Adaptive reuse of the structure for office buildings into multi-family housing

by

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Abstract

The conversion of vacant office buildings into residential housing offers a sustainable and cost-effective solution to rising urban vacancies and the housing crisis. This report evaluates the feasibility and environmental impact of the structural adaptive reuse compared to new construction, highlighting its potential to reduce greenhouse gas emissions, minimize material waste, and improve affordability. A case study of a four-story office building in Kansas City, Missouri, evaluates sustainability metrics using the Embodied Carbon in Construction Calculator (EC3) and cost analyses based on RS Means data. Findings reveal that the structural adaptive reuse can reduce embodied carbon emissions by approximately eighty-four percent and significantly lower construction costs compared to new developments. Additionally, key structural modifications – such as load adjustments, material reuse, and code compliance – are examined to determine practical implementation challenges and solutions. This research highlights the broader implications of office-to-housing conversions in meeting sustainability goals, reducing urban sprawl, and promoting long-term economic and environmental benefits.

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Chapter 1. Introduction

This report assesses the structural sustainability and feasibility of renovating existing structures, specifically vacated office buildings, into multi-family housing. The opportunity to adapt existing office buildings into housing has the potential to improve the amount of greenhouse gas emitted through the construction process by utilizing existing structures and implementing other sustainable designs (Aigwi, Duberia, & Nwadike, 2023). Constructing more sustainable housing could also help the United States of America's Net-Zero goals by 2050 through the reuse of materials (Energy.gov, 2021). An added benefit is increased access to safe, sustainable, and affordable housing.

The sustainability and feasibility of new build construction compared to renovations is presented. How materials and traditional construction methods affect the environment and how new, proposed methods could improve the negative environmental impacts are analyzed. Additionally, a comparison of the environmental and economic impacts of the different construction methods is presented. A theoretical case study assessing the impacts of adaptive reuse compared to new construction is used to investigate the environmental impacts.

The second chapter analyzes the background information about why office to residential conversions are necessary, the history of building codes and sustainability, the basics of sustainability calculations, and a literature review. In the third chapter, a case study investigates the sustainability and feasibility of renovating an office building in Kansas City, Missouri as well as examining a couple other adaptive reuse projects. After the case study, an analysis and interpretation of the results is conducted followed by conclusions and recommendations.

Chapter 2. Background and Literature Review

The COVID-19 pandemic left a lasting impact on numerous aspects of society including in the real estate sector. One of the most significant changes has been the increase in vacant buildings specifically in the commercial and urban sectors. With numerous businesses being forced to close, an increase in working remote, and instabilities in the economy, vacancies drastically increased to unprecedented levels. The effects of the pandemic are clearly evident in commercial spaces, retail properties, and residential housing.

2.1 Office Building Vacancies

A major impact of the pandemic is the rise of commercial building vacancies mainly due to companies transitioning to remote work reducing need for office spaces (Goodman, 2023). Despite eased restrictions, a significant number of businesses opted for hybrid or fully remote work options. This led to a decline in demand for commercial office space. As companies have reevaluated their long-term space requirements, many office buildings remain unoccupied or underutilized.

With the rise in vacant office buildings, a viable alternative to vacancies or demolition is renovating them into sustainable housing. In this report, an investigation of adapting four story office buildings into multi-family housing is conducted to help understand the structural sustainability and feasibility of renovating existing buildings versus demolishing and rebuilding. The building analyzed is constructed of steel framing with a concrete foundation located in Kansas City, Missouri. Adapting and renovating existing structures could reduce the overall construction cost and reduce the amount of greenhouse gas emissions emitted during construction having positive impacts on the environment and fiscal spending.

In the past five years, a decrease of almost twenty percent in available undeveloped land has occurred (Land Use, n.d.). Correlating to less land available when constructing new buildings. In addition to the lack of undeveloped land, new buildings cost almost twice as much to construct compared to renovating a similar space. Both building costs and carbon emissions are impacted by construction materials specifically in the super-structure and foundation.

At the start of 2023, twenty to twenty-five percent of office buildings in major cities had been vacated (Rao, 2023). These numbers are expected to continue to rise, posing a growing challenge in determining the future use of these existing buildings. Figure 1 graphically depicts the increase in office to apartment conversions over the past four years, based on Yardi Matrix data and RENTCafe (Neculae, 2024).

Figure 1. Office-to-Apartment Conversions Pipeline More Than Quadrupled in 4 Years (Reproduced from (Neculae, 2024))

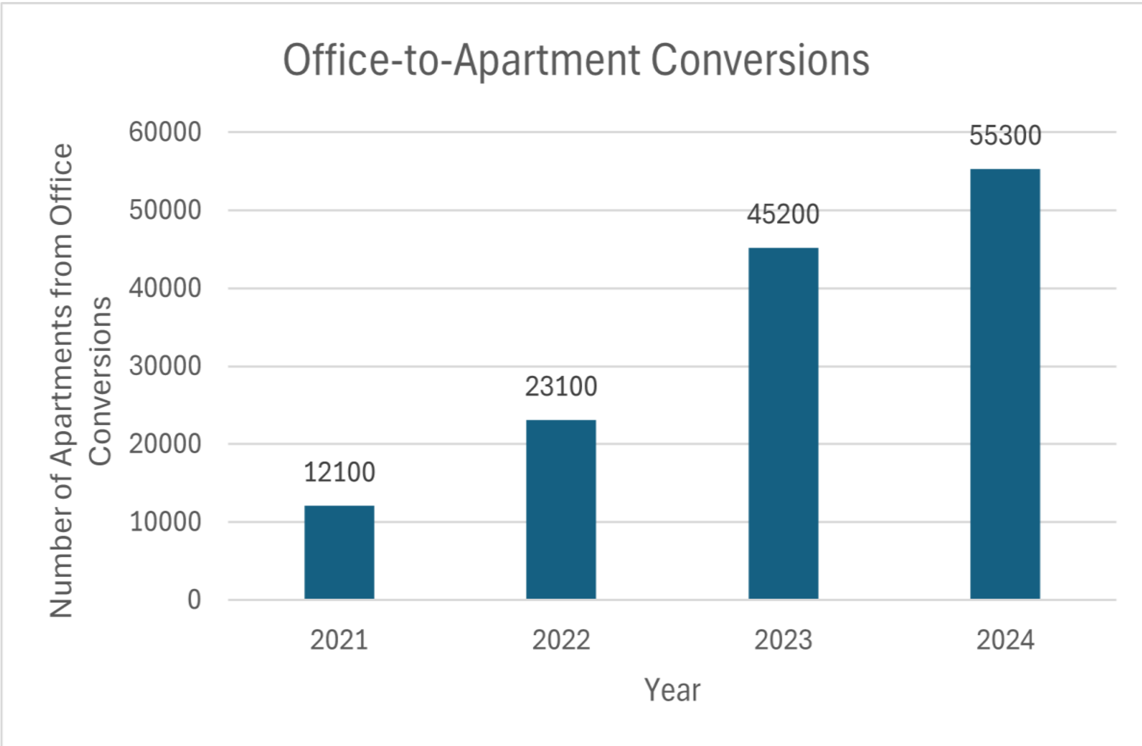


Figure 1 highlights the increase in converting vacant office buildings into housing. Between 2022 and 2023, the number of office buildings adapted in the United States of America (USA) doubled, and that number is anticipated to increase again between 2023 and 2024. Office building conversions to apartment buildings represent the largest share of adaptive reuse projects, accounting for nearly forty percent of such developments (Neculae, 2024). The metropolitan areas with the largest office-to-apartment conversions are Washington, D.C., New York, NY, and Dallas, TX. Kansas City, MO is the eight largest with 1,510 in 2024. In Kansas City, Missouri specifically, approximately fifty percent of renovation projects are noted as being future apartment projects (Neculae, 2024). This shows the increasing trend and depicts how an increasing number of developers are utilizing abandoned spaces.

The Biden Administration has set aside funding to help subsidize the prohibitive costs of adaptive reuse projects (Stephens, 2023). In addition to the billions of dollars set aside by the federal government, there are also city and state tax credits earmarked specifically for adaptive reuse. Despite these funding opportunities, developers must overcome substantial roadblocks to convert aging office buildings into housing units. The average age of office buildings developers are targeting for adaptive reuse today is seventy-two years old, that is twenty years younger than those previously converted. According to RENTCafe, this "suggests a strategic preference for buildings that might require less investment in refurbishment and are more likely to meet modern standards, potentially simplifying the conversion process" (Neculae, 2024).

2.2 Increase in Homelessness

Homelessness in the USA has increased to high levels in recent years, with rising numbers of individuals and families experiencing housing insecurity (Torres, 2025). The issue affects communities nationwide, both urban and rural, highlighting deep-rooted socio-economic problems.

Several factors contribute to the increase in homelessness, the most significant is the lack of affordable housing. Housing costs have risen dramatically, outpacing wage growth and leaving many unable to secure stable living conditions. A severe shortage of low-income housing further exacerbates the issue, forcing families into shelters or the streets. With a steady increase in the cost of living, many are failing to find affordable housing options. As many struggle to find feasible housing, the homeless population has continued to increase. Between 2022 and 2023, the population of those without adequate housing increased by more than twelve percent (Thornton, 2023). Figure 2 graphically depicts the increase in the homeless population over the past eight years.

Figure 2. Homelessness Trends (Reproduced from (Soucy, Janes, & Hall, 2024))

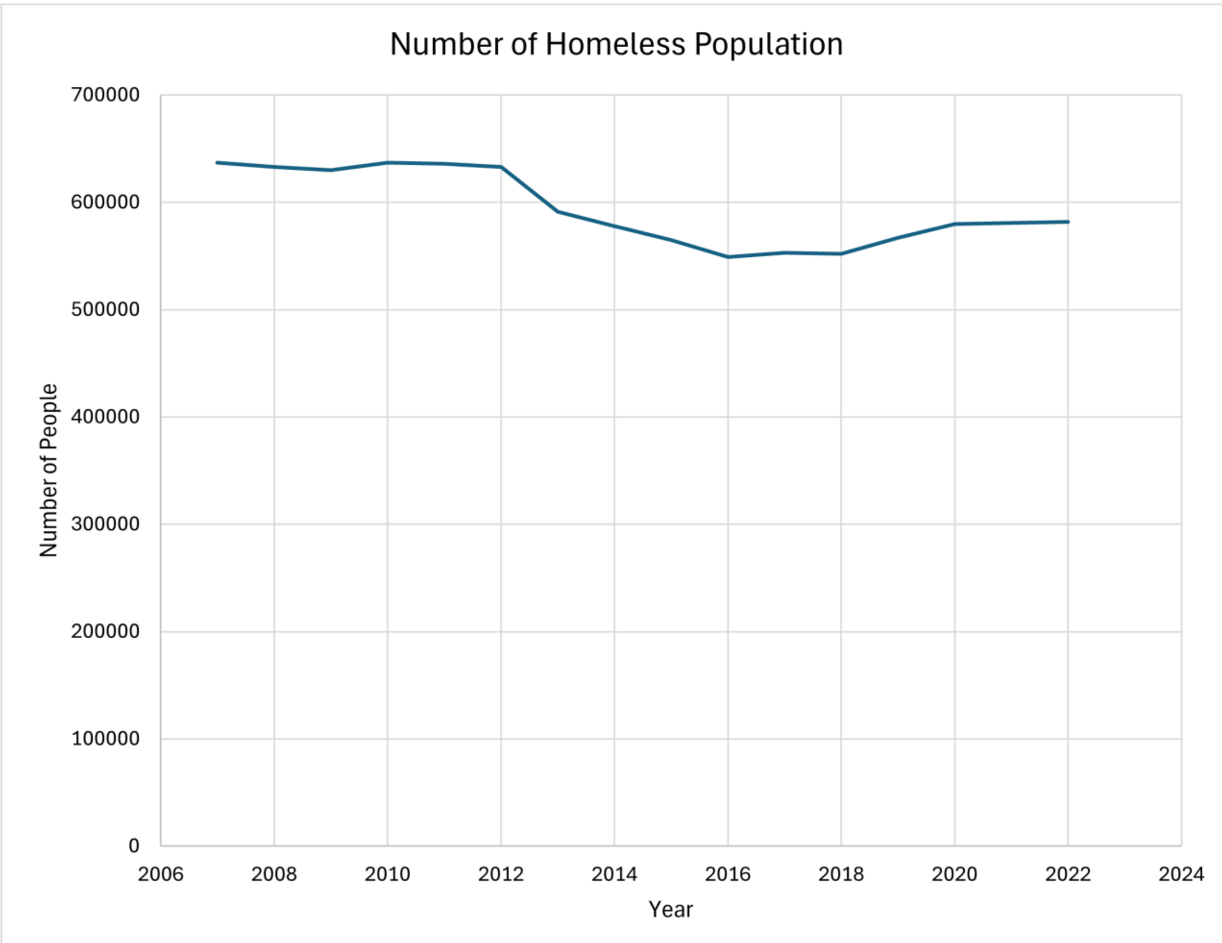


Figure 2 denotes the increase in the overall homeless population over the span of fifteen years. Between 2015 and 2022, the number of people without adequate housing in the USA increased by 32,500 people with the largest increase being between 2018 and 2020 (Soucy, Janes, & Hall, 2024). This shows an increasing trend and depicts that this issue is becoming more prevalent to address.

Some other factors that have led to an increase in the population of homeless include economic instability, mental health and substance abuse, and social inequalities (10 Causes of Homelessness, n.d.). The volatility of the job market, high inflation rates, and the rising cost of living make it difficult to maintain stable housing for individuals with a lower income. The pandemic intensified financial hardships, leading to job losses and evictions.

Addressing homelessness requires a comprehensive and multi-faceted approach. One of the most effective solutions is expanding affordable housing initiatives. Programs such as "Housing First," which prioritize providing stable housing before addressing other issues, have proven successful in reducing homelessness.

The increase in homelessness is a complex issue driven by economic, social, and systemic factors. While the problem continues to grow, solutions such as expanding affordable housing, improving economic opportunities, enhancing mental health services, and finding alternative methods of housing can help mitigate its impact. Addressing homelessness requires a collective effort from government agencies, community organizations, and individuals to ensure that all individuals have access to stable and secure housing. Adaptive reuse of existing buildings into housing is a creative solution to address this issue. By implementing long-term, sustainable solutions, everyone can work towards reducing homelessness and fostering a more equitable society.

2.3 Sustainability in Building Design

In the face of global climate change and increasing resource depletion, sustainable building design has become a crucial element in modern architecture. Sustainable Building Design addresses environmental, economic, and social concerns by minimizing negative impacts on the planet while enhancing efficiency and livability. Sustainable building design incorporates energy-efficient technologies, eco-friendly materials, and innovative construction techniques to create structures that are both functional and environmentally responsible.

One of the primary benefits of sustainable design is its positive impact on the environment. Traditional construction methods often contribute to high carbon emissions, excessive energy consumption, and resource depletion. Sustainable design mitigates these issues by incorporating renewable energy sources and improving energy efficiency through better insulation, natural ventilation, and high-performance windows. Additionally, sustainable buildings use recycled and locally sourced materials, reducing waste and the carbon footprint associated with transportation and production.

Economic benefits also play a significant role in the push for sustainable buildings. While the initial investment in green technology and sustainable materials may be higher, the long-term savings outweigh the costs. Energy-efficient buildings reduce electricity and water usage, leading to lower utility bills for occupants. Moreover, sustainable buildings often require less maintenance and have higher property values due to their resilience and efficiency. Businesses and homeowners alike benefit from these financial savings while contributing to a healthier environment.

Beyond environmental and economic considerations, sustainable building design enhances the wellbeing of its occupants. Traditional construction materials often contain harmful chemicals that can negatively impact indoor air quality, leading to health issues such as respiratory problems and allergies. Sustainable buildings prioritize non-toxic, low-emission materials and incorporate natural lighting, improving both air quality and overall comfort. Furthermore, access to green spaces, proper ventilation, and biophilic design elements have been shown to boost mental wellbeing and productivity.

Governments and organizations worldwide are recognizing the importance of sustainable building design and implementing policies and certifications, such as the Leadership in Energy and Environmental Design and Living Building Challenge, to encourage environmentally friendly construction practices. These initiatives promote sustainable design principles and ensure that new buildings adhere to energy efficiency and environmental responsibility standards.

Sustainable building design is no longer an option but a necessity since it reduces environmental impact, offers economic benefits, and improves human well-being. As technology advances and awareness grows, sustainable architecture will continue to shape the future of the construction industry, paving the way for a greener, more resilient planet. Embracing sustainability in building design is a collective responsibility that will yield lasting benefits for generations to come.

2.4 History of Building Codes

Building regulations can be traced back thousands of years. As civilization has evolved and modernized, so have building codes. The International Building Code (IBC) is a fundamental set of regulations that governs the design, construction, and maintenance of buildings. The development of the IBC represents a long history of effort to standardize safety, sustainability, and efficiency in construction. From ancient building regulations to modern international standards, building codes have evolved and improved in response to disasters, technological advancements, and the need for uniformity in the construction industry.

The Industrial Revolution brought significant changes in architecture and construction materials, necessitating more standardized building regulations (The Industrial Revolution Transforming Cities and Architecture, n.d.). The rapid urbanization and increasing complexity of buildings led to concerns over structural safety, fire protection, and sanitation. Many countries began to develop their own building codes to standardize minimum requirements for buildings. Prior to 2000, the United States of America (USA) had three main building codes: the Uniform Building Code (UBC), the Standard Building Code (SBC), and the Building Officials and Code Administrators National Building Code (BOCA) (Kelly, 2013). Each building code was used in a different region of the USA: the UBC was primarily for the western region, the SBC was utilized in the southeastern region, and the BOCA was used in the northeastern and midwestern regions. These separate codes led to inconsistencies in construction regulations across different regions, creating challenges for builders and designers working in multiple areas. The IBC was designed to be adaptable, incorporating best practices from various building codes while allowing for regional modifications (Understanding the Purpose of the International Building

Code and Regional Model Building Codes: A Comprehensive Overview, n.d.). It covers structural safety, fire protection, accessibility, energy efficiency, and more.

2.4.1 The International Building Code

The IBC details building requirements and was created as a combination of the three codes. The first IBC was published in 2000 as a central building standard. Prior to the year 2000, many building codes were based on the region. By creating a combined building code, building safety became standardized. The IBC is updated every three years to reflect advancements in construction materials, engineering practices, and safety research. It also plays an important role in sustainability and energy efficiency. The IBC is a model code developed by the International Code Council (ICC) to establish minimum safety standards for buildings and structures worldwide. The IBC is widely adopted by governments and jurisdictions across the USA and internationally as the basis for local and national building regulations. The key features of the IBC Code are structural safety, fire safety, energy efficiency, accessibility, mechanical, plumbing, and electrical systems, materials and construction methods, occupancy, and use classifications. The IBC is a part of the International Codes developed by the ICC with each code specifying specific requirements for each portion of the design. Jurisdictions may adopt and modify the IBC to suit local regulations and environmental conditions.

The IBC represents centuries of progress in construction regulations, shaped by historical events, technological advancements, and the need for safety and uniformity. From ancient building laws to the modern IBC, building codes have continuously evolved to protect lives, ensure structural integrity, and promote sustainability. As construction techniques continue to develop, the IBC will remain a vital tool in shaping the built environment worldwide.

In addition to the IBC, the International Existing Building Code (IEBC) pertains specifically to existing buildings. The International Building Codes are updated every three years and cities must adopt the codes to be enforced. These codes determine what is required for a structure to be safe for inhabitants.

In the next chapter, a case study analyzing how adaptive reuse is more sustainable than demolishing an existing building to build a new structure is presented. The case study analyzes a four-story office building constructed of structural steel with composite deck, a concrete foundation, and brick veneer façade. The office building will be located in a medium sized city, meaning one that has between 75,000 and 100,000 residents, specifically Kansas City, Missouri. The case study excludes the façade, solely focusing on the structural system environmental impact when comparing an adaptive reuse to a new construction. The scope will not include demolition nor the sustainable or feasible impact of transportation of the building materials.

2.4.2 Code Changes

The change in code requirements for buildings and loading is investigated in the case study. In the 1970's, Kansas City, Missouri utilized the 1973 Uniform Building Code (UBC) to determine occupancy requirements, design loads, and construction regulations. While code requirements have changed and improved in the last fifty years, no change to dead or live loading requirements have occurred. Specifically looking at roof live loads, roof live loading has not changed; it was twenty pounds per square foot in the Uniform Building Code and remains that load in the 2022 American Society of Civil Engineers (ASCE) Minimum Design Loads and Associated Criteria for Buildings and Other Structures (International Conference of Building Officials, 1964) (American Society of Civil Engineers and Structural Engineering Institute, 2022). The allowable resultant wind pressure per the 1973 UBC was forty pounds per square foot of combined inward and outward pressures on exterior surfaces of ordinary square buildings at thirty feet above ground and thirty pounds per square foot from the ground to thirty feet above the ground (International Conference of Building Officials, 1964). For the case study presented in Chapter 3, the wind pressure would have been thirty pounds per square foot up to the third floor and forty pounds per square foot from the third floor to the roof. In current design, a design wind speed is utilized to determine the wind loading on a building. Utilizing the ASCE 7 Hazard Tool, the design wind speed is 110 miles per hour (American Society of Civil Engineers, n.d.). For seismic loading, Kansas City, Missouri was located in seismic Zone 1 which means very low to low seismic hazard (International Conference of Building Officials, 1964). This is similar to the current seismic classification for Kansas City, Missouri which is Seismic Design Category B (American Society of Civil Engineers, n.d.).

2.5 History of Sustainability

Sustainability in building design has evolved over centuries, adapting to environmental, technological, and social changes. The concept of sustainable architecture is not new as many ancient civilizations constructed buildings with their surroundings using passive design strategies. The modern sustainability design has emerged in response to industrialization, urbanization, and climate change.

Early structures were typically made of local materials, constructed by humans. The Industrial Revolution led to mass production of materials such as steel and concrete. This allowed large-scale construction to become more prominent but also lead to an increase in energy consumption. Additionally, with an increase in large-scale construction, cities grew rapidly, leading to pollution, overcrowding, and inefficient buildings. The energy crisis in the 1970s was the initial concern that led to a renewed focus on energy-efficient building. In subsequent years, more sustainable building organizations and codes emerged like the International Council for Local Environmental Initiatives. The Leadership in Energy and Environmental Design (LEED) system was introduced to set global sustainability standards.

2.5.1 Leadership in Energy and Environmental Design

The Leadership in Energy and Environmental Design (LEED) certification was established by the United States Green Building Council (USGBC) in 1998 as a response to growing environmental concerns in the building industry (The Evolution of LEED Certification Standards, 2024). The goal was to create a standardized framework for designing, constructing, and operating high-performance, sustainable buildings. The LEED certification has gone through a number of updates. Version 1.0 was the pilot phase that was not adopted by many in the industry. The certification improved the rating system and incorporated life cycle assessment in versions 2.0 and 3.0. Version 4.0 focused on performance-based outcomes and material transparency. The current version is version 4.1 that included further refinements from version 4.0, making the certification more accessible and flexible. Today, LEED is one of the most widely recognized green building certification worldwide, influencing sustainable design across all building types (Real Estate Today Staff, 2025).

There are many impacts the Leadership in Energy and Environmental Design certification has had on sustainable design. First are the environmental benefits. The LEED certification reduces the carbon footprint by encouraging energy-efficient building designs, promotes water conservation, encourages sustainable materials such as recycled and low-impact building materials, and enhances indoor air quality by reducing toxic materials and improving ventilation. In addition to environmental benefits, there are also economic benefits. Through energy efficiency and lower water usage, there is a decrease in operating costs. Additionally, LEED-certified buildings are in higher demand, so there is an increase in property values. Finally, there is a reduction in maintenance costs with durable materials and efficient systems.

In addition to the environmental and economic benefits to the LEED certification, there are also social and health benefits. The certification improves occupant well-being by ensuring better indoor air quality and natural lighting, enhances employee productivity in the workplace due to healthier environments, and encourages community sustainability by integrating green spaces and reducing urban heat islands. LEED has influenced international green building standards. Many governments and corporations have adopted LEED policies, requiring certification for public and private projects. The standard has helped drive the net-zero building movement, pushing the construction industry toward carbon neutrality.

While LEED has significantly advanced sustainable design, there have been some challenges and criticisms. The high upfront costs for certification and implementation as well as the complex requirements of documentation make some weary of applying for LEED certification. Additionally, there are some performance gaps where certified buildings may not always meet sustainability goals post-construction. LEED is evolving to include carbon neutrality goals, resilience planning, and enhanced life cycle assessments to further its impact on sustainability in the built environment. LEED has played a significant role in the history and advancement of sustainability, but due to the high cost to meet LEED certification requirements, an alternative sustainability measurement was determined necessary.

Sustainable design has evolved from ancient passive strategies to high-tech green buildings. While industrialization led to energy-intensive construction, modern sustainability movements are reversing this trend. The future of sustainable design will focus on carbon neutrality, circular economy materials, and smart building innovations.

The construction industry is focused on creating more sustainable construction methods and create more energy efficient buildings with the goal of seventy-five percent of buildings being Net-Zero by 2050. This focus is because the construction industry contributes to forty percent of the global greenhouse gas emissions and around thirty-five percent of the global energy consumption (Kyaw, Fufa, & Kraniotis, 2023). The initial focus has been on reducing building emissions during building operation. Once these emissions have been addressed, the next focus is on the structural aspects of the building, specifically on building materials as this has the largest negative impact on the environment.

Due to the number of buildings that exist, the option to demolish and build all new construction with optimized energy performance is unrealistic. This would take approximately one hundred years to rebuild the existing buildings (Langston, 2008). The more effective route would be utilizing the existing structure, if structurally sound and acceptable per code, and altering the internal use. This method would allow a reduction in carbon emission effects on the climate.

Many reasons why a building may no longer be utilized include the business not being needed any longer, poor upkeep, and outdated facilities are some examples. Buildings eventually become vacant due to obsolescence; there are many factors that play into this. This can include physical, economic, functional, technological, social, legal, and political (Langston, 2008). Physical impacts can include poor maintenance or the inability for a buildings layout to change efficiently. A building's useful life can also be reduced if the building feasibility is based on external income or if the original design quality is poor.

Building material carbon emission have a significant impact on climate change and sustainability due to their contribution to greenhouse gas emissions throughout a building's lifecycle. The emissions are categorized in two main categories: embodied carbon and operational carbon. Embodied carbon refers to the amount of carbon dioxide emitted during extraction, production, transportation, and installation of building materials. Emissions from maintenance, renovation, and end-of-life disposal are also included in embodied carbon emissions. Operational carbon emissions are from energy used for heating, cooling, lighting, and running appliances. Figure 3 graphically represents the amount of embodied carbon created in various renovation scenarios.

Figure 3. Embodied Carbon of Different Renovation Scenarios (Melton, 2022)

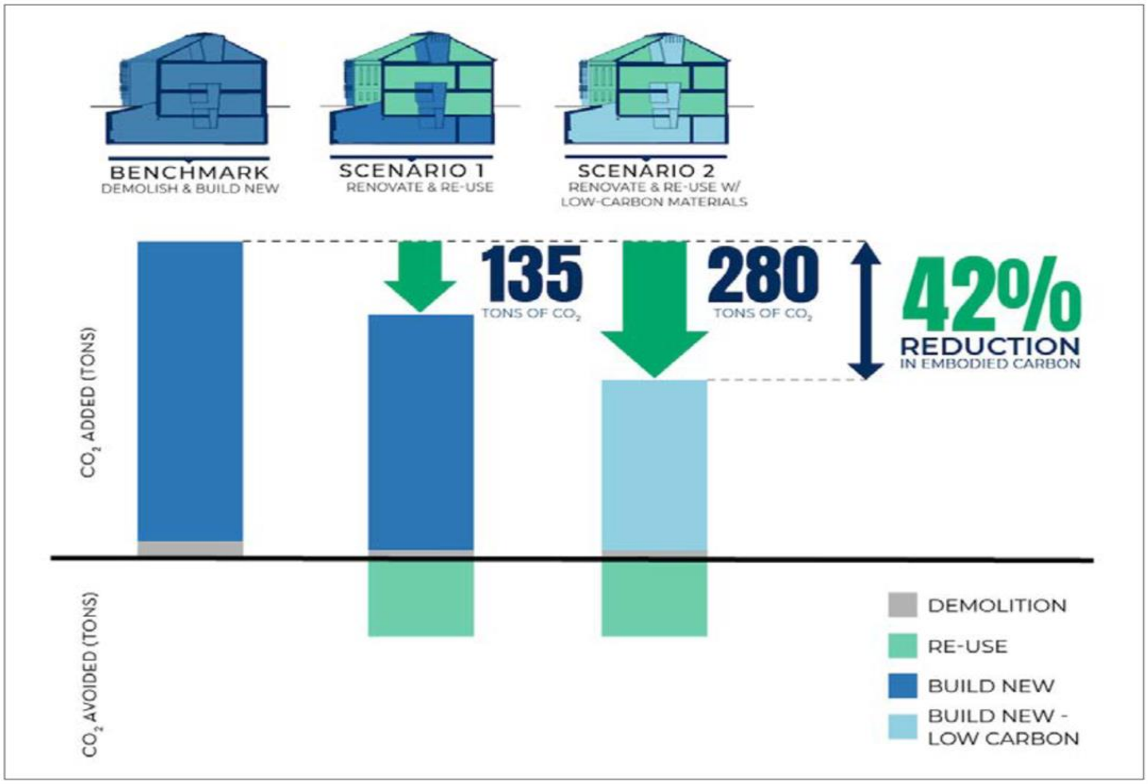


Figure 3 depicts the amount of carbon dioxide added or avoided based on three renovation scenarios: demolish and rebuild, renovate and reuse, and renovate and reuse with low-carbon materials. As shown in Figure 3, the amount of carbon dioxide added is twice as much when demolishing to build a new building than if the building were renovated and low-carbon materials were utilized. This emphasizes that the idea of demolishing all existing buildings to build new, more energy efficient buildings to meet building carbon emission goals is not feasible nor is it sustainable as it would increase carbon emissions rather than reducing them.

2.6 Adaptive Reuse

When renovating (also known as adapting) an existing structure, the base structure is preserved, and the interior is altered for new use. Figure 3 depicts the amount of embodied carbon that can be avoided when adapting a space rather than creating a new building. Consequently, renovating existing structures and making them more sustainable may be a more effective choice. As existing buildings are improved and building carbon emissions are decreased, the construction industry has also been challenged to reduce carbon gas emissions during the construction phase (Dominguez, Kakkos, Gross, Hischier, & Orehounig, 2023). Additionally, renovations emit forty percent less carbon emissions compared to new construction (Morrison, 2023).

While evidence that renovations are more sustainable, the question remains whether renovation is possible and cost effective. It has been proven that improving existing buildings has led to long-term savings and is more sustainable than constructing a new building (Cost of Renovation v. New Construction for Commercial Spaces, n.d.) (Renovating Buildings to Protect the Climate and Rejuvenate Communities, n.d.). This leads to the conclusion that renovating existing structures into housing can be more sustainably impactful than new home construction.

Adaptive reuse has emerged as a sustainable and economically viable solution for repurposing existing buildings, particularly in response to the growing concerns over environmental sustainability, urban renewal, and economic efficiency. The concept revolves around transforming obsolete or underutilized structures into functional spaces that meet contemporary needs. The article “Transformation Meter: Measuring the Conversion Potential of Buildings” presents a systemic framework for evaluating the transformation potential of buildings (Geraedts & Van der Voordt, 2007).

One of the fundamental considerations in adaptive reuse is its economic feasibility. The cost-effectiveness of building transformation depends on various factors, including structural integrity, spatial flexibility, and market demand (Geraedts & Van der Voordt, 2007). The framework of the "Transformation Meter" provides a structured methodology to assess whether a building can be repurposed at a lower cost than demolition and new construction. In many cases, adaptive reuse proves to be financially advantageous, as it minimizes construction expenses, reduces material waste, and preserves valuable infrastructure.

Beyond economic considerations, adaptive reuse is highly sustainable. The transformation of existing buildings reduces carbon footprints by minimizing the demand for new materials and energy-intensive demolition processes. Furthermore, it contributes to urban regeneration by revitalizing neglected spaces thus fostering social cohesion and cultural continuity. Considering life-cycle costs and environmental impact assessments in determining long-term benefits of reuse versus new development are further explained in the article. Despite its benefits, adaptive reuse is not always feasible. Structural limitations, outdated building regulations, and regulatory considerations. The need for a thorough analysis of a building's adaptability, including its technical, functional, and legal constraints are emphasized in the article. If a structure is too rigid or requires extensive modifications, the costs and efforts involved may outweigh the benefits.

The viability of adaptive reuse is contingent on a balance between economic feasibility, environmental sustainability, and regulatory considerations. The “Transformation Meter” framework provides a valuable tool for decision-makers in assessing the potential of building conversions. While adaptive reuse is not universally applicable, it remains a crucial strategy in promoting sustainable urban development and reducing the environmental impact of the construction industry. Moving forward, integrating innovative design solutions and flexible building regulations can further enhance the practicality of adaptive reuse as a mainstream approach to urban planning.

Figure 4. Transformation Meter Location Criteria (Reproduced from (Geraedts & Van der Voordt, 2007))

LOCATION					
Aspect		Gradual Criterion	Data Source	Appraisal	
Functional				Yes	No
1 Urban Location	1	Building in industrial estate or office park far from town center	Town map		
	2	Building gets little or no sun	On-site inspection		
	3	View limited by other buildings on 75% of floor area	On-site inspection		
2 Deistance and Quality of Ameneties	4	Shops for daily necessities > 0.62 miles	On-the-spot investigation		
	5	Neighborhood meeting place (i.e. park) > 0.31 miles	On-the-spot investigation		
	6	Hotel/restaurant/snackbar > 0.31 miles	On-the-spot investigation		
	7	Bank/Post Office > 1.24 miles	On-the-spot investigation		
	8	Basic medical facilities (i.e. group practice, health center) > 0.31 miles	On-the-spot investigation		
	9	Sports facilities (i.e. fitness club, swimming pool) > 0.31 miles	On-the-spot investigation		
	10	Education (from kindergarten to university) > 1.24 miles	On-the-spot investigation		
3 Public Transport	11	Distance to railway station > 1.24 miles	Town map		
	12	Distance to bus/underground/tram > 0.62 miles	Map or transport services		
4 Accessibility by Car and Parking	13	Many obstacles; traffic congestion	On-the-spot investigation		
	14	Distance to parking sites > 0.16 miles	Inspection/new design		
	15	< 1 parking space/1080 ft^2 road surface	Inspection/new design		
Cultural					
5 Tone of Neighborhood	16	Situated on or near the edge of town (i.e. near the highway)	Map or estate agent		
	17	No other buildings in immediate vicinity	Map or estate agent		
	18	Dull environment	On-the-spot investigation		
	19	No green space in neighborhood	On-the-spot investigation		
	20	Area has poor reputation/image; vandalism	Inspection and local press		
	21	Dangerous, noise, or odor pollution (i.e. factories, trains, cars)	On-the-spot investigation		
Legal					
6 Urban Location	22	Noise load on façade > 50 dB (limit for offices 60 dB)	Municipal authorities		
7 Ownership of Ground	23	Leasehold	Estate agent		
			Total Number of Yes's for Location:		x
			Default Weighting:	5	=
			Location Score:		A
			Maximum Possible Location Score (23x5):	115	

Figure 5. Transformation Meter Building Criteria (Reproduced from (Geraedts & Van der Voordt, 2007))

BUILDING				
Aspect	**Gradual Criterion**	**Data Source**	**Appraisal**	
Functional			**Yes**	**No**
1 Year of Construction	1 Office building recently built (< 3 years)	Year of construction		
	2 Recently renovated as offices (< 3 years)	Year of renovation		
2 Vacancy	3 Some office space still in use	i.e. NAIOP		
	4 Building unoccupied < 3 years	i.e. NAIOP		
3 Features of New Dwelling Units	5 ≤ 20 person units (540 ft^2 each) can be made	≤ 10700 ft^2 useful area		
	6 Layouts suitable for local target groups cannot be implemented	Design sketch		
4 Extendability	7 Not horizontally extendable (neighboring buildings)	On-the-spot investigation		
	8 No extra stories (pitched roof or insufficient load-bearing capacity)	On-the-spot investigation		
	9 Basement cannot be built under building	Inspection and/or estate agent		
Technical				
5 Maintenance	10 Building poorly maintained/looks in poor condition	External visual inspection		
6 Dimensions of Skeleton	11 Office depth < 33 ft	Estate agent or inspection		
	12 Module of support structure < 12 ft	On-site or estate agent		
	13 Distance between floors > 20 ft	On-site or estate agent		
7 Support Structure (Walls, Pillars, Floors)	14 Support structure is in poor/hazardous condition	On-site inspection		
8 Façade	15 Cannot be made to blend with surroundings or module > 0.32 miles	On-site or estate agent		
	16 Façade (or openings in façade) not adaptable	On-site inspection		
	17 Windows cannot be reused/opened	Inspection/new design		
9 Installations	18 Impossible to install (sufficient) service ducts	Inspection/new design		
Cultural				
10 Character	19 No character in relation to surrounding buildings	On-site inspection		
	20 Impossible to create dwellings with an identity of their own	Inspection/new design		
11 Access (Entrance Hall/Lifts/Stairs)	21 Unsafe entrance, no clear overview of situation	Inspection/new design		
Legal				
12 Environment	22 Presence of large amounts of hazardous materials	On-site or municipality		
	23 Acoustic insulation of floors < 4 dB	Inspection/new design		
	24 Very poor thermal insulation of outer walls and/or roof	On-site or municipality		
	25 < 10% of floor area of new units gets incident daylight	On-site inspection		
13 Requirements of Dutch Rules and Standards for the Building Industry	26 No elevators in building (> 4 stories), no elevators can be installed	On-site or estate agent		
	27 No (emergency) stairwells	Inspection/new design		
	28 Distance of new unit from stairs and/or elevator ≥ 165 ft	Inspection/new design		
		Total Number of Yes's for Location:		x
		Default Weighting:	3	=
		Location Score:		B
		Maximum Possible Location Score (28x3):	84	

The lists shown in Figures 4 and 5 are part of a tool called the Transformation Meter (Geraedts & Van der Voordt, 2007). This helps assess whether an existing building is suitable for being adaptively reused. Figure 4 includes the location factors to be assessed, focusing on twenty-three specific criteria to investigate. The location aspect focuses on how suitable a building's location is for transformation. The table evaluates multiple aspects of the surrounding environment and accessibility as well as the condition or quality of the building's location. Figure 5 includes the building factors, specifically listing twenty-eight criteria to assess. The building aspect focuses on whether an building's condition is applicable for adaptive reuse. This includes factors such as when it was built, what condition the building is in, whether it fits into its surroundings, and how would an adaptive reuse help. The goal is to determine the number of negative conditions that apply, indicating a challenge for transformation. The more criteria that is selected as "Yes," the more challenging a building transformation will be. The Transformation Meter is a good starting point to determine whether adaptive reuse should be pursued.

To evaluate the sustainability and feasibility, a comparison between renovations to new construction in regard to the amount of greenhouse gas emitted and the cost efficiency. Figure 6 graphically depicts the amount of greenhouse gas emitted during the various stages of construction for a new office building compared to a renovated or adapted office building.

Figure 6. GHG Emissions (Adapted from (Kyaw, Fufa, & Kraniotis, 2023))

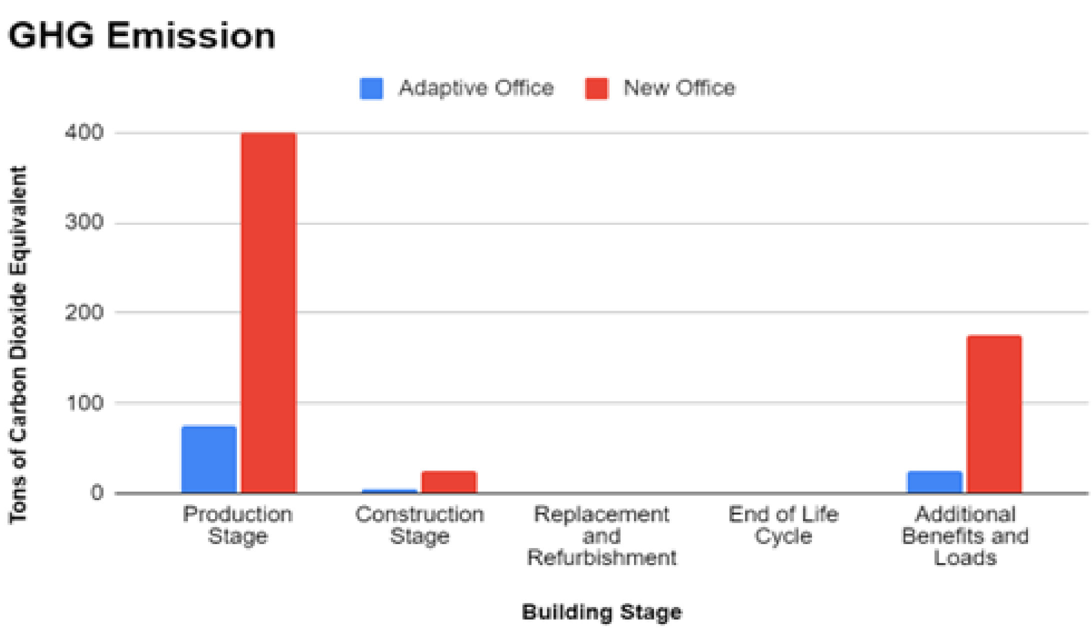


Figure 6 depicts the amount of greenhouse gases that result from construction which is the main measurement of the global warming potential of construction materials. Greenhouse gas emissions are the largest contributor to global warming and cause negative impacts to the environment. Global warming potential is measured in tons of carbon dioxide equivalent to quantify the impact an activity or process has on the environment. As shown in Figure 6, the amount of greenhouse gas emissions (GHG) when constructing new buildings compared to renovating existing buildings is almost nine times as great throughout the material lifecycle. The data collected was based on a life cycle analysis that utilized known data on material carbon emissions.

2.7 Sustainability and Feasibility Calculations

Multiple ways to determine the feasibility of the construction of a building. The two methods investigated are a basic dollar per square foot calculation which were compared with RS Means Calculations (RSMeans Building Construction Cost Data, 2018). In addition to the feasibility calculations, sustainability calculations were completed using the Embodied Carbon in Construction Calculator (EC3, n.d.).

2.7.1 Embodied Carbon in Construction Calculator (EC3)

The Embodied Carbon in Construction Calculator (EC3) is a tool that helps architects, engineers, contractors, and other stakeholders measure and reduce the embodied carbon of building materials. It was developed by the Carbon Leadership Forum with support from Building Transparency and nearly fifty industry partners. Some key features include the embodied carbon assessment, material comparison, data transparency, project-level insights, and regulatory compliance. EC3 focuses on the upfront supply chain emissions of construction materials and enables more sustainable building practices.

The EC3 utilizes embodied carbon data verified by the Environmental Product Declarations (EPD) to determine a projects overall embodied carbon emission given building dimensions and construction estimates. The EPDs detail the environmental performance of products including their global warming potential or the amount of embodied carbon emitted by a material (The EC3 Tool, n.d.). The basic equation for embodied carbon calculations is the quantity of material multiplied by the carbon factor results in the amount of embodied carbon. The carbon factors have been determined based on research and information provided by the manufacturers and are then culminated in a database.

The EC3 estimates carbon emissions by analyzing Environmental Product Declarations of construction materials. It follows a data-driven approach using life-cycle assessment principles to measure embodied carbon, which is the total greenhouse gas emissions associated with material production, transportation, and construction. The data is collected from multiple sources: manufacturers' EPDs, public databases, and industry associations. Manufacturers' EPDs are sourced from the manufacturers products life cycle assessments whereas industry associations allow EC3 to access sector-specific EPDs which enhances coverage across different materials categories. By consolidating the EPDs, the EC3 calculator to compare materials by evaluating the embodied carbon of similar materials, benchmark projects by assessing a project's overall embodied carbon footprint, and set reduction goals by establishing and monitoring embodied carbon reduction goals. While the EC3 calculator provides pertinent data for material comparison, it cannot replace a comprehensive life cycle assessment of the building.

The EC3 calculates carbon emissions by multiplying the material quantity by the amount of global warming potential for that material. One would select the material and quantity into the calculator based on project specifications. The calculator pulls data from a large database with verified documents providing the environmental impact of the material in global warming potential values. The EC3 calculator multiplies the material quantity by its global warming potential value to get the total carbon emissions for each material. The calculator then totals the embodied carbon of all materials to provide a total project embodied carbon emission estimate. Given these results, one could compare different materials to find low-carbon alternatives. The tool highlights materials with lower carbon intensity, enabling better design and procurement decisions.

Embodied carbon calculations are completed in every phase of the construction. The three main phases are the production stage, transportation stage, and the construction installation stage. The Embodied Carbon in Construction Calculator primarily focuses on upfront embodied carbon. Upfront embodied carbon covers emissions from raw material extraction, material transportation, and manufacturing and processing. The main goals for utilizing the Embodied Carbon in Construction Calculator are for transparency, comparability, actionable insights, and compliance support. Overall, utilizing the calculator enabled a better understanding of how much each material contributes to the project carbon emission as well as allowing a direct comparison between the office building construction and adaptive reuse.

The EC3 calculator supports adaptive reuse through comparing a building reuse to new construction. By quantifying the carbon savings from retaining existing structural elements such as concrete or steel, one can analyze the lower amount of embodied carbon emitted in an adaptive reuse when compared to new construction. Through the evaluation of embodied carbon of materials required for renovations, other sustainable material options are identified. Finally, the EC3 calculator provides data to optimize material reuse, minimize environmental impact, and aid in the decision to support sustainable renovations.

2.7.2 RS Means

RS Means is a widely utilized cost-estimating system in the construction industry. It provides cost data, to help contractors, engineers, architects and project managers develop accurate cost estimates. It provides data-driven insights that help professionals estimate the costs of labor, materials, and equipment across various construction projects. RS Means calculations involve using cost data published by RS Means by Gordian to estimate the total cost of construction projects. The calculations take material costs, labor costs, equipment costs, location factors, overhead, and profit into account. To estimate costs, one must identify the work items, find unit costs, adjust for location, apply overhead and profit, then summarize the estimate of all of these aspects.

RS Means was created due to a recognition for the need for standardized cost data in the construction industry. Construction projects often suffered from inconsistent pricing, making budgeting and financial planning difficult. RS Means aimed to create a reliable resource that would allow professionals to accurately estimate costs for different types of projects. The first edition was a printed manual containing construction cost data collected from a variety of sources. It provided estimates for labor, materials, and equipment based on regional pricing variations. This approach revolutionized the industry by offering a systematic method for predicting construction costs, thereby reducing financial uncertainties for project stakeholders.

RS Means has grown significantly since the first publication, expanding the scope and depth of its cost databases. The company introduced annual updates to ensure the accuracy and relevance of its data, reflecting inflation, market trends, and changes in material costs. Additionally, RS Means started developing specialized guides for different types of construction, including residential, commercial, and industrial projects. RS Means has transitioned from printed manuals to digital formats with the technological advancements in the industry. The company began offering software solutions that integrated cost estimation data with project management tools. This digital transformation allowed users to access real-time data, making cost estimation more efficient and accurate.

RS Means has continued to evolve, incorporating advanced technologies such as cloud computing, artificial intelligence, and big data analytics. The company introduced online databases and subscription-based services that allowed users to access up-to-date cost information from anywhere. A large improvement to RS Means came when it was acquired by Gordian, a leading provider of data-driven solutions for the construction and facilities management industries. Under Gordian’s ownership, RS Means expanded its offerings, integrating cost estimation with advanced project management tools, life-cycle cost analysis, and facilities planning solutions. Today, RS Means is widely used by government agencies, educational institutions, private contractors, and construction firms. It remains a trusted resource for cost estimating, helping professionals make informed decisions and manage budgets effectively.

The impact of RS Means on the construction industry has been profound. By providing standardized cost data, it has improved the accuracy of project estimates, reduced financial risks, and facilitated better decision making. RS Means has also played a crucial role in developing best practices for cost estimation, influencing how construction projects are planned and executed. Furthermore, the widespread adoption of RS Means has contributed to greater transparency in the industry. Contractors, clients, and regulatory agencies can rely on consistent cost data, which enhances trust and reduces disputes over project pricing. In addition, RS Means has helped professionals adapt to market fluctuations, as its regularly updated data reflects changes in material costs, labor rates, and economic conditions.

RS Means has played a pivotal role in the revolution of construction cost estimation. From its origins as a printed cost manual to its current status as a digital, data-driven platform, RS Means has continuously adapted to meet the needs of the construction industry. Its impact on budgeting, financial planning, and project execution has made it an indispensable tool for professionals worldwide. As technology advances, RS Means will likely continue to innovate, further shaping the future of construction cost estimation.

Chapter 3. Case Study Analyses

To analyze the impacts of adaptive reuse, the sustainability and cost effectiveness through material cost and greenhouse gas emission calculations comparing an adaptive reuse to new construction is investigated.

3.1 *Adaptive Reuse of Industrial Heritage Building – Comparative Life Cycle Assessment Using a Case Study*

The construction industry is one of the largest contributors to global greenhouse gas emissions with material production playing a dominant role. However, existing building stocks, such as industrial heritage buildings, present an opportunity to enhance resource efficiency and mitigate environmental impacts. This literature review explores the adaptive reuse of industrial heritage buildings, focusing on life cycle assessment methodologies and sustainability considerations.

When searching for a building to utilize for the case study, an article on an adaptive reuse of an industrial building in Norway was found. The article is titled "Adaptive Reuse of Industrial Heritage Building – Comparative Life Cycle Assessment Using a Case Study" (Kyaw, Fufa, & Kraniotis, 2023). In this article, the life cycle assessment of four adaptive reuse situations is investigated. While the building type is different, the analysis of the sustainability aspect was very beneficial. The case study focuses on an industrial heritage building in Skien, Norway. There were four scenarios considered: adaptive reuse as a warehouse, adaptive reuse as an office, new construction of a warehouse, and new construction of an office. Additionally, it was discovered that this type of adaptive reuse, transforming industrial buildings into residential occupations, was more common in the USA. This can be due to the increased number of unoccupied factories in the last fifty years. As more office spaces become unoccupied due to an increase in remote working, it is believed there will be more office-to-residential conversions in the future.

The study evaluated the environmental impact of adaptive reuse of industrial heritage buildings compared to new construction, using a Life Cycle Assessment approach. Life cycle assessment is a critical tool for evaluating the environmental impact of buildings. Research indicates that adaptive reuse typically results in lower carbon footprints than new constructions due to the retention of existing materials and structural components. Adaptive reuse refers to the process of repurposing existing buildings for new functions while maintaining the structural integrity. Several studies highlight its benefits, including energy conservation, waste reduction, and historical preservation. The sustainability advantages of adaptive reuse are well-documented in environmental impact assessments, which emphasize reduced embodied carbon and material consumption compared to demolition and new construction. Several comparative studies demonstrated that refurbishing industrial heritage buildings leads to significant reductions in energy use and waste generation over a building's lifespan.

In the adaptive reuse scenarios, the carbon footprint was lower than a new construction of the same building. The adaptive reuse as a warehouse resulted in the lowest total greenhouse gas emissions while the new office construction had the highest. Adaptive reuse reduced over eighty percent of emissions compared to new construction. New construction had significantly higher greenhouse gas emissions in the production phase. It also resulted in high emissions from concrete, insulation, and metal. Adaptive reuse scenarios saved greenhouse gas emissions across all life cycle stages, specifically in material use. Adaptive reuse saved emissions on key building elements like floors, ceilings, and walls. Windows and doors had slightly higher emissions in the adaptive reuse scenarios. A lack of historical data on materials and construction methods requires assumptions in the Life Cycle Assessment approach, thus, future research should include a comprehensive database of historic building materials.

Despite its benefits, adaptive reuse faces challenges such as high renovation costs, structural limitations, and regulatory barriers. Studies also suggest that the effectiveness of reuse depends on factors like building location, condition, and intended function. Additionally, ensuring energy efficiency in retrofitted buildings requires integrating modern technologies and sustainable design principles.

From this analysis, numerous conclusions were made regarding adaptive reuse. First, adaptive reuse of industrial heritage buildings significantly reduces environmental impact. Next, minimal material replacement during adaptation maximizes sustainability benefits. Finally, future construction should prioritize durable materials and flexible building designs as adaptive reuse will become more common. One thing to note was that a more comprehensive Life Cycle Assessment approach, including cost and social factors, would provide a more holistic evaluation of adaptive reuse.

Empirical research based on case studies, such as those examined in this document, reveals practical applications of adaptive reuse in reducing greenhouse gas emissions and enhancing sustainability. Comparisons between reused and newly constructed buildings highlight the economic and environmental advantages of preserving industrial heritage structures.

The adaptive reuse of industrial heritage buildings offers a viable solution to reducing the environmental footprint of the construction sector. By leveraging life cycle assessment methodologies, policymakers and industry professionals can make informed decisions that balance sustainability with economic feasibility. Further research is needed to optimize reuse strategies and overcome associated challenges in implementation.

3.2 *Repurposing Existing Office Buildings – Structural Lessons Learned*

While attending the National Council of Structural Engineers Association conference in November 2024, a speaker presented on an adaptive reuse of an office building in Washington, D.C. (Greenawalt, 2024). The office building was repurposed to residential usage, and the speaker covered two case studies, key structural engineering challenges in repurposing, understanding additional slab penetrations, and evaluating strengthening and demolition procedures.

The case study focused on was the DC Watermark, an office to residential conversion. This project involved converting an existing office building into a residential complex, requiring significant structural modifications to accommodate new loads, layouts, and modern residential amenities. The project was a 590,000 square foot, nine story building completed in 2020; DC Watermark was a concrete structure. The structural modifications made to the building included demolition, strengthening measures, core drilling adjustments, considerations for overbuilding, and lateral system analysis.

The demolition includes two new courtyards and new elevator openings. To introduce natural light and improve airflow in the new residential spaces, portions of the existing structure were demolished to create two large courtyards. These openings required careful structural adjustments to redistribute loads from upper floors. Additionally, residential buildings have different elevator requirements than office buildings, necessitating the cutting of new vertical shafts. The structural engineers had to analyze and reinforce the affected floor slabs and surrounding columns.

The building's original design was meant for office loads, which differ from residential loads in terms of distribution and intensity. Strengthening measures were necessary to meet new performance requirements. In areas where load concentrations increased, such as near the new elevator cores or reconfigured column locations, the existing slabs were vulnerable to punching shear failure. Strengthening techniques were used to prevent slab-column connections from failing under increased loads. The slab was strengthened with fiber reinforced polymers due to its high strength-to-weight ratio and minimal impact on existing structures. It was applied in thin layers to reinforce slabs without adding significant weight, preserving the original structural design. Another challenge was that converting an office floor plan into residential units required modifying slab edges to accommodate new balconies, terraces, and exterior extensions. To address this, slabs were extended using reinforced concrete additions to create new cantilevered spaces and additional support was introduced where required to prevent excessive deflections.

Structural integrity assessments revealed areas where previous wear and tear had compromised the concrete and steel components. Necessary repairs and reinforcements were carried out before adding new structural elements.

In addition to the strengthening measures, there were also overbuild considerations. Instead of excessively reinforcing old slabs, engineers opted to redistribute loads efficiently to avoid overloading weak areas. This approach minimized the need for invasive strengthening, preserving the original building framework. Another challenge on this project was that office buildings are designed with large open floor plan and minimal plumbing infrastructure, whereas residential buildings need multiple bathrooms, kitchens, and HVAC systems. To address this, extensive core drilling was conducted to install necessary vertical plumbing, electrical, and mechanical systems. Engineers had to ensure that these modifications did not compromise the slab integrity or weaken the structure. The final item addressed is the lateral system analysis. The goal is to ensure that modifications did not compromise the building's ability to withstand wind and seismic forces. Some structural adjustments that were made included strengthening shear walls in critical areas, additional bracing and steel reinforcement to improve lateral stability, and redistribution of loading to compensate for removed structural elements.

The presentation provided key insights to structural modifications required for repurposing office buildings. It highlighted the challenges and solutions for demolition, strengthening, and overbuilds while ensuring the stability and functionality of the new space. The key takeaways were that demolition for reconfiguration requires careful structural assessment to maintain stability, strengthening techniques help adapt office buildings for new uses, overbuild strategies must consider weight limits and load redistribution, core drilling is essential for new plumbing and electrical systems in residential conversions, and lateral system modifications are necessary to maintain overall building stability.

3.3 Case Study Parameters

A fictitious building plausible in any medium size cities in the USA is a four-story office building constructed in the 1970's that has a composite steel structure, a concrete foundation, and brick veneer façade. Additionally, the building is located in Kansas City, Missouri and is being converted from an office occupation to residential apartments. The building dimensions are fifty feet by one hundred feet with a total building square footage of twenty thousand. This is similar to the average office building size of sixteen thousand square feet (Commercial Buildings Energy Consumption Survey (CBECS), 2015). The assumption that the building will need asbestos abatement was made since the decline of asbestos use in construction began in the 1970's, thus it is assumed that it would still be present in construction. Most buildings constructed before 1989, when the Environmental Protection Agency banned the use of asbestos, have asbestos containing materials (The Lawson Group, 2022).

One thing to determine was whether the fictitious building would be applicable in an adaptive reuse scenario. Utilizing the Transformation Meter, numerous parameters were taken into consideration for both the building location as well as the physical building condition. Decisions for the case study building were made based on the typical location of office buildings in the Kansas City, Missouri area. The location and building criteria results can be seen in Figures 7 and 8.

Figure 7. Transformation Meter Case Study Location Criteria (Reproduced from (Geraedts & Van der Voordt, 2007))

LOCATION					
Aspect		Gradual Criterion	Data Source	Appraisal	
Functional				Yes	No
1 Urban Location	1	Building in industrial estate or office park far from town center	Town map		X
	2	Building gets little or no sun	On-site inspection		X
	3	View limited by other buildings on 75% of floor area	On-site inspection		X
2 Deistance and Quality of Ameneties	4	Shops for daily necessities > 0.62 miles	On-the-spot investigation		X
	5	Neighborhood meeting place (i.e. park) > 0.31 miles	On-the-spot investigation		X
	6	Hotel/restaurant/snackbar > 0.31 miles	On-the-spot investigation		X
	7	Bank/Post Office > 1.24 miles	On-the-spot investigation		X
	8	Basic medical facilities (i.e. group practice, health center) > 0.31 miles	On-the-spot investigation		X
	9	Sports facilities (i.e. fitness club, swimming pool) > 0.31 miles	On-the-spot investigation		X
	10	Education (from kindergarten to university) > 1.24 miles	On-the-spot investigation		X
3 Public Transport	11	Distance to railway station > 1.24 miles	Town map	X	
	12	Distance to bus/underground/tram > 0.62 miles	Map or transport services		X
4 Accessibility by Car and Parking	13	Many obstacles; traffic congestion	On-the-spot investigation	X	
	14	Distance to parking sites > 0.16 miles	Inspection/new design		X
	15	< 1 parking space/1080 ft^2 road surface	Inspection/new design		X
Cultural					
5 Tone of Neighborhood	16	Situated on or near the edge of town (i.e. near the highway)	Map or estate agent		X
	17	No other buildings in immediate vicinity	Map or estate agent		X
	18	Dull environment	On-the-spot investigation		X
	19	No green space in neighborhood	On-the-spot investigation		X
	20	Area has poor reputation/image; vandalism	Inspection and local press		X
	21	Dangerous, noise, or odor pollution (i.e. factories, trains, cars)	On-the-spot investigation		X
Legal					
6 Urban Location	22	Noise load on façade > 50 dB (limit for offices 60 dB)	Municipal authorities		X
7 Ownership of Ground	23	Leasehold	Estate agent		X
			Total Number of Yes's for Location:	2	x
			Default Weighting:	5	=
			Location Score:	10	A
			Maximum Possible Location Score (23x5):	115	

The first section of the location criteria considers the functionality of the location. Determining if the building was far from town, the amount of sunlight the building receives, and the amount of view limited by other buildings were criteria that made up the urban location section of the list. It was determined that the building was located near the town center, gets an adequate amount of sunlight, and that the view was not limited for seventy-five percent of the floor area. The next section of the location functionality criteria assessed the distance from and quality of amenities. This includes determining the distance to grocery stores, parks, hotels, restaurants, banks, fitness centers, and schools. The building was in an adequate proximity to each of these as recommended by the criteria. The third section of the functionality portion was the location and accessibility of public transportation. Kansas City, Missouri does not have ample public transportation opportunities. This was taken into consideration when determining if the building was located close to a train station, bus route, or subway station. It was determined that the building was located further than one and a quarter mile from a train station. There is ample bus routes and opportunities to ride this form of public transportation, so this was deemed acceptable for the given criteria. The last aspect of the functionality portion is the accessibility by car and parking. The roadways can get congested especially during rush hour, so it was determined that the building location would not be acceptable for this criteria. Most buildings have dedicated parking areas or garages for employees, so this was not deemed an issue. Additionally, there are more than one parking space per one thousand square feet of road surface. The next section of the location criteria considers the cultural aspect of the location. This section includes the tone of the neighborhood, assessing the location of the building in relation to the highway, the number of buildings located near it, the amount of green space in the vicinity, how the area is perceived by the community, and how safe the location is. It was determined that the building is located near the highway and has other buildings located near it. Additionally, the environment is lively with a good image by the community. There is green space near the building limited noise or odor pollution. The final section of the location criteria assesses the legal aspect of the building location. This section determines if the location is urban and what the ownership of the ground is. The building had less than fifty decibels of noise on the façade, meaning it is adequate for an adaptive reuse scenario. Additionally, there was no leasehold on the building which is good for an adaptive reuse. This resulted in only two yes's for the location factor, meaning the location score was 10A. With ten out of one hundred fifteen total points possible, the location was optimal for an adaptive reuse.

Figure 8. Transformation Meter Case Study Building Criteria (Reproduced from (Geraedts & Van der Voordt, 2007))

BUILDING				
Aspect	Gradual Criterion	Data Source	Appraisal	
Functional			Yes	No
1 Year of Construction	1 Office building recently built (< 3 years)	Year of construction		X
	2 Recently renovated as offices (< 3 years)	Year of renovation		X
2 Vacancy	3 Some office space still in use	i.e. NAIOP		X
	4 Building unoccupied < 3 years	i.e. NAIOP		X
3 Features of New Dwelling Units	5 ≤ 20 person units (540 ft^2 each) can be made	≤ 10700 ft^2 useful area		X
	6 Layouts suitable for local target groups cannot be implemented	Design sketch		X
4 Extendability	7 Not horizontally extendable (neighboring buildings)	On-the-spot investigation	X	
	8 No extra stories (pitched roof or insufficient load-bearing capacity)	On-the-spot investigation		X
	9 Basement cannot be built under building	Inspection and/or estate agent	X	
Technical				
5 Maintenance	10 Building poorly maintained/looks in poor condition	External visual inspection		X
6 Dimensions of Skeleton	11 Office depth < 33 ft	Estate agent or inspection		X
	12 Module of support structure < 12 ft	On-site or estate agent		X
	13 Distance between floors > 20 ft	On-site or estate agent		X
7 Support Structure (Walls, Pillars, Floors)	14 Support structure is in poor/hazardous condition	On-site inspection		X
8 Façade	15 Cannot be made to blend with surroundings or module > 0.32 miles	On-site or estate agent		X
	16 Façade (or openings in façade) not adaptable	On-site inspection	X	
	17 Windows cannot be reused/opened	Inspection/new design		X
9 Installations	18 Impossible to install (sufficient) service ducts	Inspection/new design		X
Cultural				
10 Character	19 No character in relation to surrounding buildings	On-site inspection		X
	20 Impossible to create dwellings with an identity of their own	Inspection/new design		X
11 Access (Entrance Hall/Lifts/Stairs)	21 Unsafe entrance, no clear overview of situation	Inspection/new design		X
Legal				
12 Environment	22 Presence of large amounts of hazardous materials	On-site or municipality		X
	23 Acoustic insulation of floors < 4 dB	Inspection/new design		X
	24 Very poor thermal insulation of outer walls and/or roof	On-site or municipality		X
	25 < 10% of floor area of new units gets incident daylight	On-site inspection		X
13 Requirements of Dutch Rules and Standards for the Building Industry	26 No elevators in building (> 4 stories), no elevators can be installed	On-site or estate agent		X
	27 No (emergency) stairwells	Inspection/new design		X
	28 Distance of new unit from stairs and/or elevator ≥ 165 ft	Inspection/new design		X
		Total Number of Yes's for Location:	3	x
		Default Weighting:	3	=
		Location Score:	9	B
		Maximum Possible Location Score (28x3):	84	

The first section of the building criteria considers the functionality of the building. Determining what year the building was constructed and if the building was renovated recently were criteria that made up the year of construction section of the list. It was determined that the building was built more than three years ago and had not been renovated. The next section of the location functionality criteria assessed the buildings' vacancy. This includes determining if the building is still occupied and how much office space is in use. The building did not have office space being utilized and had been unoccupied for more than three years. The third section of the functionality portion assessed the features of the new dwelling units. Determining if units greater than five hundred forty square feet can be made and if the layout is suitable for the target group were criteria within this portion. It was determined that the units would be greater than five hundred forty square feet and that the unit layout would be ideal for the target group. The last aspect of the functionality portion is the extendibility of the building. This portion investigated if the building could extend horizontally, if additional stories existed, and if a basement could be built under the existing building. Given the previous assumption that there are neighboring buildings, it was determined that there was no ability to horizontally extend. Since the building has a flat roof, it was assumed that extra stories could be added if needed, but it was also acknowledged that retrofitting may be necessary when completing this. Additionally, it was determined that a basement could not be built under the building. The next section of the building criteria considers the technical aspect of the building. This section includes the maintenance of the building, dimensions of the skeleton, support structure, façade, and installations. It was determined that the building was not in poor condition upon assessment. Additionally, the office depth was greater than thirty-three feet, the module of the support structure was greater than twelve feet, and the distance between floors was less than twenty feet. The support structure was deemed in safe condition, thus no retrofitting would need to occur. The façade was determined to blend with surrounding buildings and windows could be opened. An issue identified with the façade is the inability to adapt or add openings since it is brick veneer. It would be difficult to alter the façade without extensive work, which was a negative on the criteria list. The last decision made in this section is that it was not impossible to install service ducts. The third section of the building criteria analyzes the cultural aspect of the building. This section assesses the character and access of the building. It was determined that the building had adequate character to the surrounding buildings while also having the ability to create dwellings with their own identity. Additionally, it was determined that the building had safe entrances with a clear overview of the situation. The final section of the building criteria assesses the legal aspect of the building. This section determines if the building environment is adequate as well as if the building meets building standards. There was no hazardous materials near the building, the insulation of the floors resulted in less than four decibels of noise, and there was adequate thermal insulation in the building. The building had more than ten percent of floor area of new units receiving incidental daylight, meaning it is adequate for an adaptive reuse scenario. Additionally, there was an elevator and stairwells in the building, and the distance from each unit to a means of egress was less than one hundred sixty-five feet. This resulted in only three yes's for the building factor, meaning the building score was 9B. With nine out of eighty-four total points possible, the building was adequate for an adaptive reuse. Utilizing the Transformation Meter, it was determined that the building in the selected location created for the case study was optimal to be utilized as an adaptive reuse.

The next thing to investigate is the building codes. This is the most important item to investigate as it will dictate many design options and decisions based on how the code requirements have changed. Based on the assumed building code utilized in Kansas City, Missouri in 1970, it is assumed that the building would have also utilized the 1964 UBC as the primary building code when the building was designed. This means that the IEBC would be utilized to determine adaptation requirements and limitations. A new building would utilize the 2021 IBC and the 2022 ASCE 7 Minimum Design Loads and Associated Criteria for Buildings and Other Structures to determine the applicable loading requirements. The change in code minimum requirements from the original UBC and the current ASCE were investigated as well as the change in loading requirements for an office building to an apartment building.

Dead, live, snow, wind, and seismic loading requirements were all investigated. Dead loads did not change between the codes as this accounts for the permanent structure load. Live load requirements for an office building are fifty pounds per square foot and forty pounds per square foot for an apartment, and the roof live load is twenty pounds per square foot. These loading minimums did not change between the UBC and the ASCE. Snow loading also remained the same between the codes. While there is an updated equation to calculate the snow load in the ASCE, it resulted in the same load of twenty pounds per square foot. Wind loading had the largest difference in calculating the load on the building. The 1964 UBC had wind loading change as the height of the building increased, so the first thirty feet of the building experienced thirty pounds per square foot of loading and the rest of the wall above thirty feet had a forty pounds per square foot loading applied. Wind load calculations are much more complex per the 2022 ASCE. Many factors from the topography, direction of wind, wind speed among others are all taken into consideration. Due to the wind pressure being relatively the same, it was assumed that this building had an adequate main wind force resisting system when originally designed. Per the UBC, Kansas City, Missouri was located in Seismic Zone 0 meaning there was a negligible seismic risk. This has remained the same as Kansas City, Missouri is classified as a Seismic Design Category B which is equivalent to Seismic Zone 0. Since the live load requirements decreased from an office building occupancy to an apartment building occupancy and no other loading drastically increased, it was determined that the structure would have enough strength and no retrofit would be necessary.

3.3.1 Feasibility Calculations

To gain a basic understanding of the feasibility of renovations, a financial comparison of the construction of a new office or apartment building compared to a renovation of either of these is developed. Two methods are utilized: cost per square foot calculation and the RS Means calculation method. These calculations are compared to determine if one was more accurate than the other.

3.3.1.1 Cost per Square Foot Calculations

The building will utilize the same parameters developed at the start of this section,

The average cost of commercial office building construction is $400.00 per square foot while the average cost of apartment building construction is $300.00 per square foot (Carlson, 2024).

Table 1. Financial Comparison of New Build and Renovated Apartment Building to New Build and Renovated Office Building (Based on information in (Carlson, 2024), (Waldek, 2023), and (Hamann, 2024))

	Apartment Building	**Office Building**
New-Build Cost	$6,000,000	$8,000,000
Renovated Cost	$1,000,000	$1,500,000

Table 1 is the tabulated comparison in costs for a newly constructed office and apartment building versus the renovation costs of these buildings. This equates to approximately six, seven hundred fifty-square foot apartments which is similar to the average apartment size in Kansas City, Missouri (Kansas City, MO Rental Market Trends, 2024). When estimating the renovation costs, the average cost of commercial building renovations was determined to be $75 to $150 per square foot while the average residential renovation cost was $50 per square foot (Majumder, n.d.). The price of a new apartment building is six million dollars while the adaptive reuse apartment building is one million dollars. An adaptive reuse is five million dollars less than the cost of a new apartment building. The price of a new office building is eight million and the adaptive reuse of an office building is one million five hundred thousand dollars. The price difference between a new apartment building and a new office building is two million dollars while the difference in the cost of an adapted office building is $500,000 more than renovating an existing apartment building of the same size. Overall, the cost to renovate a space is roughly seventeen to nineteen percent of the cost to construct a new building.

Since the cost per square foot method is a basic calculation comparison of a new construction and adaptive reuse of an office building, it was determined that a more in-depth cost analysis should be investigated. The average cost for each scenario takes into account the material, transportation, construction, and labor costs for all materials and systems in that type of building. This leads to an over generalization of the cost estimation as it does not have specifics for the certain project and all that is necessary. Two methods are utilized: the EC3 calculator and the RS Means calculation method. These calculations are compared to determine if one was more accurate than the other.

3.3.1.2 RS Means Calculations

Utilizing the RS Means building construction cost data, one can determine how much more expensive a new build is compared to an adaptive reuse building. The largest impact will be labor and material costs. For labor, the schedule of the project causes a difference in the cost of labor. A typical new build timeline is a year to a year and a half while a renovation could be six months to a year (Waters, 2023). The difference of six months has a large impact on the overall labor cost. Material cost will also decrease for an adaptive reuse since the majority of the structure could remain intact, assuming no large structural issues. Table 2 shows the material, quantity, unit price from the RS Means construction data book, and the total cost for these materials.

Table 2. RS Means Calculations for a new office building (RSMeans Building Construction Cost Data, 2018)

Material	Quantity	Unit Price	Total
Crew	360 days	$5000/day	$1,800,000
Equipment	180 days	$8000/day	$1,440,000
Cement	51,500 clb	$12.60/cubic weight	$648,900
Aggregate and Sand	26 cy	$27.00/cubic yard	$702
Steel Reinforcement	2 tons	$960.00/ton	$1,920
Footing Formwork	792 sf	$2.92/square foot	$2,313
Brick Veneer	9,765 sf	$4.32/square foot	$42,185
Steel Columns	990 lf	$66.50/lineal foot	$65,835
Steel Beams	3,400 lf	$38.50/lineal foot	$130,900
Windows	96 windows	$500.00/window	$48,000
Partition Wall	1,600 lf	$1.24/lineal foot	$1,984
Insulation	1,300 lf	$1.11/lineal foot	$1,443
Stairs	8 runs	$692.29/run	$5,538
Elevator	1 unit	$131,300.00/unit	$131,300
Carpet	10,000 sy	$39.50/square yard	$395,000
			$4,716,020

Table 2 presents the itemized cost breakdown for the adaptive reuse scenario utilizing data from RS Means Building Construction Cost Data. The major components are labor (crew), equipment, concrete, steel reinforcement, structural steel, brick veneer, windows, partition walls, insulation, and carpet. For labor, a construction crew is required for twelve months with an average cost of five thousand dollars per day. This resulted in a total labor cost of one million eight hundred thousand dollars. Since there was no schedule, the equipment use length was developed as a rough estimate. Additionally, the unit price for the equipment needed was averaged to eight thousand dollars per day. The total equipment cost was one million four hundred forty thousand dollars.

The structural aspect of the building includes the concrete footings (comprised of cement, aggregate, and sand for materials), steel reinforcement for the footings, wood to form the footings, and structural steel columns and beams. The concrete footing materials consisted of cement, aggregate and sand, and lumber for the formwork. Using a 1:2:3 ratio of cement, sand, and aggregate, it was calculated that fifty-one thousand five hundred cubic pounds of cement and twenty-six cubic yards of aggregate and sand would be needed. The cost of a cubic pound of cement is twelve dollars and sixty cents resulting in a total cement cost of six hundred forty-eight thousand nine hundred dollars. Aggregate and sand is priced at twenty-seven dollars per cubic yard, thus, the total cost of aggregate and sand is seven hundred two dollars. To develop the concrete footings, lumber formwork is needed. Seven hundred ninety-two lineal feet of lumber is utilized. The formwork costs two dollars and ninety-two cents per lineal foot. The resulting cost for formwork is two thousand three hundred thirteen dollars. Steel reinforcement cost nine hundred sixty dollars per ton of steel. It was determined that two tons of reinforcing steel is needed for the footings resulting in a cost of one thousand nine hundred twenty dollars. The other structural aspects are the steel columns and beams. The steel column was priced at sixty-six dollars and fifty cents per lineal foot and steel beams were priced at thirty-eight dollars and fifty cents per lineal foot. This resulted in a total price of sixty-five thousand eight hundred thirty-five dollars and one hundred thirty thousand nine hundred dollars, respectively. The structural aspect of the building cost one million one hundred thousand dollars of the total cost of the building.

There were ninety-six windows installed in the building with each window costing five hundred dollars per window. The total cost of the windows in the building was forty-eight thousand dollars. The next item was the partition walls; it was approximated that one thousand six hundred lineal feet of partition walls would be constructed with partition wall material construction costs one dollar and twenty-four cents per lineal foot. This resulted in a total cost of one thousand nine hundred eighty-four dollars. With the walls, insulation was not considered in the construction; approximately one thousand three hundred lineal feet of insulation was assumed at a cost of one dollar and eleven cents per lineal foot. The cost of the insulation is one thousand four hundred forty-three dollars. Two flights of stairs were assumed as a means of egress as well as an elevator. The stairs were priced at six hundred ninety-two dollars and twenty-nine cents per run, resulting in a total price of five thousand five hundred thirty-eight dollars. One elevator cost one hundred thirty-one thousand three hundred dollars. The final material for the adaptive reuse cost analysis was additional carpet. The price for carpet was forty-four dollars and fifty centers per square yard resulting in a total cost of one hundred eleven thousand two hundred fifty dollars. The overall construction cost for the adaptive reuse scenario was eight hundred sixty thousand eight hundred thirty-eight dollars.

Kansas City, Missouri has a city cost index of 99.0 for materials and 107.3 for installation with a total average cost index of 102.7. This index factor will be multiplied by the total cost to get an accurate estimate for the specific location. This would increase the total cost to $4,843,353.00. This is less than the national average of seven million dollars to construct a new office building (What is the Cost to Build an Office?: 2025 Guide and Data, 2024).

Table 3. RS Means Calculations for an adaptive reuse apartment building (RSMeans Building Construction Cost Data, 2018)

Material	Quantity	Unit Price	Total
Crew	180 days	$3000/day	$540,000
Equipment	30 days	$5000/day	$150,000
Windows	96 windows	$500.00/window	$48,000
Partition Wall	700 lf	$1.24/lineal foot	$868
Insulation	300 lf	$1.11/lineal foot	$333
Carpet	2,500 sf	$39.50/square yard	$98,750
			$837,951

Table 3 presents the itemized cost breakdown for the adaptive reuse scenario utilizing data from RS Means Building Construction Cost Data. The major components are labor (crew), equipment, windows, partition walls, insulation, and carpet. For labor, a construction crew is required for six months with an average cost of three thousand dollars per day. This resulted in a total labor cost of five hundred forty thousand dollars. Since there was no schedule, the equipment use length was developed as a rough estimate. Additionally, the unit price for the equipment needed was averaged to five thousand dollars per day. The total equipment cost was one hundred fifty thousand dollars. There were ninety-six windows installed in the building with each window costing five hundred dollars per window. The number of windows replaced was determined based on the assumption that there are more energy efficient window options that would be utilized. While windows technically fall within the architectural scope, often it is on the structural engineer as it is included in the façade. The total cost of replacing all windows in the building was forty-eight thousand dollars. The next item was the partition walls that would need to be modified or added to alter the building layout from an office building layout to residential housing. It was approximated that seven hundred lineal feet of partition walls would be altered or added with partition wall material construction costs three dollars and eighty-six cents per lineal foot. This resulted in a total cost of two thousand seven hundred two dollars. With the walls, additional insulation was necessary; approximately three hundred lineal feet of insulation was assumed at a cost of one dollar and eleven cents per lineal foot. The cost of the additional insulation is three hundred thirty-three dollars. The final material for the adaptive reuse cost analysis was additional carpet. The price for carpet was thirty-nine dollars and fifty centers per square yard resulting in a total cost of ninety-eight thousand seven hundred fifty dollars. The overall construction cost for the adaptive reuse scenario was eight hundred thirty-seven thousand nine hundred fifty-one dollars. With the total average cost index of 102.7 for Kansas City, Missouri, the total cost would be increased to eight hundred sixty thousand five hundred seventy-five dollars. (What is the Cost to Build an Office?: 2025 Guide and Data, 2024).

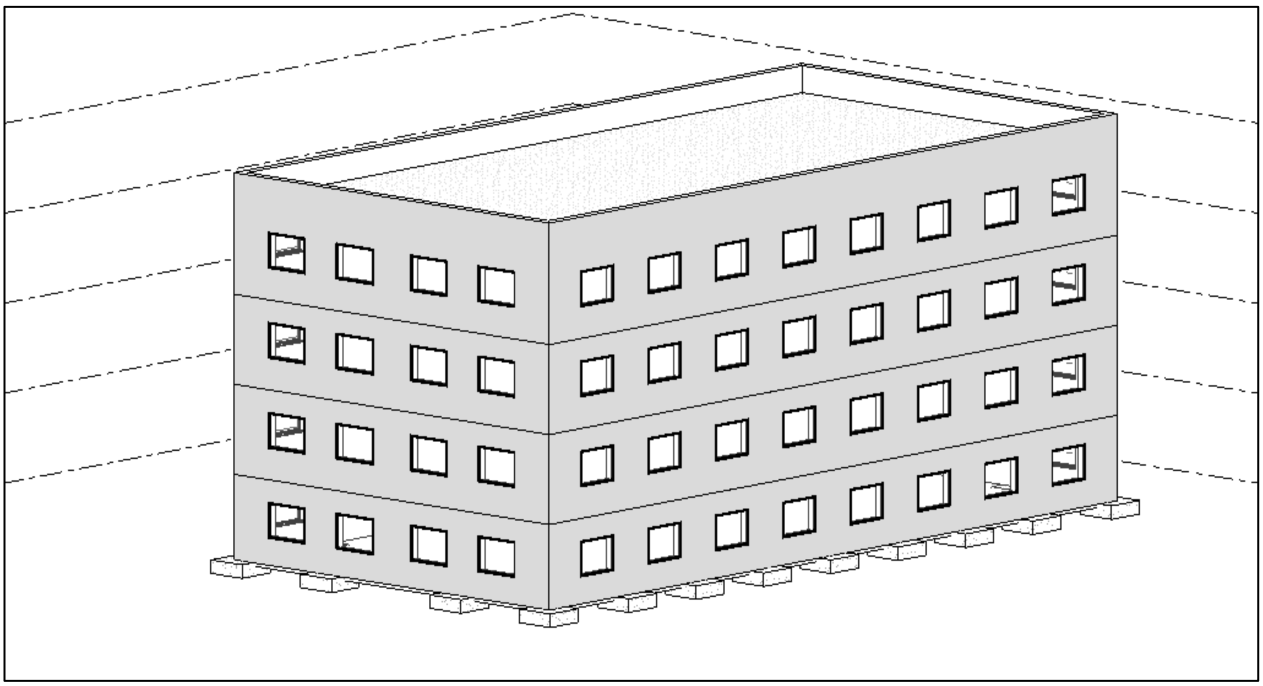
The mechanical, electrical, and plumbing systems, such as HVAC ducts, lighting, and water piping systems, were omitted when completing the feasibility calculations. This was done for a few reasons. First, it was assumed that the systems would be replaced in an adaptive reuse scenario given the advancements in energy efficiency as well as the age of the systems. Realistically, the systems would be taken out and replaced, so it was determined that it could be excluded from the calculations. Additionally, the goal of this report was to analyze the impacts that the structural system had on the feasibility and sustainability of construction. With this, it was determined that the mechanical, electrical, and plumbing system aspect would be outside of the scope, thus omitted from feasibility calculations.

Another factor to consider is the amount it costs to demolish a building. On average, the cost to demolish a building is fifteen dollars per square foot (Demolition Costs in Commercial Real Estate, n.d.). This means that the cost to demolish the building utilized in the case study would be three hundred thousand dollars. This cost does not include the amount to transport or dispose of the building material. The national average for disposal of the building is twenty-four thousand dollars (Little, 2024). The total cost of demolition and disposal is three hundred twenty-four thousand dollars. This is almost half of the cost of the adaptive reuse or the cost of the structural elements minus the concrete cost.

3.3.2 Sustainability Calculations

To get an understanding of the amount of carbon emissions generated during construction solely by the production of the materials, a model was developed to quantify the amount of each material for the case study building. The EC3 calculator utilized basic building dimensions, building materials, and estimated quantities of materials to calculate the amount of embodied carbons for the project. Two trials were completed to determine the amount of embodied carbons were emitted for a new build and an adaptive reuse scenario.

Figure 9. Case Study Revit Model (Revit 2023)



Once the Revit model was completed, a model was developed in EC3 to determine the amount of carbon emissions created from each building material. The building materials consisted of concrete (cement, aggregate, and water), structural steel, composite metal deck, brick veneer, windows, and stud framed interior walls. EC3 completes calculations based on the amount of material needed for the project and the amount of carbon emissions produced by each material. The amount of carbon emissions data is developed based on testing completed over numerous years that has been collected in a database that has been approved and monitored by the Environmental Product Declarations Board. The tabulated information of the material, quantity, and amount of carbon emissions associated with each material as outputted by the EC3 calculations is shown in Table 4. Quantities were determined from the Revit model.

Table 4. EC3 Calculations for a new office building (EC3, n.d.)

Material	Quantity	Realized Kilograms of Carbon Dioxide Emissions	Achievable Kilograms of Carbon Dioxide Emissions
Concrete	849.8 cy	293299	183928
Masonry	540000.0 lb	119319	40699
Structural Steel	131520.0 lb	83660	36382
Metal Deck	9900.0 lb	13042	9428
Wood Studs	77.8 cy	15142	857
Insulation	14960.0 sf	16324	2543
Gypsum Board	34000.0 sf	15034	6188
Wall Finish	74957.2 lb	22805	8733
Flooring	15000.0 sf	31266	8286
Windows	14976.0 lb	9900	8616
	Total	619790	305658

The structural materials selected were concrete for footings, structural steel, and composite deck. The façade includes brick veneer with windows. The partition walls are constructed with wood studs, insulation, gypsum board, and paint. The final building material was the flooring. The concrete resulted in two hundred ninety-three thousand two hundred ninety-nine kilograms of carbon dioxide emitted during the manufacturing phase. Structural steel emitted eighty-three thousand six hundred sixty kilograms of carbon dioxide and the deck emitted thirteen thousand forty-two kilograms of carbon dioxide. The brick façade resulted in one hundred nineteen thousand three hundred nineteen kilograms of realized carbon dioxide emissions. The partition walls resulted in sixty-nine thousand three hundred five kilograms of carbon dioxide emissions during the manufacturing phase. The flooring resulted in thirty-one thousand two hundred sixty-six kilograms of carbon dioxide emissions and the windows resulted in nine thousand nine hundred kilograms of carbon dioxide emissions during the manufacturing phase.

The realized kilograms of carbon dioxide emissions is the actual amount of emissions associated with the material. The achievable kilograms of carbon dioxide emissions is the potential amount of emissions under ideal or optimized conditions where sustainable measures were taken. The realized carbon emissions was utilized when analyzing the building given the assumption that no sustainable measures were taken. This was assumed to analyze the difference building materials

A new office building has almost six hundred twenty thousand kilograms of realized carbon emissions. This is the equivalent amount of carbon emitted by driving a car approximately eight thousand three hundred miles. To get a better perspective, this is equivalent to driving from Florida to Washington and halfway back. After completing the calculations for a new office building construction, an adaptive reuse apartment building was investigated. The results from this calculation are shown in Table 5.

Table 5. EC3 Calculations for an adaptive reuse apartment building (EC3, n.d.)

Material	Quantity	Realized Kilograms of Carbon Dioxide Emissions	Achievable Kilograms of Carbon Dioxide Emissions
Insulation	10060.0 sf	11364	1846
Gypsum Board	15000.0 sf	6768	3009
Wall Finish	7958.0 lb	16805	4682
Flooring	8000.0 sf	16677	4150
Windows	14976.0 lb	9900	8616
	Total	61514	22303

With the adaptive reuse, only the partition walls, flooring, and windows were selected as materials that would be produced and emit carbon emissions. The partition walls are constructed with wood studs, insulation, gypsum board, and paint. The partition walls resulted in thirty-four thousand nine hundred thirty-seven kilograms of carbon dioxide emitted during the manufacturing phase. The flooring resulted in sixteen thousand six hundred seventy-seven kilograms of carbon dioxide emissions and the windows resulted in nine thousand nine hundred kilograms of carbon dioxide emissions during the manufacturing phase.

Comparing the results between the new office building and the adaptive reuse apartment building, it is evident that the amount of realized carbon emissions is greatly less for the adaptive reuse. By not altering the super-structure, the amount of carbon emissions decreases by eighty-five percent. This is important when also considering the amount of carbon that could be emitted during deconstruction and demolition. While this is not investigated in the case study, it is something that should be considered in full life cycle analyses. One study determined that the amount of total carbon emissions for demolition and deconstruction by workers is roughly one hundred thirty thousand kilograms (Lei, Yang, Yan, & Tang, 2023). This amount of carbon dioxide emission is equivalent to three million nine hundred thousand gallons of gasoline burned or the annual emissions of two hundred eighty-five households in the US (Tiseo, 2025).

Chapter 4. Results and Discussion

Embodied carbon refers to the total greenhouse gas emissions generated throughout the lifecycle of building materials, including extraction, production, transportation, and installation. New construction involves significant embodied carbon due to the manufacturing of cement, steel, glass, and other materials. Cement production alone accounts for nearly eight percent of global carbon dioxide emissions. When constructing a new building, the carbon-intensive process of demolishing an existing structure further adds to emissions. In contrast, renovations utilize existing structural components, reducing the need for new materials and lowering embodied carbon. By preserving walls, foundations, and roofing systems, renovation projects can significantly decrease the demand for energy-intensive materials. Studies have shown that reusing structural elements can reduce embodied carbon by up to fifty percent compared to a new building of similar size and function. This was proven in the EC3 calculations as seen in Table 3 and 4.

The case study analyzes the sustainability and feasibility of converting a four-story office building into residential apartments. The study compares the financial and environmental impacts of adaptive reuse versus new construction. The economic feasibility of converting an office building into an apartment building is evident in the basic cost comparison and even more in the RS Means cost data calculations. The estimated cost of a new construction is 7.5 million dollars. When compared to the adaptive reuse where the structure would remain, the cost of construction would be less than 1 million dollars. The largest cost saving is in the structural materials – concrete, steel, brick veneer, and windows. Without these additional costs, the overall project cost is roughly fourteen percent of that of a new construction. Labor and material costs are significantly reduced since the existing structural system is retained. Additionally, an adaptive reuse project has a shorter construction timeline than that of a new construction, also reducing the labor impact to the price.

In addition to the economic feasibility, the sustainability of adaptive reuse was also investigated. The EC3 calculations showed an eighty-four percent decrease in embodied carbon for renovations compared to new construction. The utilization of existing materials and the retention of the existing structure reduce emissions from the concrete and steel production. A major component of the analysis involves evaluating the carbon footprint of new construction versus adaptive reuse. The EC3 calculator estimates that new office construction emits almost six hundred twenty thousand kilograms of carbon dioxide whereas adaptive reuse results in significantly lower emissions, roughly ninety-five thousand kilograms of carbon dioxide. Additionally, it was determined that new construction emits nearly nine times more greenhouse gas emissions than an adaptive reuse. This stark contrast underscores the environmental benefits of repurposing existing structures. The reduction in material consumption, particularly in concrete and steel, plays a crucial role in lowering emissions. The material lifecycle analysis confirmed that renovations lead to significantly lower carbon footprints than those of new construction. Specifically, the insulation, flooring, and wall finishes contribute less to the carbon footprint compared to foundational structural elements. Overall, this proves that an adaptive reuse of an existing structure is more sustainable than the construction of a new building.

Demolishing an old building to make way for new construction generates substantial waste, much of which ends up in landfills. The disposal of materials like concrete, steel, and wood contributes to methane emissions and resource depletion. Renovation mitigates these effects by reusing materials, reducing waste, and promoting a circular economy. Additionally, renovating buildings often allows for the integration of recycled materials, reducing demand for new resource extraction. Adaptive reuse can further maximize sustainability since converting a space requires fewer materials than demolishing and constructing a new building, thereby reducing emissions.

There are many acknowledged challenges associated with adaptive reuse projects. One of the identified issues is that the cost of an adaptive reuse still results in a fairly high price for rent. Since the goal would be to utilize the adapted apartments for low-income or transitional housing to address the housing insecurity issue, the average cost of an apartment exceeds what one could afford. Through the use of tax credits or community funding, a building owner may be more inclined to adapt an office building into multi-family housing. This is due to the gap in renovation and maintenance costs to the amount one could pay for the apartment.

If a retrofit were to occur, it is assumed that the cost and carbon emissions associated with the retrofit would be similar to the amount for one bay of framing. Assuming that five percent of the floor plan were to be retrofit with more openings for stairs, there is approximately eighty-five lineal feet of steel needed for the framing. The additional openings would need twelve additional beams for framing. The necessary cost associated with this is three thousand two hundred seventy-three dollars. Additionally, the beams produce sixteen and a half kilograms of carbon dioxide emissions per pound of steel. This results in one thousand four hundred kilograms of carbon dioxide emitted for the retrofit. This verifies that the cost and amount of carbon dioxide emissions associated with a retrofit is the same amount of one bay of the building due to the amount of new materials and equipment needed for the retrofit.

Something to acknowledge is the additional cost and carbon emissions associated with demolition. This was not included in the scope due to the lack of data available about the amount of carbon emissions associated with demolition. It was determined that the cost associated with demolition is three hundred thousand twenty-four dollars. Additionally, it was determined that the amount of carbon dioxide emitted during demolition and deconstruction is 0.434 kilograms per square foot and 0.340 kilograms per square foot, respectively (Lei, Yang, Yan, & Tang, 2023). This results in an additional six thousand eight hundred kilograms of carbon dioxide emissions during the deconstruction phase and eight thousand six hundred eighty kilograms of carbon dioxide emissions during demolition for a total of fifteen thousand four hundred eighty kilograms of carbon dioxide emitted during the razing of the building. When comparing an adaptive reuse to new building, this would need to be considered for a new building since the old building would be torn down to reuse the site for the new building.

While adaptive reuse offers many advantages, it is not always a feasible option. Some buildings may be structurally unsound, contain hazardous materials like asbestos, or require extensive modifications to meet modern building codes. In such cases, a life-cycle assessment is necessary to determine whether renovation or new construction is the more sustainable choice. Additionally, not all renovations achieve significant carbon reductions. If a building remains energy-inefficient after renovation, the benefits of preserving embodied carbon may be offset by continued high operational emissions. Therefore, sustainability-focused retrofits should prioritize energy efficiency, renewable energy integration, and responsible material sourcing.

Chapter 5. Conclusion and Recommendations

Sustainability in the construction industry has become more of a forefront concern. The construction industry is already implementing methods of adapting existing buildings into functional and thriving structures. There is an increasing trend in adaptive reuse of office buildings into apartments. Sustainable building design minimizes negative environmental impacts, reduces operational costs, and enhances occupant well-being.

The case studies provide strong economic and environmental justification for office to residential conversions. Renovations allow for faster project completion and lower expenses as well as being more sustainable than demolishing and rebuilding. This makes it a viable strategy for addressing affordable housing shortages and reducing carbon footprint. The sustainable aspect of the adaptive reuse aligns with the goal for buildings to be net-zero by 2050 by minimizing construction waste and greenhouse gas emissions. It also reduces urban sprawl by repurposing existing buildings instead of expanding into undeveloped land.

Renovating existing buildings presents a compelling opportunity to reduce carbon emissions compared to new construction. By preserving embodied carbon, minimizing demolition waste, and improving operational efficiency, renovation can significantly lower a building's overall environmental impact. While new construction can incorporate sustainable design principles, its high initial carbon footprint often outweighs long-term savings. As the construction industry moves toward net-zero carbon goals, prioritizing building reuse and energy-efficient renovations will be essential in mitigating climate change.

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Glossary of Terms

Adaptive Reuse – The process of reusing a structure or building for a purpose other than the original purpose for which it was built or designed

Greenhouse Gas Emissions (GHG) – Comprised of Carbon dioxide, Methane, Nitrous oxide, and Fluorinated gases, these gases trap heat in the atmosphere and contribute to climate change

Net-Zero – The amount of emissions produced is offset by actions that remove an equivalent amount of greenhouse gases, thus reaching net-zero emissions

Sustainability – The ability to meet present needs without compromising the ability of future generations to meet their own needs. It involves balancing environmental, social, and economic factors to ensure long-term well-being for people and the planet