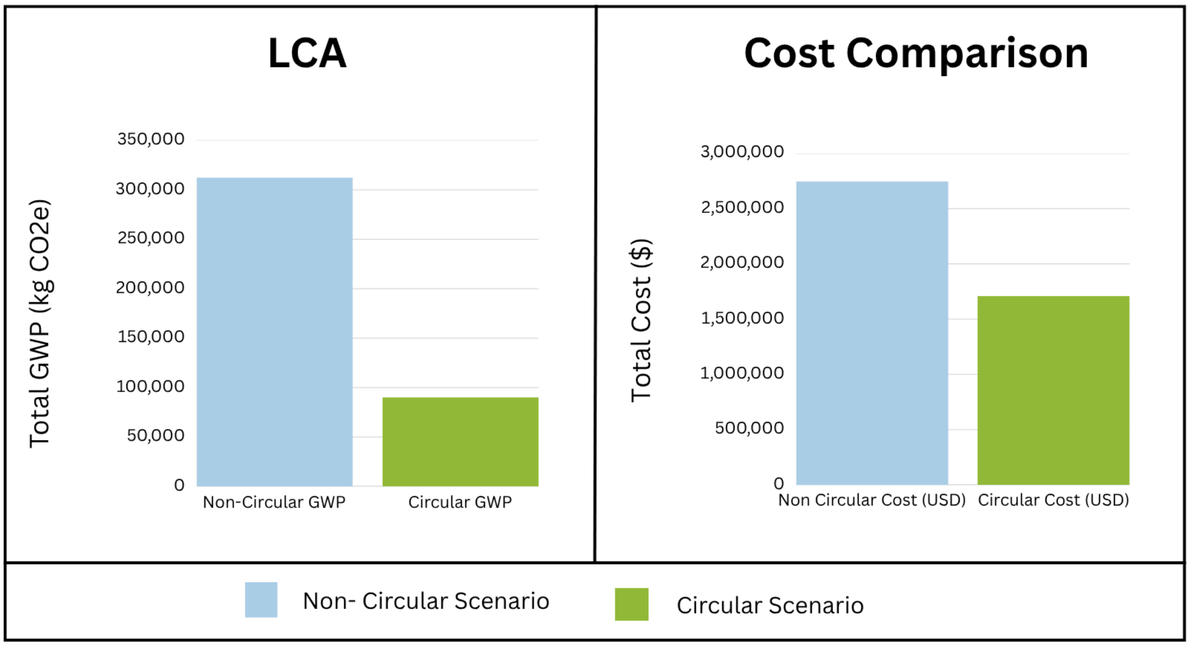

Figure 4: Circular and Non-Circular Scenario Comparison

4.4 S-LCA Demonstration

In addition to environmental and economic evaluation, the proposed assessment method incorporates a Social Life Cycle Assessment (S-LCA) component to assess the broader human and organizational impacts of circular construction strategies. This component is informed by the principles outlined in ISO 14075, which provides guidance for evaluating social impacts across product life cycles. While ISO 14075 focuses specifically on S-LCA, its methodological foundation is aligned with the broader LCA framework established in ISO 14040 and ISO 14044. These standards emphasize a structured, transparent assessment process. The S-LCA components in this study are adapted to the context of construction project delivery, where social impacts are often qualitative and project-specific rather than purely quantitative.

4.4.1 Stakeholder Identification and Impact Categories

The S-LCA process begins with the identification of relevant stakeholder groups. Project owners and developers, construction managers, designers, field workers, material suppliers, and local vendors were found to be primary stakeholders for a project of this type. These groups were selected because they are directly involved in the implementation of construction strategies and are most affected by changes introduced through circular economy practices.

Social impacts were organized into a set of qualitative categories. These include skills, training, working conditions, and job complexity, supplier relationships and local sourcing, market competitiveness and industry positioning, and project disruptions. Together, these categories capture both workforce and organizational-level impacts associated with implementing circular strategies.

Data for these categories should be collected through a structured questionnaire distributed to project stakeholders involved in the case studies. The questionnaire was designed to capture changes in training requirements, installation methods, coordination effort, stakeholder relationships, and overall perceptions of circular strategy implementation. Responses are to be evaluated qualitatively and used to identify positive and negative patterns and recurring themes across stakeholder groups. Within the assessment method demonstration, these categories are applied conceptually to illustrate how social impacts differ between the circular and non-circular scenario.

4.4.2 Application of S-LCA to Theoretical Demonstration

Within the assessment method demonstration, the S-LCA component is applied conceptually rather than through project-specific responses. This reflects the demonstration's purpose as a controlled illustration of how the assessment method operates.

For the two scenarios defined, social impacts may include increased coordination among project stakeholders, greater technical complexity in integrating unfamiliar circular systems, opportunities for new roles related to material reuse and deconstruction, and increased interaction with local or suppliers in the case of local material reuse and specialized disposal.

This comparative approach allows the assessment to capture how circular strategies may influence not only environmental and economic outcomes, but also workforce development, collaboration, and industry practices.

Unlike the environmental and cost components, the S-LCA results are not expressed as numerical outputs. Rather, they are evaluated as categorical impacts across stakeholder groups.

Section 5: Case Study Selection

The second phase of this study is the identification of the case study that will be evaluated for its environmental, economic, and social benefits. The case study selection process began with evaluating 15 projects previously contacted by Idris Soliu (Table 6). These projects have a range of circular economy strategies implemented, and vary widely in terms of project scope, building type, contractors, and completion date.

Choosing a single project to work with presents the risk of losing contact or project teams being unable or unwilling to share sensitive data, such as a bill of materials, BIM files, or financial data, as this is sensitive information. Projects were scored according to their perceived desirable traits for an in-depth case study analysis, which refined the list to 5 projects. Contact was attempted with the 5 case studies, and formal preliminary interviews were scheduled with 4 of the 5 projects. After contact with the project team and evaluation of engagement level, 2 projects were selected for the final analysis, in order to provide a look into the greatest possible number of circular economy strategies. These projects were selected based on the number of strategies implemented, completion date, proximity of site, and completion date. Because this is a detailed study, projects such as Google Westlake presented too large a scope to reasonably evaluate, given the time frame. Ideal projects also must be recently completed, as project staff are likely to be more engaged with recently completed projects, and staff who participated in these projects are likely to still be with the selected contractor. However, projects that are still in progress are difficult to evaluate because they carry a degree of uncertainty in terms of cost and final environmental impact. Once the project is chosen, the study can begin.

Overall, the research study is broken down into 3 analysis frameworks to address the triple bottom line: LCA, LCC, and S-LCA. Because these processes require an interview phase with the construction team and a quantitative analysis phase, the evaluations will occur simultaneously, but have been broken down into their individual sections for clarity.

5.1 Defining Selection Criteria

In order to narrow down the projects from 15 to 5 preliminary options, a selection matrix was created in order to evaluate the best projects to move forward with. These selection criteria are ranked and assigned a number of points based on importance.

1. **Access (High Level Assessment)**

The most important factor for whether to move forward with a project, in this case, is access. The project team must be responsive and willing to disclose detailed project information, such as a bill of materials, construction documents, financial data, and personal experiences from staff. If the project team is unable or unwilling to share this sensitive information, an assessment will not be possible. After initial contact with project teams was made, their willingness to participate was evaluated on a scale of 3, 6, or 9. Projects with a score of 3 are automatically designated as a no-go. Projects assigned a 6 are not ideal to work with, either because they are unlikely to share sensitive information, or because they have been unresponsive in the past. Project teams that are both responsive and able to share project information are assigned a score of 9.

2. **Breath of CE (Scale of 1-9)**

Because of the small number of projects evaluated, the number of CE strategies used in the project is also highly relevant as a selection criterion. As this assessment is based on the 9Rs of the circular economy for construction, projects will be ranked on the number of strategies that they fulfill, with zero being the minimum number of strategies, and 9 being the maximum.

3. **Manageable Scope (Descriptive analysis 1-3)**

Due to the level of detail required for this analysis and time constraints of the research timeline, projects must have a manageable scope of work. Projects that are overly large or complex receive a score of 1 and are automatically disqualified. Projects with an unideal but manageable scope are assigned a score of 2, and projects that are small and/or replicable are assigned a score of 3.

4. **Completion Date (1-3)**

A recent completion date is ideal for projects because team members are more likely to still be with their respective companies and engaged with the projects. Details of personal experience will also be fresh on team members' minds, which is ideal for an S-LCA assessment. However, risks associated with older completion dates can be mitigated by working with a highly engaged team. Projects with a completion date between 2023 and 2026 receive a score of 3, projects completed between 2018 and 2022 receive a score of 2, and projects completed either before 2018 or after 2026 receive a score of 1 and be disqualified.

5. **Proximity (Tiebreaker Criteria)**

Local projects provide the benefit of being more accessible, and teams working in the area may be more willing to participate in local research. The risk of disengagement from more remote projects can be mitigated by a responsive project team, which is why this criteria has been designated as a tiebreaker. Projects will receive a score of 1 or 2, on the basis of whether they are in the Seattle area or not.

Scoring of Projects:

Project Title	**Access**	**CE Breadth**	**Scope/ Managable**	**Date**	**Proximity**	**Total Score**
Google Westlake	**9**	**6**	**1**	**2**	**2**	**20**
NTT H2 Data Center	**9**	**5**	**1**	**3**	**1**	**20**

UW Anderson Hall	**9**	**7**	**3**	**3**	**2**	**24**
Esterra Park	**6**	**6**	**2**	**3**	**2**	**20**
15th & Market	**6**	**5**	**2**	**2**	**2**	**17**
UW Haring Center	**9**	**4**	**3**	**3**	**2**	**21**
Union Stables	**6**	**7**	**3**	**1**	**2**	**19**
Troy Block	**6**	**7**	**3**	**1**	**2**	**19**
Federal Reserve Building	**6**	**6**	**3**	**2**	**2**	**19**
Haggett Hall	**9**	**5**	**3**	**1**	**2**	**20**
Vela Apartments	**9**	**6**	**2**	**3**	**2**	**22**
The Kendeda Building	**9**	**9**	**3**	**2**	**1**	**24**
1 Hotel Seattle SLU	**9**	**6**	**2**	**3**	**2**	**22**
Kincaid Hall	**6**	**6**	**3**	**2**	**2**	**19**
Rejuvenate Queen Anne	**9**	**9**	**3**	**2**	**1**	**24**

Table 6: List of Case Studies

5.2 Evaluation of Projects

With a score of 24 points, the Anderson Hall renovation at the University of Washington, Rejuvenate Queen Anne in Seattle, and the Kendada Building in Atlanta, Georgia scored the highest initially, marking them as ideal projects for this type of assessment. With engaged teams that are highly responsive, a manageable building scope for a detailed assessment, and a comprehensive number of CE strategies, these projects are the lowest risk options for study. The Kendada building is a fully circular building, which was completed in 2019, while Anderson Hall has an ideal completion date of January 2026, and is physically accessible, but lags slightly behind in its CE completeness.

After attempting initial contact with the case study project teams, initial interviews were conducted with 4 of the 5 initially selected high-scoring projects:

1. The 1 Hotel Seattle Commercial Renovation, JTM Construction
2. The Kendeda Building New Construction, Skanska
3. The Vela Apartments, Compass Construction
4. Rejuvenate, Queen Anne, Compass Construction

Anderson Hall initially ranked highly during project screening. As a historic renovation of an existing university building, the project preserves many of the building's original architectural and structural elements. The building is protected under the National Historic Preservation Act of 1966 (NHPA), as it was completed in 1925. As a result, there was a strong incentive to retain as much of the original building fabric as possible while simultaneously addressing accessibility requirements under current ADA requirements, which were not considered at the time of the building's construction. This created a compelling case for examining the social and cultural value of preserving a historic structure, in addition to the long-term financial benefits associated with upgrading inefficient mechanical, electrical, and plumbing (MEP) systems.

However, access delays arose during attempts to arrange stakeholder interviews and project meetings. Multiple efforts to schedule discussions ultimately resulted in loss of contact and unresponsiveness from the project team. Although other strong candidates were selected, this limitation reduced the study's ability to make full use of the proposed assessment method. It is also important to note that this was not an isolated occurrence. Similar issues emerged with several other high-ranking projects. In those cases, initial contact was established, but available information was fragmented, and project teams were unable to provide the desired level of detail. This information gap was anticipated, which is why multiple case studies were selected for initial outreach. Construction project teams frequently transition from one project to another, and stakeholder availability is often unpredictable. Nevertheless, it is significant that the projects that initially received the highest screening scores were not fully utilized due to these practical constraints. As discussed in the following section, the initial interview phase found that the Vela apartments were not an ideal project for this type of assessment. However, the general contractor (GC) proposed an alternative project that was currently being worked on, an office-to-residential retrofit project. This project, "Rejuvenate," is the 4th and final case study to participate in the initial interview process.

The projects that were ultimately used, a hotel-level commercial remodel emphasizing reused materials, and an office-to-residential retrofit, still provide valuable and relevant scenarios for evaluating CE strategies. However, they are not fully capable of capturing the breadth of CE implementation across the built environment on their own. For example, although projects such as 1 Hotel Seattle pursued LEED Silver certification, many custom materials were incorporated, and reported benefits relating to cost savings, carbon reduction, and stakeholder outcomes were primarily anecdotal in nature. Material quantities were provided, but material specifications were not. As a result, the assessment method was able to identify general trends in the cases of the 1 Hotel and Rejuvenate, but the precise magnitude of improvements could not be determined.

Because of these access constraints, the methodology evolved to better demonstrate the potential significance of the assessment method. An expanded literature review was developed to strengthen the justification for the assessment method and its application. Existing literature confirms that skepticism remains within the construction industry regarding the benefits of sustainable strategies broadly, and circular economy approaches specifically, as viable pathways to sustainability. The literature review also indicates that the TBL assessment method may serve as an effective means of demonstrating value to investors and decision-makers by presenting sustainability initiatives, such as CE, as worthwhile investments. In particular, the review shows that LCA, LCC, and S-LCA are commonly used to evaluate the environmental, economic, and social dimensions of the TBL.

Furthermore, the practical information gap identified in the case studies led to the addition of the assessment demonstration chapter, which illustrates how the methodology functions under an ideal information scenario. This ultimately creates a more robust comparative synthesis, as the study is able to demonstrate the level of insight that can be extracted under both ideal and constrained data conditions. As CE becomes a more widely adopted sustainable construction strategy, it is hoped that project information will be better organized and shared more transparently, allowing for more comprehensive analyses of the environmental, economic, and social benefits of these strategies across the TBL. By incorporating these supplemental elements into the research design, the study reduces its dependence on stakeholder interview access while still demonstrating the broader applicability of the proposed assessment method.

Section 6: Initial Interview Phase

6.1 Interview Structure

To collect qualitative data on circular economy strategies implemented in construction practice, a semi-structured interview was conducted with key members of the 3 project teams involved in the construction overview process of the case study projects. The interviews included participants from the general contractors, ranging from project managers, project executives, and dedicated circularity or sustainability experts, depending on the projects. The members were preselected based on interest and participation in a previous case study. Project team members were directly involved in managing and tracking sustainability measures on the project. The academic participants included the researcher and faculty members supervising related research on circular economy frameworks in construction.

The purpose of the interview was exploratory. At this stage of the research, the objective was not to collect detailed quantitative data, but rather to understand the nature of the circular strategies implemented on the project, and to determine what forms of project information might be available for future assessment, as well as doing a final gauge of interest in participating in the study. As the study was conducted with information that some contractors would consider sensitive, a certain degree had to be taken to both ease participants into this type of study and to understand whether the scope of the project could be measured accurately according to the proposed circular assessment method. The interview therefore, focused on identifying relevant project decisions, sustainability strategies, and documentation processes that could later support environmental, economic, and social analysis.

6.2 Kendeda Building

The Kendeda building appeared as one of the strongest contenders for this type of assessment. This project is part of two sustainability initiatives: the Living Building Challenge and Skanska's own circularity department based in Atlanta, Georgia. The Kendeda building aligns well with circular economy principles because of the LBC Material Petal, which requires buildings to use sustainable materials. (Georgia Institute of Technology) The Kendeda building is a mass timber building, with a structure made from Nail-Laminated Timber (NLT). The wood for this composite was salvaged from theater sets, as these projects require lumber that is used temporarily. Rather than discard the wood, Skanska was able to use Georgia Tech's Grinnell Building as a salvaged materials warehouse, which stocked various materials such as tile, lumber, metal fixtures, and others (Edelstein, 2019). In addition to the salvaged wood NLT structure, the project team also salvaged tiles, granite curbs, and metal fixtures for the building, although these strategies do not encompass nearly the same scale of the building.

The Kendeda building achieved significant sustainability parameters through its waste diversion program, and according to the interviewed team member, the building "diverted more materials away from the landfill than it sent to the landfill". The building accomplished this through a comprehensive waste sorting program, where the majority of materials were recycled. The total weight of salvaged/reused material in the building totaled 57,300 lbs, while only 48,560 lbs of material were sent to the landfill, although the materials sent to recycling centers, sent back to the warehouse, or used in other construction projects were not specified.

Although the Kendeda building is a new construction project and does not benefit from the reuse of an existing structure, it succeeds in implementing circular economy principles through this comprehensive reuse of materials at the end of their life.

The contractor team from Skanska was extremely engaged in the process of circularity, having gone so far as to personally perform some of the tasks, such as creating mock-ups of the NLT wood structure. Overall, the Kendeda building is an exceptionally sustainable building, and the material strategies used were influenced by both the owner's and GC's belief in the importance of sustainability, rather than financial benefit. Georgia Tech, which was the owner in this case, was committed to the Living Building Challenge and its rigorous standards. Skanska, as the contractor for this project, utilized warehousing services through the university, as well as its own Lifecycle building center, which has operated in Atlanta for over 10 years (Mitchell, 2022). Skanska's sustainability values, combined with the material reuse infrastructure, allowed for an incredibly low rate of waste on this project.

Despite its strong alignment with circular economy principles, the Kendeda Building was ultimately not selected as a primary case study for quantitative assessment. The objective of this research was not only to identify circular strategies but also to develop a methodology capable of being replicated across a broad range of construction projects. While many of the circular practices implemented on the Kendeda Building were innovative and highly successful, several relied on unique project conditions that are not commonly available within the construction industry. In particular, the project benefited from access to established salvaged material warehousing infrastructure and a highly engaged project team willing to invest significant effort into material recovery and reuse activities.

The building's use of salvaged lumber to create Nail-Laminated Timber (NLT) creates strengths and limitations of the project as a case study. Although this strategy represents an impactful form of material reuse, the process required substantial intervention that is not yet widely documented within existing literature. Because the lumber processing and assembly activities were performed directly by project management staff, detailed information regarding labor inputs, associated costs, and environmental impacts was not available. As a result, it was difficult to establish a comparable non-circular baseline scenario or quantify the environmental and economic implications of the strategy using a consistent and replicable methodology.

For these reasons, the Kendeda Building was determined to be a valuable example of circular economy implementation, but a less suitable candidate for demonstrating the assessment method of this study.

6.3 The 1 Hotel Seattle South Lake Union

The 1 Hotel Renovation by JTM utilized several CE strategies as part of what would otherwise seem a typical hotel renovation project. The scope of this project is comparatively small to other projects, encompassing only the ground floor of the hotel, with a lobby area and restaurant lounge. The hotel remained operational during the construction of the project, allowing for significant cost savings on the owner’s end. The hotel rooms themselves were remodeled by a separate GC and are not considered under the scope of this study. The hotel renovation was done as part of brand requirements, and the demand to keep luxury hotels “up to date.” The scale of the renovation is considered a major renovation, which is appropriate for the project's age and change in ownership. The new brand image defines itself as "sustainable luxury," and the project did pursue a LEED silver certification. Circularity was not a project goal by name, although the renovation did include several sustainable strategies that fit under the definition of one of the 9Rs, particularly with preserving building components such as the canopy, floor tiles, and reused doors, bringing continued profit to the hotel (El-Sayed, 2023).

Although the hotel was renovated for financial reasons, as occupancy rates need to stay high for the project to stay profitable, an updated aesthetic increases demand, and the renovation incorporates a surprising number of sustainable strategies that, by the definitions provided in the 9R framework, would be considered circular.

Many of the project's circular strategies go against well-established norms and the design team's initial wishes, which makes establishing non-circular alternatives straightforward. Where a luxury renovation project would typically order new doors and replace outdated, discolored stone tile, this project chose to sand and refinish these components. The contractor noted a particular difficulty with the flooring tiles. There were claims from the designer that the flooring tiles would not be able to be restored to their original tone of white, however the contractor was able to show acceptable results through mockups. The GC also noted that demolishing and replacing floor tiles, although preferred by the designer for aesthetic purposes, presented the additional risk of requiring the demolition of underlayment, which could have caused delays in the construction schedule. Ultimately, due to cost and time constraints, the design team gave leeway for reuse strategies. Other reused components include the canopy, which was clad in wood, and hardware, which was repainted.

Interestingly, this project used one of the only circular strategies observed in this study with true life cycle costing implications. Artists were commissioned to decorate the space with preserved plants. This not only diverts waste from landfills by salvaging plants that were at the end of their life cycle, processing them, and using them as project features, but the investment of this artwork was also designed for minimal maintenance. The preserved plants require less water over time and need not be replaced as often as traditional plants, resulting in decreased operational costs for the project.

6.4 Vela Apartments

The Vela Apartments case study is a mixed-use, market-rate residential development. This project combines adaptive reuse and renovation with new construction. The project began as a two-story commercial from the 1980s, which shifted into a mixed-use commercial and residential development with approximately 141 residential units. While roughly 80% of the project consisted of new construction, the remaining 20% retained the existing structure, and some structural elements were reused, resulting in cost, material, and energy savings. The design and reused components were in response to strict zoning constraints, including height limits and setback requirements, which made a full demolition less advantageous than reworking design in certain portions of the site. The project expanded vertically, adding three stories atop part of the existing structure, as well as horizontally, with the addition of a new five-story residential building, and excavation for an underground parking garage, while maintaining and upgrading portions of the original building's core, shell, and some mechanical, electrical, and plumbing (MEP) systems.

Several strategies implemented in this project fit into what the 9R framework classifies as circular economy, though not to the full extent of the building. Most notably, the partial reuse of the existing building's core and shell represents construction circularity by extending the life of existing structural materials like concrete and steel and reducing the need for new resource extraction, as foundations and structure can consist of up to 55% or a building's global warming potential (GWP) through embodied carbon of concrete and steel, and between 25-30% of a building's total construction cost (Pearson, 2019). This means that if a project has the opportunity to either completely reuse or minorly upgrade these elements, it can be a significant source of cost and energy savings. This included structural retrofitting (reinforcing foundations and adding steel), as well as preserving existing retail spaces, which would otherwise have been demolished and rebuilt. Additional strategies include upgrading and/or reusing MEP systems where feasible, improving building performance through targeted interventions such as window resealing, insulation improvements, and limited system replacement, and maintaining functional commercial spaces to avoid unnecessary reconstruction. These strategies are a cost-effective way of both extending the lifespan of building materials, as well as reducing operational costs. Together, these actions align with circular principles of reuse, building lifecycle extension, minimizing C&DW, and minimizing material waste.

The implementation of these strategies in the project by the GC was driven primarily by economic and regulatory considerations rather than sustainability goals or certifications. The decision to pursue formal sustainability documentation is typically an owner preference, and was not requested in this case. The decision to reuse the existing structure was largely motivated by cost efficiency. As stated previously, the core and shell consume a significant amount of money and time on a construction project. Thus, avoiding demolition and reconstruction of spaces that would have ultimately been rebuilt in a similar form is preferable. While there were some energy efficiency improvements and standard utility rebates for "efficient systems", the project did not pursue sustainable certifications like LEED or LBC, as the certification process was not seen as providing sufficient financial return or tenant demand to justify additional costs. Overall, the circular strategies employed were purposeful but practical, reflecting a balance between cost savings, design constraints, and functional optimization rather than an explicitly sustainability-driven agenda.

6.5 Rejuvenate Queen Anne

The Rejuvenate building in Queen Anne, Seattle (Rejuvenate), is an interesting case for unintended circularity because it is one of Seattle's first office-to-residential retrofit projects. This conversion is an impact of Seattle's Office to Residential Conversion Program, which incentivizes the retrofit and rezoning of existing and unused or underused commercial office spaces into residential housing as a more sustainable way to combat post-pandemic housing scarcity in Seattle (City of Seattle, 2024).

In the years leading up to Covid 19, Seattle saw a massive increase in commercial office construction, with companies like Microsoft and Amazon building many new campuses and buildings in the city. However, with the post-pandemic shift to remote work, many of Seattle's office buildings were left unoccupied. At the same time, housing demand in Seattle continued to rise, and an increase in multifamily housing was needed to increase density. The city's solution to this was to incentivize developers, architects, and contractors to convert these buildings into residential buildings, as this would be more efficient than simply demolishing them. In return for retrofitting existing buildings over demolition and new construction, project teams are incentivized with shorter permitting timelines, waived fees, and some flexibility with code requirements in older buildings.

The intent behind this project was a combination of economic and environmental motivations. The contractor representative for Rejuvenate Queen Anne (Rejuvenate) stated that expedited permitting allowed for construction to mobilize significantly faster, reducing overall project cost. The building had previously been abandoned, and the GC did face unexpected challenges during site inspection, such as inadequate plumbing connections and severely damaged mechanical systems on the ground floor. Still, the project manager affirmed that the cost of remedying these issues was significantly less than demolition of the structure and building a new residential building.

The building was able to use all existing structural concrete and facade elements, and add a 5th story to the structure. Accounting for one level of below-grade parking, the building footprint has a total of 6 floors. In order to accommodate increased loads of the additional floor and higher weight loads of a permanently occupied residential building, carbon fiber reinforced polymer was wrapped around the existing concrete columns. The facade was repainted, and custom glazing was made for sections of the building's glazing due to operable window requirements in residential units. The project was able to retain existing stairway connections between floors despite updated ADA requirements and built stairs between the 4th and 5th floors. This reuse of structure and facade elements in the building, even during a change in use and zoning, aligns with circular economy in construction, and there was clear value retained in waste diversion, embodied carbon reduction, and economic burden.

Because there is a well-defined boundary between the existing 5 floors, and one new floor of new construction, there is an opportunity to compare the cost of constructing the 5th floor, and one of the retrofitted floors, which in this case is the 4th floor. The circular strategies identified were Carbon fiber reinforced polymer (CFRP) wrapping on concrete columns, retaining facade, retaining concrete waffle slabs, partial replacement of glazing, and reuse of the existing stair connection.

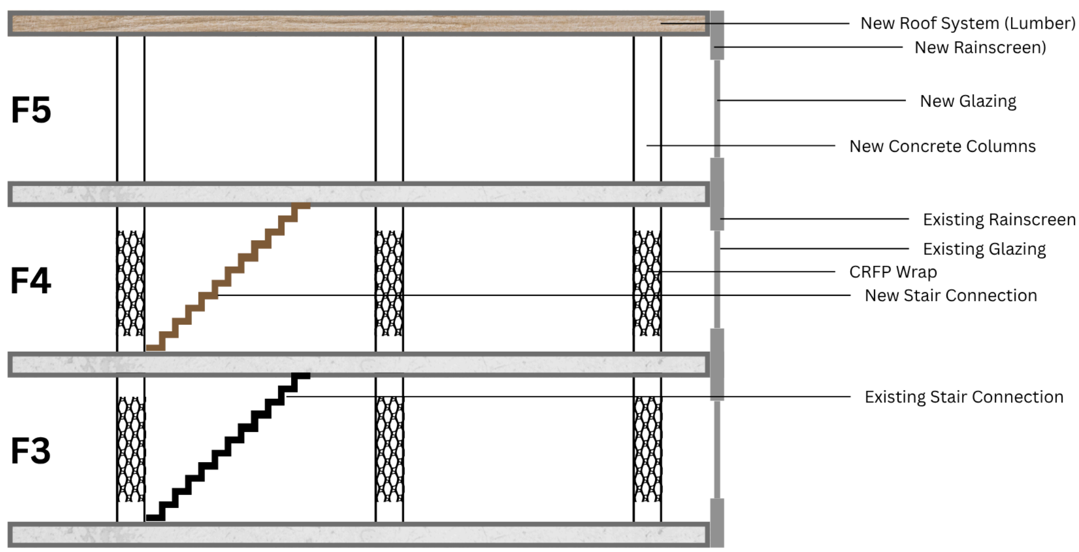

Figure 5: Example of Scenario Described in Rejuvenate Project

Section 7: Data Collection

7.1 Defining the Nature of Required Data for a Successful Assessment

To complete the three assessment types, one must break down the information presented by the project team into more digestible pieces. These strategies include things such as reuse of individual building materials (old doors, old decorations), the repurposing of building materials (salvaged wood, recycled concrete as site fill), use of recycled materials, renovation, and conversion of an existing abandoned office building into a residential building. Based on the interview discussions, small scopes of work were used as strategies, such as doors, tiles, columns, glazing, and other elements that are likely to be broken down by cost. The strategies were then assigned to the "R" that it aligns the most with for future comparison.

In addition to defining the circular strategy, a non-circular alternative must be defined for a meaningful comparison. Because circularity in this case deviates from the typical take-use-dispose practices in the construction industry, this is what defines the non-circular alternatives. By speaking with the project teams, typical alternatives were proposed by simply asking, "What was the alternative to doing this, and what has been done in past projects?" This means that the non-circular alternative is project-specific. Although many of these practices are likely used in many other projects, this study only concerns itself with the practices used by the GCs in these specific case studies. Circular vs. non-circular alternatives include:

- ➔ *Using salvaged wood vs using a manufactured wood product that would perform the same function.*
- ➔ *Wrapping existing concrete columns in carbon fiber reinforced polymer (CFRP) for added structural support vs. pouring new concrete columns*
- ➔ *Refinishing tile in the lobby of the building to meet designer specifications vs Demolishing existing tile, potential underlayment demolition, and new tile procurement.*

The project teams were briefed on CE concepts, so there was an assumed precedent of knowledge of what encompasses a circular vs non circular strategy. Once the strategies for the projects were defined, measurable data is required for each individual strategy in order to find an environmental, economic, or social impact.

LCA Required Information

This section of the analysis focuses on upfront, or A1-A3 emissions, and will estimate the carbon impact of choosing the circular strategy over the standard strategy. Project teams were asked how a record of materials used in the projects was kept. In order to determine the quantity of materials used in the various strategies, the following sources would be acceptable:

1. **Existing complete bill of materials (BOM):** This would be the most straightforward, but unlikely method of getting material information. In this case, a dedicated BOM would be preexisting. This is the most likely to occur for projects such as the Kendeda building, which have material sourcing requirements as a result of the LBC requirements. Projects pursuing LEED sourcing of raw materials credits are also likely to have this type of documentation, as they would have been required to prove that between 15-30% of materials used in the project by cost fit sustainability criteria outlined by LEED (USGBC).
2. **Quantity Takeoff (QTO) from a detailed estimate**: When bidding on projects, general contractors (GCs) must complete a quantity takeoff. For these estimation documents, materials are estimated based on specifications, usually design drawings, and cost of building scopes are determined based on these takeoffs. However, this information will only reflect estimated material and will not account for actual ordering.
3. **Design Drawings (Least Ideal):** If neither a BOM nor a QTO document can be used to record material quantities, building drawings can be used to obtain material quantities. This is the least realistic option on the GC side. Design software such as Revit has the

ability to make a material takeoff schedule, but this would be managed by the design team, not the construction team. For renovation projects, existing building drawings can be used to perform a manual takeoff, although this is not ideal.

Once material quantities are established, suppliers should also be looked at in order to determine the carbon impact. Project teams were not able to give exact suppliers for materials such as concrete, lumber, and tile, particularly where the specified material is a non-circular alternative. Because the alternative is theoretical, a baseline value or EPD from the CLF North American Material Baselines Report was used (Waldman, 2023). Given exact material quantities from one of these sources, and having the nature of the material specified, an A1-A3 LCA comparison can be made for the materials.

LCC and Cost Required Information

LCC, or Life Cycle Costing, is a way of measuring the impact of a strategy, in this case, a circular building strategy, on the building's cost over the course of its life cycle. LCC is commonly conducted in building construction in order to determine the long-term benefit of strategies that are an initial investment, such as adding solar panels to a roof, upgrading inefficient HVAC systems, or installing high-performance glazing for insulation. These strategies are all at an increased upfront cost to the contractor, but pay themselves off over time due to increased efficiency (Sandanayake, 2018). This is the argument for using sustainable operations strategies in building construction; an upfront investment may be compensated if those costs can be saved, or an even greater amount can be saved down the line.

In the case of CE strategies, not many of them have a significant impact on the building's life cycle and operations over the years. In fact, the intent behind many of the strategies is to mimic the alternative performance exactly, but at a lower cost and/or environmental cost. For example, reusing and refinishing old floor tile does not increase or decrease efficiency in the building and does not impact operational energy costs. Many of the CE strategies identified in the case studies for this assessment are material strategies with a neutral impact on operational cost over a building's life cycle. For this reason, the majority of CE strategies and their non-circular alternatives are evaluated on the basis of up-front cost only. One notable exception is strategy H6 from the 1 Hotel case study, where using preserved plants diverted materials at the end of life from landfills, but also provided a scenario where less water is consumed over time for irrigation, and the plants need to be replaced less frequently. Cost information on the case studies' CE strategies can be obtained from the following methods:

1. **Estimated Cost of Strategies and Alternatives:** This is the most comprehensive and ideal, yet unlikely scenario that a building construction team would be willing to provide, due to the amount of documentation required. Existing cost analysis studies would provide the most straightforward answer on which strategies are the most economically viable, and are a typical practice in building construction projects. It is a standard design procedure for Progressive Design Build projects at the University of Washington, such as the Anderson Hall renovation. This is a preliminary type of study that establishes several alternatives, and may or may not have alternative pricing built in. If estimated pricing is not available, an estimate can be made using typical costs of line items in the design strategy. ROM estimates of total project cost and basic scope breakdown can be combined with schematic design elements in order to determine an estimate of pricing on specific line items. However, this method is time-consuming, makes project assumptions

that may not be accurate, and requires access to design drawings, which a GC may not be authorized to release.

2. **Actual Project Cost:** If estimated costs of design strategies are established, this can be validated using actual project cost data, if given. By comparing the estimated cost of strategies to their actual upfront costs, a more accurate representation can be made of the upfront cost of individual strategies. Depending on the pricing and contracting strategy used in the project, such as guaranteed maximum price (GMP) or estimated maximum price (EMP), over the course of the project can be broken down to proportionally reflect how much a certain scope, such as foundations or framing, consumes in a typical project. The various strategies implemented will be evaluated for their impact on a building's renovation/lifespan impact. If it is determined that a reused or recycled material has an impact on operational costs over the building's lifespan, or decreases the usable lifespan of a building, these costs should be investigated.
3. **S-LCA Required Information**: S-SCA is the least studied of the 3 frameworks, but offers a greater amount of flexibility in measurable criteria and can give an idea of relevant social implications to construction projects. In order to measure social impact, relevant project stakeholders must be identified, which in this case are the owner/developer, general contractor/construction manager, subcontractors, and suppliers. These parties are the most impacted by the construction process, whether they are in charge of making major project decisions or are exposed to potentially dangerous conditions associated with construction worksites. Safety and worksite-related questions can broadly inquire into whether there was a positive or negative risk and impact on the health and safety of workers associated with specific circular strategies. The social

concerns with workers mainly relate to job-site safety and expansion of work opportunities. The project team will be asked questions such as:

- ➔ Did this strategy require any additional PPE or safety training?
- ➔ During this part of construction, were there more or fewer safety incidents?
- ➔ Were additional workers hired for this strategy?
- ➔ Did workers gain new transferable skills as a result of this strategy?
- ➔ Did sustainability expertise result in a wage increase for project employees?

This process simply requires access to the buildings and permission to distribute information to former project staff. In the case of completed projects, the questions can be asked of the project team member available. If one can be accessed, a safety manager would be able to give insights into job-site safety and where it was most successful.

7.2 Case Study Narrowing

Based on the qualities identified during the initial interview phase, two projects were selected based on the ease of measuring the circular strategies identified. In some cases, the project scope was ambiguous or too large for the parameters of this study. After speaking with the project teams, one of the projects did not appear to have an adequate level of information organization to complete the study. Another project was simply not replicable, or relied heavily on infrastructure that is not widely available in the United States yet.

7.2.1 Scope Ambiguity with the Vela Apartments

The Vela apartments were not used in the final impact assessment due to ambiguity in defining new construction and retained structure scope, both as material quantities and proportional cost of the project. The project did benefit from reusing elements of the existing commercial structure, but after discussion, the GC did not readily have a breakdown of existing versus new structural elements in the building, making a meaningful and accurate comparison between alternatives difficult. Because the building did not pursue sustainability initiatives, limited material quantity information was recorded. For example, rather than separating concrete, steel, and facade elements used in the retrofitted commercial building from the materials used in the new construction section, each material quantity was recorded simply by material type, regardless of where it was placed in the complex. The project consisted of multiple buildings, and a deeper analysis of the design drawings would be required to properly assess how much material retention affected the cost and environmental impact of construction.

7.2.2 Challenges of Unique Buildings (Kendeda Building)

Despite its commitment to circularity, the Kendeda building is not an ideal project for this assessment and was not used because it is a unique building, and its material reuse strategies are dependent on warehousing infrastructure that is unique to Atlanta, and not widely available in the United States. The Kendeda building is a university building, which was uniquely designed, in comparison to a hotel, office building, or multifamily residential building. This makes it difficult to propose non-circular alternatives to design elements, as the building's design is informed by the desire to create a circular building. The University of Georgia provided warehousing services to the Kendeda project at no cost, and Skanska operates the Lifecycle Building Center as a permanent entity, which is incredibly uncommon in the United States.

Because of these circumstances, it is difficult to use findings obtained by this project to advise other contractors on whether these sustainable strategies would be feasible for their own projects.

7.2.3 Characteristics of Ideal Projects

For an assessment using the proposed methodology, an ideal project is replicable, well-documented, and of limited scale. An ideal project is also ideally limited to one purpose, and mixed-use projects add an additional layer of complexity that the assessment method is not equipped to measure at this time. Projects like office buildings and apartment buildings not only have the tendency to have similarities across projects, but they also tend to have repetitive elements within the project itself. This is the case for the Rejuvenate building, which follows a typical office floor plan, and conversion follows an expected multifamily residential floor plan. The floors are nearly identical to one another, facilitating a floor-to-floor comparison. The 1 Hotel building is more unique and less repetitive in layout as a luxury commercial space, but at 20,000 GSF, the project scope is more manageable, and individual elements such as doors and tile are more easily quantified.

7.3 Strategy Categorization

Many strategies discussed in the interviews fell into one or more categories, however for the case of this comparison, broad strategies were broken down, and the strategy that the activity fell the most clearly into was selected. Across the interviewed case studies, the majority of strategies fell most cleanly into 4 of the 9 strategies defined in the 9R framework:

R5: Repurpose/Redesign (2 Strategies)

In the context of the case studies, contractors found a discarded material, commonly tile, and reused the tile in a different context from its original function. This could be a floor tile turned wall tile, or roof tile turned wall tile. Although this is an assumption, these cases typically take a material that is worn down due to its heavy use context, and places that material in a place where it will not experience as much wear over time. Floor and ceiling tiles may crack and become dysfunctional due to the elements and foot traffic. By moving these materials to a wall, a building can save on the procurement of new tiles for the wall, and divert materials that would have otherwise gone to the landfill.

R6: Refurbish/Renovate (3 strategies)

These strategies were limited to office-to-residential adaptive reuse projects. Based on interviews conducted during this study, this strategy would be applicable almost exclusively to adaptive reuse projects due to code requirements associated with the change in function. Examples of this include CFRP wrapping of existing concrete columns, which were used to help support the increased load of permanent residential tenants on the structure, as well as the addition of the 5th floor as a static load. Additionally, code requirements require operable windows inside units, which commercial buildings do not, so a partial retention of the glazing was done, and custom windows had to be manufactured to aesthetically match the existing glazing. These strategies "upgrade" large elements of a building for a change in function.

R7: Retain (7 Strategies)

This is the single most common circular material strategy identified in the case studies, as well as one of the smallest scale. As opposed to major structural elements requiring some kind of upgrade, this strategy focuses on smaller repetitive elements that could either be kept or discarded for new items. This strategy is similar to repurpose/redesign in that it concerns commonly discarded materials; however, in R7, the materials are reused for the same function with very minor alterations. This strategy is easier to implement than R6, and could be more easily applied to small-scale construction renovations, but is not typically done because procuring new materials in this case is the standard procedure. Retaining and simply painting old doors and hardware is significantly less expensive than procuring those items new, but design norms for commercial spaces have made new procurement the default. The hotel renovation project stated multiple times that the team faced pushback from the design team, who wanted new doors, hardware, and floor tiles for aesthetic purposes, at a great cost deficit.

R9: Recover

This strategy is the most likely scenario for new construction projects such as the Kendeda building. Because new construction generates the most waste by default, having building materials which already come from waste, such as salvaged lumber, can have a great benefit to the project's cost and carbon footprint. Although a significant amount of coordination is required for this strategy, it does greatly help to reduce waste on both ends, as far as new construction goes. Waste materials from one building will be passed onto the next building, or materials used on temporary structures, such as play sets, can be disassembled and used for a permanent building structure.

Strategy ID	**9R ID (Primary Strategy)**	**Circular Description**	**Non-Circular Alternative**
The 1 Hotel Seattle			
H1	R1: Rethink	Design centered around existing fireplace	Unconstrained design with fireplace demolition

H2	R7: Retain	Reused and repainted 45 existing doors	45 New doors
H3	R7: Retain	Repainted 45 hardware sets	45 new hardware sets
H4	R5: Repurpose/ Redesign	Refinish existing lobby tiles 3000 SF	New lobby tiles and potential underlayment redo 3000 SF
H5	R7: Retain	Wood cladding over existing canopy 1700 SF	Wood cladding over existing canopy 1700 SF
H6	R9: Recover	Moss and bark decorations (preserved plants) 1200 SF	Traditional Plant Decorations (Not Preserved) 1200 SF
Rejuvenate Queen Anne			
Q1	R6: Refurbish/ Renovate	CFRP wrap existing concrete columns F4	New Concrete Columns F5
Q2	R7: Retain	3rd to 4th Floor Existing Metal Stairwell	New 4th to 5th Floor Stairwell
Q3	R6: Refurbish/ Renovate	Mixed existing glazing and Operable windows F4	F5 New Glazing
Q4	R6: Refurbish/ Renovate	Existing exterior rainscreen assembly	5th floor wall assembly rainscreen
Q5	R7: Retain	Existing lumber studs portion of wall	5th floor wall assembly lumber stud quantity
Q6	R7: Retain	Existing insulation portion of wall	5th floor wall assembly insulation quantity

Q7	R7: Retain	4th floor concrete waffle slab	New wood ceiling assembly

Table 7: Analysis of Circular Strategies Found in Case Studies

Section 8: Results

There is measurable value to be gained, financially, environmentally, and socially, from implementing certain circular strategies. Although these strategies may differ from what is typically done, and require additional coordination up front, many material-based strategies had positive impacts on schedule, building use, and upfront costs.

The biggest tradeoff with implementing circular strategies appears to be design flexibility. As the contractor stated in the office-to-residential project, this is not commonly done yet because an "ideal candidate" must be found for this type of project to pencil out. Developers may be apprehensive about investing in feasibility studies on projects with extreme constraints such as these. Even seemingly simple strategies face criticism from designers. In the case of strategy H3, although these tiles may be refinished and re-stained, the new stain had to be exact preexisting color specifications by the designer, and any deviation from this desired color would have resulted in costly changes.

Because the standard procedure in the construction industry is take-use-dispose, potentially beneficial strategies are not considered.

The findings of this research support assertions made in previous research about barriers to the implementation of CE in building construction. In the United States, especially, knowledge and formal legislation are far too limited for CE to be implemented on a project scale. Although some contractors have a vague familiarity with the idea of CE, none of the circular strategies implemented on these construction projects were done so with the pure intention of being circular. The decisions were a mix of economically, socially, and environmentally motivated. The strategies were simply circular by coincidence. However, the evaluated strategies did have generally positive impacts.

8.1 Environmental Impact

The environmental assessment evaluates the impacts of circular economy (CE) strategies using a Life cycle assessment (LCA) perspective. Due to limitations in contractor ability to provide quantitative data, the analysis is conducted as a comparative, qualitative LCA, focusing on differences between circular strategies and their conventional, or non-circular, alternatives. In order to complete the original qualitative LCA approach, a full building LCA would likely need to be done, which would take inventory of material quantities in the existing structure, wood framing in order to accommodate residential units across all floors, new construction additions, and upgrading of existing systems such as the stairwells and carbon fiber reinforced polymer (CFRP) reinforcing for structural concrete columns, and custom vinyl fittings.

The system boundary is defined as cradle-to-gate, emphasizing embodied environmental impacts associated with material extraction, manufacturing, and transportation. Operational impacts are largely excluded, as most strategies do not significantly alter building energy performance.

8.1.1 Embodied Carbon Reduction Through Material Retention

The most significant environmental benefit across both projects is the reduction of embodied carbon through material retention and reuse. The main difference identified between the two projects was that whereas the 1 Hotel focuses on small-scale material reuse, Rejuvenate implements retention of structural components such as foundations and wall systems.

8.1.2 Interior Material Reuse (the 1 Hotel)

Strategies such as reuse and repainting of doors (H2), reuse of door hardware (H3), refinishing of existing lobby tiles (H4), and retention of canopy structure (H5) avoid the need for new material production. From an LCA perspective, this eliminates impacts associated with raw material extraction (A1), manufacturing processes (A2), and transportation of new materials to the site (A3). Additionally, these strategies reduce C&DW, contributing to lower end-of-life environmental burdens. While each individual intervention is relatively small in scale, its cumulative effect across multiple building components results in meaningful embodied carbon savings.

8.1.3 Structural and Envelope Retention (Rejuvenate)

Rejuvenate used material retention strategies in its structure and envelope system, which are significant portions of a building. When making a direct comparison between floor 4, which was retrofitted from an existing office space, and floor 5, which was a complete new construction, we can see reuse of structural concrete elements with the addition of CFRP (Q1, Q7), Retention of existing stairwells (Q2), Partial reuse of glazing systems (Q3), and retention of wall assemblies, insulation, and framing (Q4–Q6). Despite a complete interior change in function and zoning, the building was able to retain all of its structural elements, which encompass the majority of a building's carbon footprint. These strategies are particularly impactful because materials such as concrete, steel, and glass are among the most carbon-intensive building components.

By avoiding demolition and reconstruction, these strategies eliminate emissions that would have been incurred from new material production and transportation, and avoid emissions associated with demolition activities and transport of waste materials to landfills. This shows the impact that office-to-residential retrofitting can have on the environment. Typically, these conversions were not done in the past due to differing code and load capacity requirements between commercial and residential spaces, but as a result of increased demand for dense, multifamily housing combined with a surplus of underutilized office buildings in Seattle, the city now incentivized these conversions as of 2024. As one of the first examples of this type of retrofitting, Rejuvenate serves as a landmark case, and its completion may influence other construction projects like it in Seattle and other cities facing similar housing shortages.

8.1.4 Waste Reduction and Resource Efficiency

Across both projects, circular strategies contribute to waste minimization and improved resource efficiency and reduced the overall GWP and carbon footprint of the project. Retention and refurbishment strategies reduce construction waste generation, while reuse of existing materials like tile and doors decreases demand for virgin resources. Additionally, adaptive reuse, as in Rejuvenate, prevents large-scale demolition waste. These outcomes align with key LCA indicators such as reduced material throughput, lower material and processing waste generation, and improved resource circularity

Despite overall positive outcomes, several trade-offs and constraints were identified; partial reuse strategies such as a mixed glazing system may result in suboptimal performance compared to full system replacement, though no significant operational penalties were identified in this study.

Overall, the results of this qualitative environmental assessment demonstrate that circular economy strategies provide potential environmental benefits, primarily through reductions in embodied carbon and material consumption. Whether through small-scale material interventions, such as refinishing tile that does not align with designer specifications, or larger-scale interventions, such as navigating the complexities of designing an office space for residential use in order to avoid demolition, CE building strategies deviate from American building construction norms and have a positive environmental impact.

8.2 Cost Impact

The cost impact assessment evaluates the financial implications of circular economy (CE) strategies implemented in two case study projects: 1 Hotel Seattle and Rejuvenate Queen Anne. While the initial intent of this study was to conduct a full Life Cycle Costing (LCC) analysis, this approach was determined to be unsuitable for most strategies due to their negligible impact on overall building lifespan. As both projects would have been constructed regardless of the selected strategies, and the circular strategies used did not significantly extend or reduce the building's service life, the analysis instead focuses on up-front material comparisons between circular and non-circular alternatives.

Labor costs were excluded from the comparison, based on the assumption that installation of reused or refurbished materials is comparable to that of new materials. As such, the results reflect relative material cost impacts rather than total project cost differences.

8.2.1 Material Cost Impacts by Strategy

Interior Reuse and Refurbishment Strategies (H1–H6): Interior-focused circular strategies implemented in Project 1 generally resulted in positive or neutral cost impacts. Door and hardware reuse (H2, H3) demonstrated clear cost savings by avoiding the purchase of new components. Lobby tile refinishing (H4) reduced material costs associated with new tile procurement and subfloor preparation. Canopy cladding retention (H5) avoided full replacement costs while achieving desired aesthetic outcomes. Design centered around existing elements (H1) was not directly quantifiable in cost terms but likely avoided demolition and reconstruction expenses.

The only neutral cost strategy identified was strategy H6, Preserved plant installations, where upfront costs were comparable to traditional plant installations. However, this strategy differs from others in that it introduces long-term operational cost implications, discussed further in Section 7.3.3. Overall, these findings indicate that reuse and retention strategies consistently reduce or stabilize upfront material costs, particularly when they replace high-volume materials.

Foundation, Structural, and Envelope Retention Strategies (Q1–Q7): Circular strategies implemented in Rejuvenate focused on structural reuse and building envelope retention, and were assessed as likely positive in cost impact.

Structural reinforcement (Q1) using CFRP wrapping was far less costly than the alternative of pouring new concrete or installing wood columns. Retention of existing stairwells (Q2) avoided the cost of new vertical circulation systems. The partial reuse of glazing systems (Q3) reduced material procurement costs relative to full replacement. Retention of wall assembly components (Q4–Q6) minimized the need for new materials, particularly lumber and insulation. Reuse of structural slabs (Q7) eliminated the need for additional ceiling and floor assemblies.

These strategies demonstrate that large-scale material retention in structural systems offers significant cost advantages, primarily through avoided material procurement.

8.2.2 Comparing Trends Between Projects

Across both case studies, several consistent cost trends emerge. The first trend is material avoidance as a primary cost driver. The dominant source of cost savings is the avoidance of new material purchases, particularly in high-volume or high-individual-cost components such as doors, finishes, and structural systems.

Scale of Impact: Interior finish strategies (the 1 Hotel) produced moderate but consistent savings across multiple smaller-scale interventions. Structural retention strategies (Rejuvenate) produced larger, system-level cost benefits, though often classified as "likely" due to variability in project conditions.

Long-Term Cost Considerations: Although most strategies did not significantly impact life cycle costs, Strategy H6 (preserved plant installations) represents an exception. Compared to traditional plant installations, preserved plants require minimal maintenance, eliminating ongoing watering and maintenance costs, and have a longer effective lifespan in interior applications

As a result, while initial costs are neutral, this strategy is expected to produce long-term operational cost savings, making it one of the few strategies in this study with measurable life cycle financial benefits.

Cost Barriers and Constraints: Despite generally positive cost outcomes, several barriers to implementation were identified through contractor feedback, including perceived cost uncertainty during early project phases and dependence on project-specific conditions, particularly for adaptive reuse feasibility

These findings suggest that cost savings from circular strategies are not always immediately apparent and may require greater upfront coordination and transparency to be implemented effectively.

8.2.3 Summary of Cost Findings

The results indicate that circular economy strategies in construction can be economically viable and often advantageous at the material level, even in the absence of full life cycle cost benefits. Overall, this study finds that circular strategies in these cases result in positive or neutral upfront material cost impacts. Structural and large-scale reuse strategies offer the greatest cost savings potential, but interior reuse strategies still provide consistent, incremental savings and should not be overlooked. Successful implementation of these circular strategies depends on early stakeholder alignment. Ultimately, the findings challenge the perception that circular construction strategies inherently increase costs, instead demonstrating that they can be cost-competitive or cost-saving under the right conditions. Although the direct cost impacts of individual circular strategies could not be quantified at the assembly level, Figure 6 provides contextual insight into how the overall project costs compare with industry benchmarks for similar building types. The 1 Hotel Seattle project, a luxury hotel renovation, appears to fall on the lower end of the reported cost-per-square-foot range for comparable projects. Similarly, Rejuvenation, an office-to-residential conversion, falls between typical multifamily renovation and multifamily new construction cost ranges. While these comparisons do not formally establish relationships between circular economy strategies and project cost performance, they suggest that the implementation of circular strategies did not prevent either project from achieving costs that are generally consistent with, or favorable relative to, comparable construction projects.

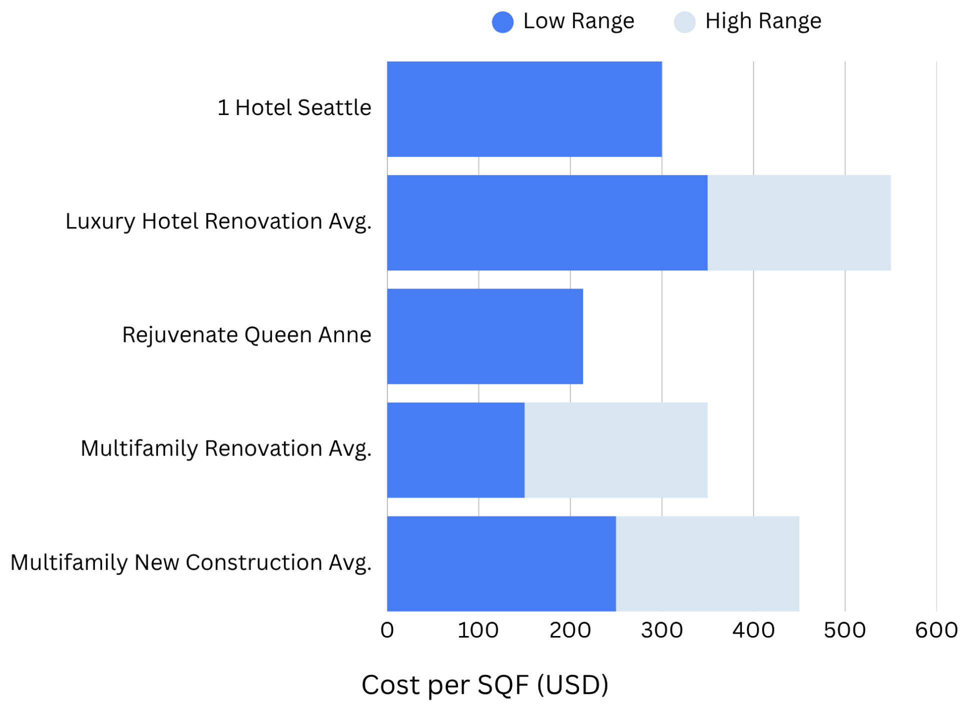

Figure 6: Comparing Cost Per Square Foot

8.3 Social Impact

Overview of Assessment Findings: The social life cycle assessment (S-LCA) portion of this assessment evaluated the two case studies: the 1 Hotel Seattle (the 1 Hotel) and Rejuvenate Queen Anne (Rejuvenate) to assess the social impacts associated with the implementation of circular economy strategies. Findings are organized across key stakeholder categories, including construction workers, owners, and local communities, and reflect some positive and some negative social outcomes.

Overall, both projects found that when circular strategies were introduced, the result was increased coordination requirements and technical complexity. That being said, the circular strategies also resulted in localized social benefits, such as new employment opportunities and strengthened relationships with local suppliers.

8.3.1 Field Worker Related Impacts

The implementation of circular strategies had a limited but notable impact on workforce skill requirements. In the 1 Hotel, new skills were required for tracking material quantities and sustainability metrics through specialized software due to the project pursuing LEED silver status, and having a material tracking requirement, indicating an expansion of technical capabilities. Rejuvenate did not require additional workforce training, as specialized tasks were subcontracted out to experienced vendors. Despite minimal formal training requirements, both projects demonstrated that circular strategies can enhance team capabilities indirectly. The 1 Hotel reported improved quality control processes for suppliers and vendors, while Rejuvenate contributed to broader industry learning by serving as a model for office-to-residential retrofit projects.

The 1 Hotel generated new, localized employment opportunities through the engagement of a local artist for the implementation of design elements using preserved plants. This reflects a positive social contribution to local creative economies.

Circular strategies influenced work conditions primarily through changes in installation methods and processes. In the 1 Hotel, material reuse strategies, as in the case of repainting doors and refinishing lobby tiles, required work to be performed in active, occupied spaces, increasing logistical complexity and requiring careful scheduling to minimize disruption. Similarly, Rejuvenate required customized installation approaches for integrating custom vinyl windows into the existing glazing. These findings suggest that circular strategies may increase task complexity and coordination demands, which can be seen as benefiting workers by providing new applicable skills, or hurting workers by increasing the demand on mental capacity and workload.

8.3.2 Impact on Suppliers, Owner, and Other Project Stakeholders

The 1 Hotel demonstrated strong engagement with local suppliers and small businesses, which were identified as critical to the success of circular strategies. This indicates a positive shift toward more localized and potentially more transparent supply chains. Rejuvenate did not report similar impacts, largely due to the nature of its strategies, which focused more on structural reuse than material sourcing.

Both projects highlighted the importance of early stakeholder alignment, particularly between owners, designers, general contractors, and suppliers. In the 1 Hotel, circular strategies required increased coordination and communication across stakeholders to meet project goals, strengthening collaborative relationships over time. Subcontractors in both projects were generally receptive to circular strategies, particularly when expectations were clearly communicated during the bidding phase. This suggests that resistance can be mitigated through early engagement and transparency.

Circular strategies contributed to enhanced market positioning in both cases. As these projects are in the hotel and residential sector, a positive public image is vital for engagement with investors and project owners. The 1 Hotel improved competency related to sustainability compliance, while Rejuvenate gained external recognition as a demonstration project for adaptive reuse, attracting attention from developers and industry groups.

This indicates that circular strategies can provide reputational and competitive advantages, even when direct financial or operational benefits are less immediate.

Circular strategies had mixed time and logistical impacts related to project scheduling and sequencing. The 1 Hotel experienced extended activity durations and increased coordination needs, particularly for in-place refurbishment tasks. In contrast, Rejuvenate achieved a self reported 30% reduction in overall schedule through structural reuse, demonstrating a significant efficiency benefit. Both projects experienced temporary disruptions associated with circular strategies. In the 1 Hotel, ongoing construction in occupied spaces required frequent adjustments to access routes, potentially impacting building users. However, these disruptions were actively managed through scheduling and coordination. Rejuvenate reported schedule compression due to structural reuse, which reduced overall project duration but increased pressure on specific long-lead items. This reflects a trade-off between time efficiency and workflow intensity.

8.3.3 Barriers and Enablers

The primary barriers identified across both projects include cost uncertainty and perceived cost inefficiency (Rejuvenate), need for early stakeholder buy-in and high collaboration, and feasibility constraints, particularly the availability of suitable existing buildings for adaptive reuse (Rejuvenate). Critical enablers for successful implementation include early alignment among owners, designers, and contractors; transparent cost structures; clear communication of project goals during procurement; and willingness of subcontractors to adapt when expectations are established early.

The results indicate that in the case of these two case studies, circular economy strategies in construction produce net positive social impacts, particularly in terms of local economic engagement, industry innovation, and stakeholder collaboration. However, these benefits are accompanied by increased coordination demands, potential workflow delays, and/or disruptions. Importantly, the success of these strategies is highly context dependent. Circular strategies are most effective when integrated early in the project lifecycle and supported by transparent communication and shared objectives among all participants.

Section 9: Discussion

This study evaluates circular economy strategies through a triple bottom line (TBL) lens, integrating environmental performance through life cycle assessment (LCA), social performance through social life cycle assessment (S-LCA), and economic performance through cost analysis. Across both case studies, the findings reveal an alignment between environmental and economic outcomes, while social impacts are more nuanced and dependent on project-specific conditions. Positive social impacts mostly benefit jobsite workers and designers, with increased job and learning opportunities. However, innovative strategies are accompanied by some tradeoffs for executives and project managers, as new sustainable strategies deviate from standard construction methods that require increased coordination in the early phases of the project. Overall, circular strategies tend to deliver clear environmental and financial benefits, with social performance varying based on how these strategies are implemented.

A key finding of the study is the positive qualitative relationship between environmental and economic performance. Strategies that reduce embodied carbon, particularly through material reuse and retention, can also reduce material costs by minimizing or even eliminating the need for new procurement of certain project elements. These elements can be as small as door hardware and as large as an entire building's core and shell. Structural reuse strategies, as observed in Rejuvenate, yield the most significant environmental benefits alongside the greatest cost savings because foundations and structure are such a large part of construction costs and a building's carbon footprint. Meanwhile, interior reuse strategies, as seen in the 1 Hotel, provide more consistent but incremental improvements across both dimensions. These findings challenge the common assumption that sustainable construction necessarily incurs higher costs, instead demonstrating that circular strategies can be both environmentally and economically advantageous, especially when new material avoidance is maximized.

In contrast, social outcomes are more variable and largely dependent on the processes through which circular strategies are implemented. Positive social impacts include the creation of local employment opportunities, such as engaging local artists, strengthening relationships with local suppliers, and fostering increased collaboration and stakeholder engagement. However, these benefits are contingent on early stakeholder buy-in, effective coordination, and transparent communication. At the same time, circular strategies can introduce challenges such as increased coordination demands, higher construction complexity, and temporary disruptions to building users.

9.1 How Successful was This Study

This study identified gaps in circular economy research and responded to those gaps by adapting LCSA into a practical, assembly-focused assessment method that measures said CE strategies against different markers of success. The markers of success in this case were benefit to the environment, measured by carbon or GWP impact, economic benefit measured as a change in upfront cost, and social impact to various project stakeholders. While the assessment demonstration provides a replicable analysis of a circular building scenario, case study findings reveal trends in existing American construction projects. In ideal circumstances, and if provided with the right information, this assessment method, or a similar method, could have the potential to influence project decisions and policy decisions.

The study succeeded in outlining an assessment methodology and demonstrating its intended application, but not in anticipating challenges related to interview engagement and information storage. The assessment is built to be customizable to different project types, whether they be renovations, partial renovations, or new construction. Assisted by definitions provided by the 9R framework, this assessment method was successfully able to identify and define CE strategies in construction projects, whether these strategies were done with circularity in mind or not. Once the strategies were identified, non-circular alternatives were identified for the strategies, and units were established so that a direct comparison could be made between the two strategies.

In the case of the 1 Hotel, the study was successful in extracting most material and cost information. Some assumptions had to be made for suppliers, such as for paint, tile floor alternatives, and a new canopy. Those materials can only be estimated. This case study was likely the most complete because it had the most manageable scope. Elements like doors, hardware, tiles, and plants are distinct items with very defined scope limits. By comparison, when attempting to categorize and quantify case studies involving structural elements such as nail-laminated timber (NLT), mass timber, structural concrete, and glazing, it is much more difficult to identify material quantities, and thus, quantitative analysis was unable to be completed at the proposed level without making uninformed assumptions and estimates.

9.2 Needed Industry and Legislative Changes

As discussed before, one of the greatest barriers to implementing a circular economy in the United States is the lack of formalized language and policy around this sustainable building strategy. Certification systems like LEED and LBD are successful because they have specific criteria to abide by and legal weight, which CE does not have in the United States. If CE were to be implemented in the United States, it would benefit from a more structured approach, which is what this study tries to provide at a rudimentary level.

Programs related to CE do exist at a small level, such as Skanska's Lifecycle Building Center in Atlanta, Georgia, which provides much-needed infrastructure for the storage and sorting of salvaged construction materials (Mitchell, 2022). These programs must expand in scale and accessibility so that the impact of salvaged materials can be properly studied and quantified.

Some government incentives related to the circular economy are also beginning to take hold in the Pacific Northwest, such as Seattle's Office to Residential Conversion program, which was inaugurated in 2024, as well as Portland's Deconstruction Ordinance and Grants (City of Portland, Bureau of Planning and Sustainability, 2025).

9.3 Call for Future Research

This study shows the growing relevance and potential benefits of circular economy in building construction; however, it also underscores the need for further research to create statistical significance, show quantitative proven impact, and improve the rigor of methodology. Future research is necessary to expand understanding of circular construction practices within the United States context, where data availability and standardized approaches remain limited.

A key limitation of this study is the relatively small sample size of case studies. While the findings provide valuable insights, additional case studies are required to achieve statistical significance. Expanding the dataset across diverse project types and geographic regions would enable more robust comparisons and support the development of industry benchmarks for circular construction performance. In addition to increasing the number of case studies, future work should prioritize more in-depth, data-driven analysis. Comprehensive whole building LCA should be conducted using detailed material inventories derived from BIM platforms such as Revit, which features built in material quantity takeoff options. Access to this data in existing projects would significantly improve the precision of embodied carbon calculations and allow for more accurate comparisons between circular and non-circular design approaches.

Further research is also needed to address the lack of standardized terminology and frameworks for circular economy implementation within the construction industry, which this study begins to address. Many existing sustainability initiatives incorporate principles aligned with circularity, but do not explicitly define or measure them with CE explicitly in the language. Studies should explore the development of formalized circular economy language and metrics, similar to how the LEED framework provides a detailed checklist of criteria. This can be done either by adapting existing programs, such as the Seattle office-to-residential conversion initiatives, or by proposing new, dedicated circular policy frameworks. Increasing the visibility and national recognition of circular economy as a valid sustainable building practice is critical to advancing its adoption. Future research should examine the role of policy and legislation in driving circular practices, drawing comparisons to international precedents such as the European circular economy policy framework. In the United States, where no equivalent federal framework currently exists, research could influence policies that embed circularity into building codes and sustainability certification systems.

Section 10: Conclusion

This study explored how circular economy strategies in building construction can be evaluated against the triple bottom line through a practical assessment method adapted from the Life Cycle Sustainability Assessment (LCSA) method for application in the United States construction industry. Building upon existing sustainability assessment approaches, including life cycle assessment (LCA), social life cycle assessment (S-LCA), and economic evaluation methods, the research organized circular strategies according to the 9R framework and translated them into measurable interventions at the assembly level. In doing so, the study sought to address a gap between the growing theoretical discussion surrounding circular economy and the practical challenge of quantifying its impacts within real construction projects.

The findings demonstrate that circular economy strategies can be systematically identified at the assembly level, and assessed across environmental, economic, and social dimensions using existing data sources. Through the assessment demonstration, a replicable procedure was developed to estimate the embodied carbon and direct cost implications of circular interventions using CLF baseline data and RSMeans cost information. While the demonstration was theoretical in nature, it showed how circular strategies can be translated into quantifiable metrics, providing a practical example of how future studies and project teams may evaluate the impacts of material retention, reuse, and other circular practices. The results of the demonstration indicated reductions in both embodied carbon and direct project costs within the circular scenario, suggesting that environmental and economic objectives may, in some cases, be mutually supportive rather than inherently conflicting.

The qualitative case study phase further contributed to the understanding of circular economy implementation in current construction practice. Interviews revealed that many circular strategies are already being employed within projects, even when they are not formally identified as circular economy initiatives. Participants reported a range of environmental, economic, and social benefits and tradeoffs associated with these strategies, supporting the broader premise that circular approaches have the potential to contribute positively to all three dimensions of the triple bottom line. At the same time, the case studies highlighted the project-specific nature of many social outcomes, which are often influenced by stakeholder priorities and project constraints.

A significant finding of this research was the challenge associated with obtaining sufficient project information to conduct a comprehensive quantitative assessment of circular economy impacts in existing projects in the United States. While the assessment method was successfully used to identify strategies and organize available information, limitations in project documentation, data availability, and record standardization restricted the extent to which environmental, economic, and social impacts could be fully quantified. As a result, the study not only demonstrated a potential approach for evaluating circular economy strategies but also identified important barriers to implementation and measurement within the current construction industry. These findings suggest that the development of more consistent project documentation practices, material tracking systems, and standardized reporting procedures will be necessary to support rigorous future assessments.

Overall, this research does not seek to definitively prove that circular economy strategies are universally superior to conventional construction approaches. Rather, it demonstrates that circular economy impacts can be evaluated in a structured and measurable manner, providing a foundation for more robust future research. By adapting existing assessment approaches into a practical method, testing their applicability through case studies, and illustrating their use through a quantitative demonstration, this study contributes to the growing body of knowledge surrounding circular economy in construction and provides a pathway for future research. As the construction industry continues to pursue sustainability goals, improved data collection, broader implementation of circular practices, and supportive policy frameworks that explicitly reference circular economy will be critical for generating stronger empirical evidence regarding the benefits and tradeoffs of these strategies. Ultimately, the findings suggest that circular economy represents a promising approach to reducing environmental impacts, retaining economic value, and creating positive social outcomes within the built environment when evaluated through a TBL perspective.

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Appendix 1: Interview Guide

Overview of Meeting Objectives

This is a relationship building meeting with the goal being to understand their project and the sustainable strategies they incorporated, the overall project, delivery method, and gauge interest in my study. There will be no data questions as part of this interview process, just context and fit.

Outline

Part 1: Intro Statement

Introduce ourselves, names, interest in the built environment.

"This first conversation is just to understand your project at a high level and learn how circular strategies showed up in practice. No data requests today—this is about context and fit. I'd like to get to know about you and your role in this project. Then I'd like a bit of a high level overview of the project, and the sustainable strategies used. When you met with Idris, he discussed what circular economy strategies look like in a construction project, and define circular economy as a framework. My study assesses the circular economy and how it affects the environment, profits, and people. I'm conducting this meeting to gauge your interest and one's general ability to conduct the study. Even if you're unable to give the necessary information, I'd still like to discuss the barriers of gathering that type of information with you

I'd just like to review what was done in X Project in terms of sustainable strategies
Additional insight/scope questions:

Part 2: CE Questions

If they are unable to speak on specific circular economy strategies, dive in with more specific questions such as:

Was materials reuse or recovery used in the project?

Was this project designed for adaptability or disassembly?

What kind of waste reduction or on-site reuse did this project have?

Did you make any procurement or supplier choices with sustainability in mind?

Overall Framework Questions

Environmental (Planet)

From your perspective, how did these strategies affect environmental outcomes?

Were there any noticeable tradeoffs?

Cost & Schedule (Profit)

How did these circular/environmental strategies affect project cost or scheduling, if at all?

Were there areas where costs increased but paid off elsewhere?

Stakeholders (Laborers, GC Employees, Owner) & Worksite (People)

Did any of these strategies affect workers' day-to-day experience?

Were there changes to safety, training, or coordination?

Part 3: Data Related Questions

Looking back, what types of project data do you think *might* exist related to these strategies?

Are there any types of information that would be especially difficult to share?

Who typically controls access to cost or safety records on projects like this?

Part 5: Wrapup and Potential Follow Up

After I synthesize what I've learned across projects, would I be able to follow up with a short summary and a proposed scope for a second conversation? no obligation

Appendix 2: Information Request Template

Assessing Circular Strategies Against the Triple Bottom Line

Julia Carceroni

University of Washington

Department of Construction Management

Case Study Data Request - Project Name

Confidentiality and Anonymization Note: after completing the document, a meeting will be held to establish the required amount of data anonymization and/or normalization required before publishing. No data will be shared without the consent of the other party.

How to Use This Document

Purpose of this request

To assess the *environmental, cost, and social impacts* of specific circular strategies implemented on this project

Each strategy will be compared against a *typical (non-circular) alternative*

Results will be reported at both strategy levels (i.e. Reused tile, waste diversion) and overall project level (i.e total cost savings or total estimated carbon impact)

Scope clarification

This study does *not* require a full bill of materials for the entire building.

Information is requested only for the circular strategies discussed in the initial meeting, plus a typical baseline alternative for those strategies.

LCA & LCC Boundaries and Definitions for Reference

LCA Life cycle stage: **Cradle to gate (A1–A3)**

-Upfront Costs and emissions only. Operational carbon (emissions during use of the building will *not* be accounted for.)

Estimated Completion Time

Strategy materials & costs: - 30 min

Social / workforce questions: -10 min

Whole Project Level Questions

Project Name:

Project Type: Short description, new construction or renovation, key features related to circularity.

Gross Floor Area of Scope:

Total Project Cost:

Is the cost actual or estimated?

Total estimated emissions of project (leave blank if unavailable):

If applicable, how was the emissions total calculated?

Circular Strategies Assessed

Confirmed Circular Strategies

After the discussion, these are the project strategies that were found to have a measurable impact.

Strategy Number	Building Element	Circular Strategy	Alternative	Confirm / Edit
#	General element	Description	Description	☐
#	General element	Description	Description	☐
#	General element	Description	Description	☐
#	General element	Description	Description	☐
#	General element	Description	Description	☐
#	General element	Description	Description	☐

Circular Strategy Material Quantities:

This section aims to break down the scope of individual strategies used. For example, if salvaged tile was used, this can be described as the number of tiles, total weight of tiles, or wall coverage area of tiles. If any sections are not directly answerable, feel free to leave them blank.

Alternatively, if there is an existing bill of materials with costs per material, as well as typically used alternatives, please attach. All sections of the document are optional, please complete to the best of your ability.

Strategy	**Quantity**	**Unit**	**Portion of Building Affected % or Description**
Strategy #: Description			
Strategy #: Description			
Strategy #: Description			
Strategy #: Description			
Strategy #: Description			
Strategy #: Description			

Material Types and Costs:

Strategy	Unit Cost or Total Cost	Cost Basis (Bid/Invoice/Estimate)	Additional Handling/Prep Cost	Spec for Alternative Material
Strategy #: Description				
Strategy #: Description				
Strategy #: Description				
Strategy #: Description				
Strategy #: Description				
Strategy #: Description				

Strategy-Level Social & Workforce Impacts (S-LCA)

1. For any of the strategies listed, was additional training required?

2. Did any of the listed strategies have a different handling or installation method?

3. Please describe any increased coordination and planning as a result of one of these strategies.

4. Did implementing circular strategies require new skills, certifications, or training for your team?

5. Did these strategies create new roles or employment opportunities (material auditing, deconstruction specialists)?

6. Do you feel these strategies enhanced your team's technical capabilities or market competitiveness? If so, how?

7. Were subcontractors or tradespeople resistant or receptive to adopting these strategies? Why or why not?

8. Did implementing circular strategies affect collaboration or trust between the contractor, owner, and subcontractors?

9. Did sourcing reclaimed materials create relationships with local suppliers or community-based businesses?

10. Did circular strategies affect work schedules, sequencing, or time pressure on the project?

Overall Reflection Questions

1. Would you use the above circular strategy again on a similar project? Why or why not?

2. What were the main barriers to implementation?

Appendix 3: Framework Demonstration Justification and Calculations

See attached material for calculations.