Refurbished Green Buildings and Net Carbon Emissions Nexus: Towards Safer and Intelligent Futures in South African Cities

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1 ABSTRACT

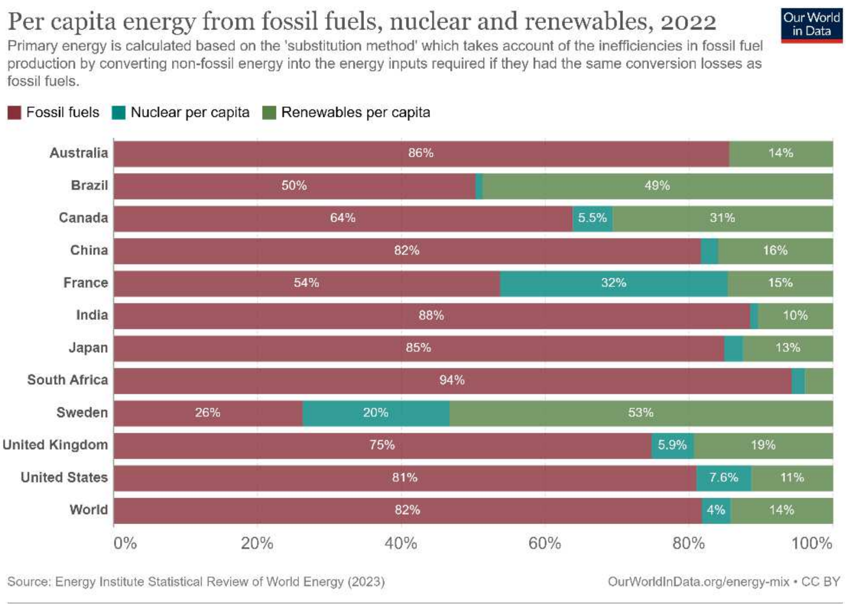
The study explores the potential of converting existing buildings into green buildings in South African cities for environmental sustainability and economic efficiency. It compares the costs, carbon footprint, and use of recycled materials between refurbishment and new construction. Refurbishment offers advantages in these aspects but presents technological challenges. The study uses Zero Emission Neighbourhood (ZEN) and Zero Energy Building (ZEB) frameworks to evaluate sustainability in refurbishment projects. It concludes that while refurbishment is a promising strategy, standardized evaluation methods, comprehensive databases of projects, and enhanced regulations are needed to support the green building industry in South Africa.

Keywords: Zero emissions, Refurbished Green Buildings, Spatial Planning, Construction, Net carbon

2 INTRODUCTION

2.1 Introduction

As energy demands increase and environmental concerns arise, innovative solutions for sustainable infrastructure are needed. Conventional energy sources, such as coal, pose risks due to high carbon emissions and contribute to global warming, affecting over 90% of South African energy production(Stefanakis, 2019:6981, Lützkendorf and Balouktsi, 2022:964-973).The energy-mix graph below indicates that over 90% of South African energy is produced from fossil fuels (coal) to date.



South Africa's economy has grown annually due to international crises, including global warming. The Paris Agreement, initiated by the United Nations in 2015, aims to combat climate change by reducing greenhouse gas emissions from human activities. Countries like South Africa have embraced the agreement and international businesses are supporting it. The South African government has developed a national coordination mechanism to strengthen development policies and improve sustainability.Architects are transforming primitive structures into smart living spaces to combat climate issues and carbon emissions. Modern refurbishment aims to increase sustainable value by integrating technological advancements and renewable energy sources. Green buildings, incorporating advanced technology, reduce dependence on electricity and increase safety. South Africa's green building industry has moderate development, but financing is limited. The Green Building Council South Africa (GBCSA) has certified over 7.7 million square meters of green buildings since 2007, demonstrating the importance of sustainability in the South African building sector.

The National Department of Public Works has established a green building policy to construct sustainable buildings, leading to substantial savings in finance, time, and space. Cape Town is recognized as the greenest city in South Africa, providing clean energy solutions across various sectors. Recognizing opportunities for refurbished green buildings is crucial for a safer future.

2.2 Role of Refurbishment in Meeting Climate Goals

Refurbishment is a key strategy for achieving climate goals by reducing greenhouse gas emissions and promoting sustainability in the built environment. It involves upgrading systems, improving insulation, and implementing energy-efficient technology to reduce reliance on fossil fuels. Refurbishment projects often incorporate renewable energy sources, such as solar panels, wind turbines, or geothermal systems, to reduce carbon emissions. Water conservation is also a key aspect, with water-efficient fixtures, rainwater harvesting systems, and greywater recycling mechanisms reducing water consumption. Using environmentally friendly materials and practices minimizes the embodied carbon footprint, while enhancing indoor environmental quality through improved ventilation systems and natural daylight. Refurbishment projects offer immense potential for transforming existing buildings into greener, more sustainable structures(van Noorloos and Kloosterboer, 2018:1223-1241).

2.3 Lack of Comprehensive Evaluations for Building Refurbishment

Building refurbishment faces challenges due to the lack of comprehensive evaluations. Robust assessment frameworks are needed to address the complexities of refurbishment projects. Comprehensive evaluations provide a holistic perspective on environmental performance, including energy efficiency, resource utilization, and sustainability. They also identify potential risks and challenges, quantify environmental and economic benefits, and support knowledge sharing and best practices. Life cycle assessment in energy refurbishment is crucial for a holistic understanding of a building's environmental performance. These evaluations help stakeholders make informed decisions and promote sustainable practices in building refurbishment.

Time Period	Evolution in Building Refurbishment	Evolution in Climate Change Understanding
Pre-Industrial (up to mid-18 Century)	Focus on maintaining structural safety and functionality using available materials and techniques.	Natural factors primarily drive climate fluctuations.
Industrial Revolution (mid 18thCentury to late 19th Century)	The advent of modern architecture and engineering led to more systematic approaches to building refurbishment.	Increased burning of fossil fuels due to the Industrial Revolution contributed to CO_2 emissions.
Early 20th Century (1900-1950)	Preservation of historic and cultural buildings became a key consideration. Energy efficiency started to be considered.	Spread of industrialisation led to increased emissions. Svante Arrhenius proposed that fossil fuel combustion could lead to global warming.
Mid 20th Century (1950-1970)	Sustainability and energy efficiency became more central to building refurbishment.	Massive increase in industrial activity and greenhouse gas emissions. Introduction of the Keeling Curve.
Late 20th Century (1970-2000)	Emergence of certifications like LEED to guide sustainability in building refurbishments.	Establishment of the IPCC, signing of the UNFCCC at the Earth Summit in Rio.
Early 21st Century (2000-2010)	Revolution of the evaluation process for building refurbishment using Building Information Modeling (BIM). Shift towards holistic evaluations began.	Kyoto Protocol came into effect in 2005.
Early 21st Century (2010-2023)	Evaluations started considering factors like potential for renewable energy use, carbon footprint, and resilience to climate change impacts.	Signing of the Paris Agreement in 2015.

Table 1: Evolution of comprehensive evaluation for building assessments and climate change

In conclusion, the current absence of comprehensive evaluations of building refurbishment poses a challenge to effectively addressing the complexities and maximising the potential benefits of such projects.Robust assessment frameworks are necessary for assessing environmental performance, identifying risks, quantifying benefits, and promoting knowledge sharing in building refurbishment.The development and implementation of comprehensive evaluations will contribute to advancing sustainable building practices and achieving climate change goals.

Outstanding Aspects	Description
Life Cycle Assessment	Comprehensive life cycle assessment, which considers the full environmental impact from extraction of raw materials to end-of-life disposal or recycling, is not universally applied in building refurbishment evaluations.
Embodied Carbon	Embodied carbon, i.e., carbon emissions associated with construction and material production processes, are often overlooked in evaluations. Consideration of embodied carbon could reduce the overall carbon footprint of buildings.
Resilience	Building refurbishment evaluations do not yet standardly include assessments of a building's resilience to predicted climate changes, such as rising temperatures and extreme weather events.
Socio-economic Factors	Evaluations tend to focus on technical and environmental factors, often neglecting socio-economic impacts. Future evaluations should consider effects on local communities, affordability, and improvements in users' quality of life.
Regulatory Compliance	There is a need for better integration of evaluation results into regulatory compliance checks. Compliance checks may not be stringent enough or fully consider comprehensive evaluation results.
Data Accuracy	Evaluation data, especially for older buildings, can be inaccurate or incomplete. Improved data collection methods are necessary for more accurate evaluations.
Technological Developments	Given the rapid pace of technological advancements, evaluation standards must be constantly updated to incorporate new possibilities, especially in areas like renewable energy, energy storage, and digital technology.

Table 2: Outstanding aspects of comprehensive evaluation for building assessments

2.4 Building Refurbishment Evaluation through the ZEN and ZEB Concepts

Building refurbishment is crucial for achieving sustainability goals and reducing environmental impact. Zero-emission neighbourhood (ZEN) and zero-energy building (ZEB) concepts offer a holistic approach to evaluating refurbishment projects. ZEN evaluates energy efficiency, renewable energy use, waste management, transportation systems, green infrastructure, and environmental performance. ZEB focuses on achieving net-zero energy consumption in refurbished buildings, quantifying energy savings, carbon emissions reduction, and economic viability. Standardized data collection methods and a comprehensive database of refurbishment projects are essential for effective evaluation. Integrating these concepts allows for a more informed understanding of environmental, economic, and social effects, enabling stakeholders to make evidence-based decisions and accelerate the transition towards more sustainable built environments(Dong, et al. , 2021:111313).

2.5 The dilapidation and tipping point in structural integrity

The rapid growth of the population and urbanization in South Africa has led to increased construction and maintenance of buildings, which may deteriorate over time due to aging and environmental factors. The Government Immovable Asset Management Act (GIAMA) was introduced in 2007 to guide the management of government-owned assets, including building maintenance. Regular condition assessments must be conducted every five years, but the implementation adds complexity and legal obligations.

Preserving the safety and durability of buildings or infrastructure relies on monitoring deterioration and reaching stability thresholds. Dilapidation refers to the decline or degradation of structures over time, compromising structural integrity. Regular assessment and monitoring are essential to identify signs of deterioration or imminent failure. Engineers and experts can evaluate a building's reliability and take measures to maintain its structural soundness. Managing building maintenance involves establishing thresholds for dilapidation detection and identifying tipping points. Integrated sensors embedded within structures and infrastructures play a crucial role in gathering data on building integrity and environmental conditions. Structural health monitoring (SHM) can help detect and evaluate performance degradation and damage in civil infrastructure as stated below.

Stage 1: Initial Wear (Minor Dilapidation)

Characteristics: Cosmetic damage, minor cracks, paint peeling, early signs of wear in non-structural components.

Recovery Strategy: Regular inspection and monitoring, cosmetic repairs and preventive maintenance, application of weatherproofing where necessary.

Stage 2: Moderate Degradation

Characteristics: Noticeable deterioration in structural components, leaks, rusting, functional impairment of non-essential systems.

Recovery Strategy: Detailed structural assessment to identify affected areas, targeted repairs and replacement of compromised components, Implementation of routine maintenance schedules as per SANS standards.

Stage 3: Advanced Decay (Major Dilapidation)

Characteristics: Serious structural issues, extensive corrosion, compromised safety, and functionality of essential systems.

Recovery Strategy: Comprehensive structural evaluation by certified engineers, major renovations and overhauls, following local regulations such as OHSA, collaboration with local authorities to ensure compliance and safety.

Stage 4: Critical State (Tipping Point)

Characteristics: Imminent failure or collapse, extensive damage that affects the building's overall integrity, immediate threat to safety.

Recovery Strategy: Immediate evacuation and securing of the site, engaging specialized emergency response teams.

Building maintenance in South Africa is crucial due to climate conditions, usage demands, and socio-economic issues. To ensure long-term durability and efficient resource utilization, it's essential to establish phases of deterioration and effective restoration methods. Recommendations include using technology like Building Information Modelling, collaboration among engineers, local authorities, and stakeholders, and implementing training initiatives. Sustainability should be integrated into maintenance practices, and emergency protocols should be in place. This framework addresses South Africa's circumstances while incorporating global best practices.

3 PROBLEM STATEMENT

South Africa's urbanization leads to increased demand for built environments, resulting in increased carbon emissions. Older structures, often inefficient, hinder green practices. Renovating these into green buildings could reduce emissions, but their impact on net carbon emissions in cities is not well understood. This research is crucial for understanding the transition and developing strategies for a sustainable urban future.

4 AIMS AND OBJECTIVES

This study aims to understand whether refurbished buildings help reduce net carbon emissions. This study examines the current state of green building refurbishment in South Africa, comparing it with global standards. It evaluates its contribution to reducing carbon emissions and aligns it with climate change mitigation strategies. It also identifies barriers and enablers to green refurbishment, assesses its social, economic, and environmental impacts, and explores public-private partnerships in fostering it. The study also proposes policy recommendations to enhance green building refurbishment practices and align with South Africa's sustainability goals.

5 RESEARCH METHODOLOGY

This study explores the intersection of refurbished green buildings and net carbon emissions in South African cities, thereby delineating the implications of eco-friendly renovations for sustainable urban development and carbon neutrality.The study employed a robust and integrative mixed-methods approach, coupled with quantitative data analysis and qualitative insights, to comprehensively understand the challenges, opportunities, and impacts of green building refurbishments(ISO 14040, 2006:).

5.1 Materials and Methods

5.1.1 Methodology of building refurbishment to achieve net-zero carbon

Achieving net zero carbon emissions from building refurbishment involves a comprehensive approach that considers the entire life cycle of a building. This includes conducting life-cycle analysis (LCA) to assess the carbon footprint of a building, including embodied carbon emissions from construction materials, transportation, and manufacturing processes. Energy efficiency measures, renewable energy generation, and electrification are implemented to minimize operational carbon emissions. During the refurbishment process, low-carbon and sustainable materials are selected to reduce embodied carbon. Monitoring and control are implemented to optimize energy performance, identifying areas for improvement. Education and occupant engagement are also crucial for promoting sustainable behavior and reducing energy consumption. Integrating ISO 14040 and NZED principles can lead to a more sustainable built environment, optimizing energy performance and achieving net-zero carbon emissions.

5.2 Data Collection

The study used SPSS to collect and analyze data from a 200-participant sample. The process involved selecting variables, designing instruments, sampling participants, collecting data, entering and cleaning the data, conducting descriptive analysis, formulating hypotheses, testing hypotheses with one-way ANOVA, interpreting results, and reporting findings. The online survey included participants from various age groups, financial backgrounds, and working experience levels. The analysis included a one-way ANOVA test to test the hypothesis and ensure accuracy in results(Evon Abu-Taieh, Abdelkrim El Mouatasim, Issam H. Al Hadid, 2020:).

6 RESULTS

The results section of a research report or study provides a detailed presentation and interpretation of the findings obtained from the data analysis. This is a critical component of the research report, allowing readers to understand the study's outcomes and evaluate the validity of the research objectives and hypotheses.

6.1 Profile of respondents

The total number of participants selected for this survey was 200, belonging to different South African construction industry departments. Participants selected for this survey ranged in age from 20 to 60 years, with work experience ranging from 1 year to more than ten years.

	Categories	Frequency	Percentage
Sex (Gender)	Male	45	45
	Female	55	55
Age	20 – 30 yrs	54	27.0
	30 – 40 yrs	45	22.5
	40 – 50 yrs	55	27.5
	50 yrs& above	46	23.0
Income	0 - 1,00,000 ZAR	46	23.0
	1,00,000 - 2,00,000 ZAR	48	24.0
	2,00,000 - 5,00,000 ZAR	54	27.0
	Above 5 000 000 ZAR	52	26.0
Work Experience	None	51	25.5
	1 – 5 yrs	44	22.0
	5 – 10 yrs	57	28.5
	Above 10 yrs	48	24.0
Role in the construction industry	Newly joined	73	36.5
	Junior level	73	36.5
	Senior level	54	27.0

Table 3: Profile of the Respondents

The above table shows that the total number of males in the survey was 45%, whereas the total percentage of female respondents was 55%. The table also shows that the study included participants from multiple age groups. Participants aged 20-30 and 40-50 share the same percentage (27%). In contrast, the percentage of people aged > 50 years in the study was 23%. Evaluating the results obtained from the descriptive analysis, 27% of the participants had an income range of 2,00,000 -5,00,000 ZAR.

In comparison, only 26% of the participants had an income range above five million. Similarly,, around 24% of the participants had an income range of 0-1,00,000 ZAR. It also mentioned that more than 28% of participants have work experience of 5-10 years. Similarly,, the graph confirms that more than 25% of the participants had no work experience. It also mentions that the survey comprises 24% of respondents with more than ten years of working experience. The above table confirms that 36.5% of respondents were newly joined, level, and junior-level employees. Conversely, 27% of participants were senior employees.

6.2 Overall assessment of the refurbished buildings helps reduce net carbon emissions

The study compares refurbished buildings with newly constructed ones to assess the suitability of recycled content. Results show that recycled content is more suitable for refurbished buildings, and prefabricated materials can reduce carbon footprints. Refurbished buildings are less expensive than new construction, and refurbishment is a more effective strategy based on life cycle assessments. However, factors like structural feasibility should be considered before implementing refurbishment strategies. The study concludes that refurbishment outperforms new construction in terms of life cycle assessments, but requires careful consideration of all relevant factors(Corrado and Ballarini, 2016:91-106, Aghasizadeh, et al. , 2022:106897, Palacios-Munoz, et al. , 2019:106203, Sundayi, et al. , 2015:77-82, Loli and Bertolin, 2018:22).

6.3 Assessing the Impact of Refurbishment on the Environment of Energy

Refurbished office buildings, often aligned with the zero-energy building (ZEB) model, can significantly reduce carbon emissions. By modifying structures with recycled and modular components, these buildings can optimize energy efficiency and meet residual energy needs through renewable technologies. The ZEB model exemplifies building refurbishment. A 20% increase in green buildings in South Africa could lead to a 16% reduction in carbon emissions. Prefabricated buildings could also contribute to carbon emission reductions, but their impact on environmental impact is not well understood.

6.4 Alternatives for managing resource policies and building-specific characteristics.

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6.5 Assessing the Impact of Refurbishment on the Environment of Energy

Understanding the defining attributes of such structures is crucial for understanding the environmental influence of refurbished office buildings. (Rahman, et al. , 2017:112-126) defined a refurbished office building as a structure modified according to specific needs, utilising recycled and modular components. This refurbishment process often aligns with the principles of the zero-energy building (ZEB) model.

A residential or commercial ZEB optimises energy efficiency so that any residual energy need can be met via renewable technologies. This model can function within both off-grid and on-grid frameworks. However, the precise definition of ZEB can vary across enterprises, organisations, and nations. Fundamentally, the ZEB model exemplifies the essence of building refurbishments.

During the implementation of refurbishment processes, it is vital to consider all factors influencing the modification of the structure. A noteworthy observation made by(Lützkendorf and Balouktsi, 2022:964-973)was that a 20% increase in the number of green buildings in South Africa could lead to a 16% reduction in carbon emissions. These data suggest that refurbishment, in line with green building principles, can have a positive environmental impact.

An ancillary hypothesis was examined, which proposed that prefabricated buildings could contribute to carbon emission reductions. However, the one-way ANOVA quantitative analysis technique yielded a p-value of 0.67, exceeding the statistical significance threshold. This result parallels a study by(Ma, et al. , 2021:39-44) in China, which explored factors impacting environmental carbon emissions at prefabricated building construction sites.

6.6 Alternatives for managing resource policies and building-specific characteristics

South African cities often have small buildings with concrete walls and clay brick, leading to increased carbon emissions from new construction projects. Renovating buildings with low-carbon materials can mitigate environmental degradation. A study using a one-way ANOVA test found that recycled content, due to its lower carbon content, is more suitable for refurbished buildings and has general applicability.

Variables	Sum of square	df	Mean square	Sig.
Life cycle assessment of buildings for refurbishment is difficult as there are no regular protocols	2.49	4	0.623	0.019
The use of prefabricated building elements could help in reducing the carbon emission in refurbishment	0.43	2	0.218	0.69
Low-carbon materials are better for refurbishment	2.62	2	1.310	0.13
The use of prefabricated building elements could help in reducing the carbon emission in refurbishment	34.15	4	8.53	0.00
Cost is an essential factor to be considered for refurbishment	2.88	2	1.43	0.39

Table 4: Summary of measures

7 DISCUSSION

The concept of refurbished buildings supports energy and environmental conservation, with South African citizens and the government supporting refurbishment over construction. Recycled content is the most suitable refurbished building material, as approved by the Green Building Council of South Africa. Prefabrication during refurbishment is easy, and the presence of a modular element during prefabrication provides a more satisfactory result.

The primary results show that refurbishment costs are lower and environmentally friendly compared to the construction of new buildings. The current scenario of the South African construction industry supports the primary result, with the refurbishment rate of green buildings being 3500 Rand per m². However, proper planning and design are required to increase success rates. Refurbishment of a structure is diverse and requires more attention and monitoring.

Using low-carbon materials in refurbished buildings is better because it reduces the cost of construction and supports environmental construction. The life cycle assessment of a building with low-carbon materials is better than that of conventional construction materials. The possible adverse ecological effects of refurbished buildings following each of the three possible government initiatives can be significantly less compared to refurbished buildings operating in the baseline scenario.

Generalised Additive Models (GAM) and Life-Cycle Assessment (LCA) are two distinct approaches used in separate situations. LCA is used to assess the environmental effects of a good or service over the course of its life cycle, while GAM is used to model interactions between variables. Both have various non-exclusive financial benefits, such as flexibility, interpretability, management of missing data, and predictive power.

In the Business-As-Usual (BAU) scenario, external building material, thermal impedance of the ceiling, window-to-wall proportion, number of heating systems placed, annual power consumption, and affect capacity all significantly impact the effect of huge refurbished building structures. Concrete structures require the most energy to produce, accompanied by bricks and concrete structures.

In conclusion, refurbishing green buildings is an effective way to achieve a safer environment in South African cities, with the benefits of refurbishment being lower and more environmentally friendly compared to the construction of new buildings..

8 CONCLUSION

Refurbished green buildings in South African cities like Cape Town and Johannesburg are beneficial economically and environmentally. Recycling content and modular prefabrication reduce carbon content in the construction industry. Enforcing regulations, implementing low-carbon innovation, and limiting energy usage are methods for reducing CO2 emissions. The construction industry must be given due consideration to reduce CO2 emissions and develop a holistic structure to combat climate change. A thorough evaluation is needed to achieve sustainable development goals.

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