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RESEARCH ARTICLE

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Life cycle assessment of office fitouts: a case study of Australia

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ABSTRACT

Office fitouts are a critical yet often overlooked component in Life Cycle Assessment (LCA) studies, involving frequent replacement of interior elements that account for considerable material consumption and waste. This research fills this gap by conducting LCA studies of four Green Star Interiors-certified office fitouts in Australia to assess their whole life carbon (WLC) impacts. Using cross-case analysis, carbon hotspots, decarbonization strategies, challenges and considerations are identified. Findings reveal that retaining, reducing and reusing interventions offer the greatest potential for embodied carbon reduction, followed by material optimization. Operational carbon emissions can be diminished significantly through improvements of building services, including efficient lighting, HVAC, AV and IT system. Adopting decarbonization strategies can reduce carbon emissions by up to 32% compared to a business-as-usual case. Challenges and considerations relate to modelling assumptions of retained and reused materials, carbon reduction and indoor environmental performance trade-offs, data availability and accuracy, and iterative modelling process. The results enhance understanding of WLC emissions of office fitouts and demonstrate how comprehensive LCA studies effectively inform design decisions. The study provides practical insights for improving fitout practices while critically examining the limitations of LCA methodologies, thereby supporting the shift towards circular and sustainable approaches in the built environment.

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Life Cycle Assessment (LCA); office fitouts; whole life carbon assessment (WLCA); sustainable buildings; Environmental Product Declarations (EPDs); Green Star

Introduction

Urbanization continues to accelerate, and forecasts indicate that cities will host more than double the share of the world's population in 2025 (United Nations, 2025). Meanwhile, urban areas already generate a disproportionately high level of environmental impacts, consuming roughly 75% of global energy and 70% of global greenhouse gas (GHG) emissions (IEA, 2024). The built environment is among the most resource-intensive contributors to this footprint. In the Australian context, embodied carbon emissions from building activity contributed 10% of national carbon emissions in 2023 (Infrastructure Australia, 2024). The waste implications are similarly stark, with construction and demolition (C&D) activities generating roughly 29 million tonnes of waste annually (DCCEEW, 2025). These pressures underscore the need for strategies that reduce life cycle carbon emissions of buildings. In this study, the terms life cycle carbon emissions of buildings and whole life carbon (WLC) emissions of buildings are used, both referring to embodied and operational carbon emissions occurring across the entire life cycle of buildings.

Increasingly, mandatory reporting of embodied carbon emissions for buildings is being required through legislation. For example, in Europe, the revised Energy Performance of Buildings Directive (EPBD 2024/1275) expands the focus from operational carbon emissions to WLC perspective, establishing mandatory reporting and performance requirements for new and existing buildings. In the Australian context, a voluntary pathway for commercial buildings to calculate and report on embodied carbon emissions was introduced under the 2025 National Construction Code (NCC), with the Australian Building Codes Board (ABCB) investigating a future minimum standard for NCC 2028 (Husic, 2024). Thus, Australia is transitioning from voluntary disclosure to mandatory standards, broadly following the EU, but on a slower timeline.

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Within this context, office fitout represents a critical opportunity to reduce life cycle carbon impacts. An office fitout is a type of building project that relates to interior modifications, including the installation of interior elements, such as floor, wall and window coverings, partitions, doors, furniture, equipment, as well as mechanical, electrical and water services, to configure spaces for occupants (RICS, 2023). It can occur at any stage of the building life cycle, in both new and refurbished projects. The scope of a fitout also varies depending on the project, ranging from small sections of a single floor to entire buildings, with boundaries typically defined by the tenant demised area as specified in the lease agreement (Butler, 2024; RICS, 2023). Due to leasing cycles and changing tenant needs, interior spaces are frequently reconfigured or replaced in a recurring pattern of 'fitout, strip out, and do it again', typically every three to ten years (Casas-Arredondo et al., 2018; Forsythe & Wilkinson, 2015). This churn often requires the removal of existing materials and building services, followed by reinstatement to a base condition and subsequent customization by incoming tenants (Forsythe & Wilkinson, 2015).

Across a building's service life, repeated fitout cycles can accumulate substantial material flows, waste generation, and carbon emissions (Casas-Arredondo et al., 2018). In fact, approximately 25–32% of an office building's life cycle carbon emissions are attributable to fitout activities, with an average office fitout generating around 368.6 tonnes of waste (Butler, 2024; GBCA, 2026). It is notable that fitouts are explicitly excluded from current voluntary tools for commercial buildings in Australia (NABERS, 2026). However, a further legislative driver exists. Australia's mandatory climate disclosure regime under AASB S2 Climate-related Disclosures (Australian Accounting Standard Board, 2024) requires reporting of Scope 1, 2 and 3 emissions using the GHG Protocol methodology (WBCSD, 2023). In the context of this mandatory and audited accounting, both landlords and tenants have growing legal accountability for embodied carbon emissions in fitouts, from different angles. Therefore, attention should be directed towards interventions in office fitouts to reduce carbon impacts.

To identify meaningful opportunities for emissions reduction in an office fitout, it is essential to quantify its life cycle carbon emissions. Life Cycle Assessment (LCA) offers a robust methodological framework for this purpose, enabling the evaluation of upstream and downstream impacts associated with material extraction, manufacturing, transportation, installation, maintenance and disposal (ISO 14040/14044, 2006; CEN, 2011). Growing interest in circular economy principles (e.g. narrowing resource loops, slowing resource loops, closing resource loops, regenerative resources) further extends this perspective by shifting from traditional cradle-to-grave towards cradle-to-cradle assessments, emphasising strategies such as material retention, reuse, refurbishment and product take-back schemes (Andersen et al., 2022; Nußholz et al., 2023). However, existing LCA studies show diverse methodological choices, partial adherence to standards and persistent concerns about data quality and transparency (Olanrewaju et al., 2024; Somerset et al., 2025). Hence, continued methodological refinement, better data infrastructures and clearer guidance are central to making LCA more robust.

It is crucial to distinguish between product LCA and building LCA. Product LCA focuses on the environmental impacts of individual building materials or products (CEN, 2019), often using databases like generic Ecoinvent or product-specific Environmental Product Declarations (EPDs), which can show significant variability in impact results (Lasvaux et al., 2015; Xu et al., 2025). An Environmental Product Declaration (EPD) is an independently verified document that provides transparent and comparable data on life cycle environmental impacts of a product (EPD Australasia, n.d.). Building LCA, by contrast, assesses the entire building system (CEN, 2011), incorporating multiple products and their interactions, and often captures operational energy, operational water, design scenarios, building lifespan assumptions, making results more case-specific and complex (Davis et al., 2025; Saade et al., 2020). Understanding the distinction is crucial because product LCA results do not always translate directly to building performance due to system complexity, functional units and life cycle stages considered (Saade et al., 2020). Accordingly, this study focuses on the life cycle impacts of office fit-outs at the system level, while drawing on the use of EPDs to inform and interpret impacts associated with specific products where relevant.

Green Building Rating Systems (GBRSs) have contributed to the growing focus on sustainable fitouts. Tools such as Green Star (Australia), BREEAM (UK), LEED (US), etc., have supported broader uptake of sustainable building practices (Mohammed et al., 2025). Within these GBRSs, LCA has been formally recognized as a valid method for evaluating environmental impacts. In Australia, for example, Green Star Interiors rating system is widely used for environmental assessments of office fitouts. Of which, up to 19 points (credit 19) can be claimed where life cycle environmental impact reduction is demonstrated using LCA (GBCA, 2019). However, while GBRSs provide guidance for applying

LCA, they expose variability in LCA scope, metrics and reporting. These differences can result in contradictory outcomes (Ng et al., 2026; Sartori et al., 2021). Thus, using GBRSs as structured guidance, combined with rigorous application and careful interpretation of LCA, offers strong potential to inform sustainable design and procurement decisions.

Various LCA studies of buildings including new and refurbishment projects exist in the literature, but they mainly focus on base building systems (Fahlstedt et al., 2024; Fnais et al., 2022). This emphasis reflects the traditional focus of building LCA on high-impact components with substantial embodied carbon emissions (e.g. structure and envelope), as well as on operational energy, which has historically been the dominant contributor to life cycle impacts. In contrast, fewer LCA studies are dedicated to fitouts and interior systems. Studies across different contexts consistently show that interior elements such as furniture, appliances, finishes and MEP systems contribute approximately 25–30% of total building life cycle impacts (Hoxha & Jusselme, 2017; Rodriguez et al., 2020). This is because the dynamic nature of fitouts with frequent fitout cycles driven by lease durations and tenant turnover (e.g. typically between 3 and 10 years) (Forsythe, 2017; Forsythe & Wilkinson, 2015). Several decarbonization strategies exist, including extending service life of interior components, retaining materials between fitout cycles, and prioritising the reuse of materials and products (Butler, 2024; MBIE, 2023). Waste minimization practices through design (e.g. design for disassembly, etc.), material and procurement (e.g. material reuse, etc.) and on-site activities (waste management plan, etc.) are also recognized as important levers for lowering embodied impacts (Butler, 2024; Heffernan & Kempton, 2025). In parallel with material-focused strategies, many fitout projects integrate operational efficiency upgrades. These interventions often involve optimizing controls, upgrading older equipment and ensuring systems operate efficiently to reduce energy and water use (AECOM, 2024). Such strategies can significantly reduce embodied and operational carbon emissions, offering pathways to decarbonization for fitouts. A summary of the literature review is demonstrated in Table 1.

However, despite these insights, existing studies remain fragmented and limited in several key aspects. Most studies rely on single case analyses or focus primarily on carbon quantification, resulting in a lack of comprehensive and comparative LCA studies across multiple projects. Although various decarbonization strategies have been proposed, there is limited empirical evidence demonstrating their application and effectiveness across different real-world cases. In addition, while evaluating interior interventions requires an understanding of embodied–operational carbon trade-offs, current studies rarely address or systematically assess these interactions. Methodological inconsistencies further compound these limitations, as LCA studies of interior systems vary widely in scope, system boundaries, functional units, reference study periods and data quality, making results difficult to compare or

Table 1. Summary of existing studies on LCA of fitouts.

Studies	Countries	Types of buildings	Focus areas	Main findings
Butler (2024)	New Zealand	Office building	LCA of an office fitout and its contribution to whole-building carbon emissions	The fitout contributes approximately 25% of a whole building's carbon emissions on average
Wu et al. (2023)	China	Office building	WLC assessment for building decoration	The materials embodied impact stage (36.3%) and the operation stage (49.8%) were the main carbon emissions contributors
MBIE (2023)	New Zealand	Office building	Embodied carbon assessment of an office internal fitout	The whole life embodied carbon emissions were36 kgCO_2e/m^2, with aluminium, carpet and timber contributing the most to material-related impacts
Rodriguez et al. (2020)	The US	Office building	Embodied carbon assessment for mechanical, electrical, plumbing (MEP) and tenant improvements (TI) (i.e. finishes, furniture, partitions) of commercial buildings	With recurring instalments during a life span of 60 years, the impacts of MEP & IT became comparable to known impacts of core and shell systems
Casas-Arredondo et al. (2018)	The UK	University building	Decision and material flows across the supply chain of fitout practices	The top-five waste streams were hardcore, mixed waste, wood, plastics and metals. Two different 'circular' paths regarding fitout resources were closed-loop recycling and the path of reuse
Hoxha & Jusselme (2017)	Switzerland	Mixed-use building	Environmental impacts of furniture and appliances in net-zero energy buildings	Furniture was responsible for around 10% and appliances for 25% of the building's overall impacts
Forsythe (2017)	Australia	Office building	Determining fitout churn rate to support building LCA	The results indicated a fitout churn rate of 8.2 years
Forsythe & Wilkinson (2015)	Australia	Office building	Quantifying the indicative number of Australian office fitouts to support building LCA	Between 46% and 70% of the floors in a high-rise office building undergo refurbishment over a five-year period

generalize. Furthermore, limited attention has been given to documenting the challenges encountered in conducting LCA for fitout projects in practice. Addressing issues related to granularity, improving the communication of impacts, and selecting appropriate assessment scales are therefore critical to enhancing the credibility and interpretability of fitout LCA studies.

In response, this study aims to address the identified gaps by investigating the potential of office fitouts to reduce life cycle carbon emissions through four real-life case studies of Green Star Interiors certified projects in Australia. By adopting a comparative approach, this research enables cross-case evaluation of outcomes and practices in terms of carbon hotspot identification, the effectiveness of decarbonization strategies, as well as methodological challenges and considerations. In doing so, this research contributes to advancing more robust and comparable approaches to LCA of office fitouts.

Research method

Case study approach

This study examines the potential of office fitouts to reduce WLC emissions. A multi-case study approach was selected because it enables direct LCA applications and provides insights into how fitouts are delivered in practice. Using this approach also offers several methodological advantages such as supporting context-rich analysis, enabling LCA methodologies to be applied in real project settings, assisting in examining practical carbon reduction measures, and allowing for detailed interpretation of carbon impacts (Nwodo & Anumba, 2021).

Multi-case study research design involves a small number of cases, often between 4 and 10 cases, to enable meaningful cross-case comparison while maintaining analytical depth (Eisenhardt, 1989; Stake, 2013; Yin, 2018). Building LCA have commonly employed around four to five case studies (Eberhardt et al., 2021; Hawkins & Mumovic, 2017). In this study, four Australian office fitouts were chosen to represent contemporary sustainable practice. Projects were included based on the following criteria: (1) pursuit of certification under the Green Star Interiors rating system, (2) intentional incorporation of sustainable design strategies and (3) adequate project data and access permissions. Table 2 outlines the four selected case studies and their characteristics.

Life cycle assessment

LCA goal and scope

LCA was conducted to quantify the life cycle carbon emissions of four fitout case studies in accordance with EN 15978:2011 – Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method. The scope of the assessment included product stage (A1–A3), construction stage (A4–A5), use stage (B1–B7) (excluding refurbishment (B5)), end-of-life stage (C1–C4), and benefits and loads beyond the system boundary (D) (reported separately) (see Figure 1).

Module B5 – refurbishment was excluded due to the study focusing on LCA of one fitout cycle only. Potential benefits captured within Module D are uncertain, depending on whether materials can actually be reused, recovered or recycled during that time. Thus, this module was reported separately. Building elements included in the assessment were internal finishes, services equipment, fittings, furnishings and equipment. Table 3 shows the scope of building elements included in the assessments.

Comparative LCA studies were performed to evaluate carbon reductions by comparing a Proposed Design with a Reference Design, and to identify sustainable

Table 2. Overview of four case studies.

Case study	Location	Net lettable area (NLA) (m^2)	Green Star Interior target	Fitout type	Fitout scope	Base building type	Fitout year of construction	Project stage
Case 1	Sydney	1735	6 Star	Office refurbishment fitout	One full-floor level space	39-storey reinforced concrete, glazed curtain wall, completed in 2016	2023	As-built
Case 2	Sydney	3311	5 Star	Office refurbishment fitout	Three levels of full-floor space	3-storey repurposed warehouse, brick, concrete & steel, completed in 2020	2024	As-built
Case 3	Melbourne	2437	5 Star	Office refurbishment fitout	One full-floor level space plus additional partial floor space	25-storey reinforced concrete, glazed curtain wall, completed in 2008	2024	As-built
Case 4	Sydney	9383	5 Star	Office refurbishment fitout	Four levels of full-floor space	11-storey steel framed structural system wrapped in glass, completed in 2009	2024	As-built

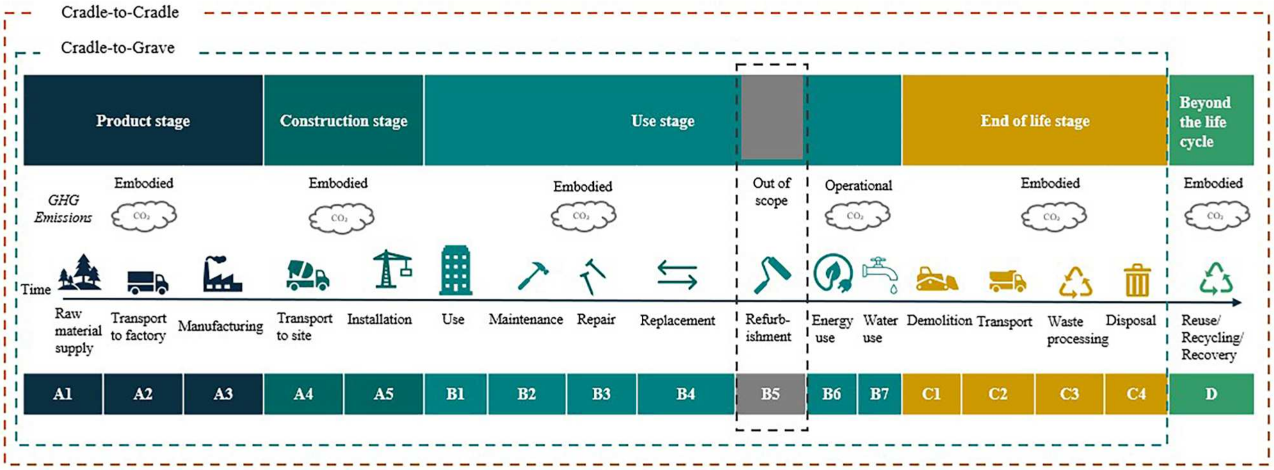

Figure 1. LCA system boundary of the study.

design strategies. This is a requirement for building LCA adhered to EN 15978 to evaluate the environmental performance of different design scenarios, encompassing various design strategies, materials, technologies and construction methods (CEN, 2011). Following Green Star Interiors v1.3 guidelines, the Reference design was defined and modelled to reflect standard industry practice and serve as a baseline for comparison, representing a business-as-usual fitout that could have been built without any sustainable strategies. The Proposed design represented the actual project design, which is an improvement of the Reference design, incorporating sustainable strategies. Table 4 demonstrates a summary of improvement strategies across four cases. Details of design scenarios can be found in the supplementary materials file. Both Reference and Proposed designs were identical in size, scale, volume and function (e.g. same floor plan and area). The functional unit was set to $kgCO_2e/m^2$ for a reference study period of 10 years for both the proposed fitout and reference case, following the Green Star Interiors v1.3 guidelines (GBCA, 2019).

Table 3. Scope of building elements.

Category	Subcategory
Internal finishes	Ceiling finishes
	Floor finishes
	Wall finishes
Furniture	Office furniture
	Casework (i.e. joinery, kitchen cabinet)
	Miscellaneous (i.e. cleaner, demolition end-of-life (EoL), etc.)
Fixtures and fittings	Ceiling suspension systems
	Interior doors & windows
	Partition walls (i.e. framing, insulation, etc.)
Services equipment	HVAC equipment
	Appliances (i.e. dishwasher, refrigeration, etc.)
	Hydraulic services (i.e. hot water system (HWS), Zip tap, etc.)
	Electrical services
	Lighting fixtures
	Fire services
	AV and IT equipment
	Communication systems

The assessment was streamlined using eTool, a robust web-based platform designed for LCA of building and infrastructure projects (Cerclos, n.d.-a). eTool complies with key LCA standards, including EN 15978, EN 15804, ISO 14040, ISO 14044 and ISO 21930 (Cerclos, n.d.-b). It offers flexibility in data input and modelling, allowing users to adjust assumptions related to transport, end-of-life treatment, material life span, assembly and more (Cerclos, n.d.-a). eTool operates using a hierarchical template system with varying levels of detail (e.g. components, sub-components, elements). Inputs and assumptions can be set based on project-specific data. The calculation method, consistent with EN 15978, is embedded within the software. Within this system, bills of materials and quantities, operational energy and water inputs for the case studies were imported and mapped to corresponding datasets. Consequently, results were generated based on project-specific inputs and assumptions.

Inventory and assumptions

Material and component inventories were derived from actual project documentation and specifications. Where data were lacking, supplier information, estimation procedures and assumptions were applied (e.g. technical datasheets and EPDs). Life cycle inventory (LCI) data were sourced from EPDs and industry averages for Australia, primarily based on Australasian LCI data supplemented by a regionalized Ecoinvent shadow database. Product-specific service lives, transport information (e.g. transport modes and distances), people and equipment, and end-of-life scenarios (e.g. landfill and recycling) were based on EPDs and industry average

Table 4. A summary of design improvement strategies across four cases.

Strategies	Case 1	Case 2	Case 3	Case 4
Retain	Retain 57% of existing carpet; Retain 100% of existing ceiling	N/A	Retain existing ceiling (4.5% of total ceiling)	Retain 9% of existing flooring; Retain 57% of existing ceiling
Reduce	N/A	Exposed ceiling (85% of total ceiling); Reduce workstations and monitors quantity	N/A	Reduce the quantity of workstations and monitors
Reuse	N/A	Reuse existing furniture, workstations and LED fittings	Reuse selected existing furniture, IT & AV equipment	Reuse existing furniture, lighting, insulation, IT & AV equipment
Improve	Low-carbon paint; eco friendly vinyl flooring; high-quality office chairs	Low-carbon ceiling finishes, carpet and paint; eco-friendly vinyl flooring; timber lockers	Low-carbon partitions and carpet; timber flooring; eco-friendly vinyl flooring	Low-carbon acoustic panels, wall and ceiling finishes and partitions; eco-friendly vinyl flooring
	Efficient HVAC equipment (with higher EER and COP), LED lighting, AV, IT and appliances			

data available in eTool software for the Australian region. A detailed material inventory and underlying assumptions are provided in the supplementary materials file.

The operational input associated with the operational energy use (model B6) and water use (module B7) was calculated in line with Green Star requirements. The energy assessment was based on an energy calculation that reflects performance improvements over a reference fitout. The reference scenario was assumed compliance with the Australian NCC, Section J, following the deemed-to-satisfy provisions for lighting and HVAC systems. For appliances and equipment, reference models were derived following the Green Star Energy Consumption and Greenhouse Emission Calculation Guide. These models represent products that are either 1.5 stars below the highest-rated option available in the market or 20% less efficient than comparable equipment no older than two years. For audiovisual (AV), computing, and IT equipment, where star ratings are not applicable, the reference scenario assumes devices that are 20% less efficient than comparable models no older than two years. The actual design scenario represented the actual energy savings after implementing improvement strategies. Similarly, the water assessment was conducted following the Green Star potable water calculator guide. Operational input was then input into eTool software for calculating emissions based on regional energy and water grid emissions factors. Detailed equipment specifications are provided in the supplementary materials file.

Table 5. Overview of LCA methodology.

System boundary	A1-A3, A4, A5, B1-B7 (B5 excluded), C1-C4, D (reported separately)
Scope	Interior fitout
Scenarios	Reference design vs Proposed design
Functional unit	$kgCO_2e/m^2$
LCI data	Australasian LCI data and regionalized Ecoinvent, EPDs
LCIA	CML v4.5
Environmental indicators	GWP
LCA software	eTool
Standards	EN 15978, ISO 14040, ISO 14044, Green Star Interiors rating scheme

Following EN 15804 and EN 15978 cut-off approach (CEN, 2011; CEN, 2013; CEN, 2019), retained and reused elements were treated as entering the new assessment boundary free of burden and the impact of using new components was avoided (Anderson, 2025). However, impacts attributed to transport activities (A4) and/or construction installation and processes (A5) should be considered. In this study, retention was modelled as avoiding upfront carbon emissions (modules A1–A5). In contrast, the reuse of components was assigned potential additional impacts in module A4 (e.g. transportation and/or temporary storage), depending on whether the material was reused within the same project or transferred to a different site, and module A5 associated with reinstallation (e.g. people and equipment). Because retaining or reusing items eliminates a proportion of upfront carbon emissions, these strategies offer significant mitigation potential. Nonetheless, impacts associated with maintenance, repair and replacement (module B), as well as end-of-life processes (module C), must still be incorporated to avoid overstating carbon savings. This is especially important for short-lived elements, where the replacement may occur during the reference study period of the fitout.

Impact assessment and interpretation

Life cycle impact assessment (LCIA) allocates LCI outcomes to impact categories and category indicators. The type of impact categories and the impact indicators for each category depend on the LCIA calculation method, also known as characterization model (European Commission, 2010). This study applied the Centrum voor Milieukunde Leiden (CML) method developed by Leiden University's Institute of Environmental Sciences (CML, 2016), focusing on Global Warming Potential (GWP), given the research objective of assessing life cycle carbon emissions. Quantitative and qualitative outputs are presented and interpreted in the findings section. Table 5 summarizes the overview of LCA methodology applied in this study.

The four case studies represent real-world fitout projects, which typically progress under compressed design and delivery timeframes and require LCA modelling to remain aligned with evolving architectural and building services documentation, as well as the requirement of the Green Star rating system. Within this context, formal sensitivity and uncertainty analyses were not undertaken, which was acknowledged as a methodological limitation. Nevertheless, a consistent LCA framework was applied across all case studies, providing a robust basis for comparison, assessment and interpretation. All case studies underwent third-party verification to ensure quality assurance and compliance with EN 15978, ISO 14040, ISO 14044 and the Green Star Interiors rating system.

Cross-case analysis

A cross-case synthesis was employed as an analytical technique following the completion of the LCA studies. While these cases exhibited inherent heterogeneity in terms of size, location and characteristics, they were fundamentally comparable on the basis that all were office fitouts pursuing Green Star Interiors certification and analysed using a consistent LCA framework. Utilizing a maximum variation perspective, the objective was to identify overarching patterns and differences across the selected fitout projects. This approach ensures that any emergent theoretical propositions hold robustly across diverse contexts, thereby enhancing the transferability of the findings (Eisenhardt, 1989; Patton, 2014).

For each case, LCA results were examined alongside major themes related to overall quantified carbon emissions, carbon hotspots, decarbonization strategies implemented in practice, as well as the challenges and considerations encountered during the LCA modelling process. These findings were first organized and tabulated using Microsoft Excel to facilitate systematic comparison and visualization of key indicators. The synthesis process involved identifying similarities, differences and associations across cases, which were then documented and structured in Microsoft Word for narrative analysis and reporting. Subsequently, patterns were derived using replication logic, which involves comparing cases to confirm or contrast theoretical propositions through literal and theoretical replication (Yin, 2018). This approach enhances the robustness of the analysis by systematically exploring convergent and divergent evidence across multiple cases, thereby strengthening internal and external validity (Cruzes et al., 2015).

Findings

Across the four case studies, the Proposed designs achieved substantial WLC reductions (excluding module D) relative to the Reference designs, ranging from 29% in Case 4 to 32% in Case 2 and Case 3, as shown in Figure 2. In the Reference designs, operational carbon emissions (B6–B7) dominated the WLC profile, contributing about 80% of total carbon emissions, with the remaining 20% attributable to embodied carbon emissions (A1–A5, B1–B4, C1–C4), as shown in Figure 3. Table 6 provides a detailed breakdown of the saving percentage associated with each model per case. Accordingly, the Proposed designs prioritized abatement in operational performance while concurrently reducing embodied burdens. Across all four case studies, this integrated focus delivered substantial carbon reductions relative to a standard-practice reference fitout. These outcomes were enabled by design decisions that (i) conserved existing assets and finishes, (ii) minimized demand for new materials, (iii) extended service lives through durability and (iv) enhanced material performance alongside energy and water efficiency. Collectively, these decisions coalesced into four guiding principles: retain, reduce, reuse and improve, which structured the interventions across the identified carbon hotspots.

From a WLC perspective, Cases 3 and 2 delivered the greatest overall savings, primarily through the combined effect of operational energy-efficiency measures and embodied-carbon strategies. When considering the embodied carbon perspective only, Case 2 performed best due to early-stage material selection and reduction interventions. Within the embodied carbon scope, the most effective levers were retaining existing finishes and reducing new material demand, complemented by reusing furniture and equipment to extend lifecycles and improving materials via low-carbon specifications (EPDs) and substitution of high-impact options. The applicability and magnitude of these strategies varied by project context and functional requirements, so not all principles were implemented uniformly across cases. The results presented here exclude Module D. However, as shown in Figure 3, even when Module D was included, the differences between options were minimal and did not meaningfully affect the overall results.

Embodied carbon hotspots

Across the four case study reference designs, the embodied carbon profile was consistently concentrated in a limited number of product categories. On average, office furniture accounts for about 28.7% of total embodied carbon emissions, followed by AV and IT equipment (16.3%), floor finishes (10.6%), partition walls (8.5%), ceiling finishes (6.3%) and HVAC equipment

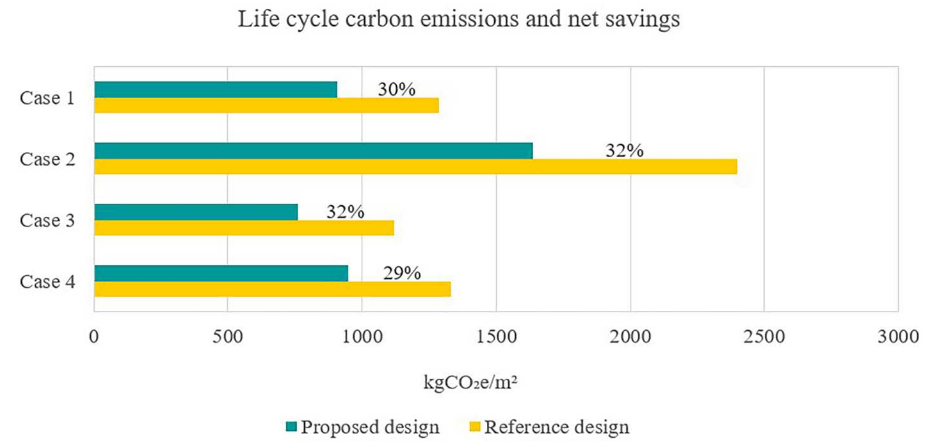

Figure 2. Life cycle carbon emissions and net savings. *Note:* Emissions reported on Modules A-C only, excluding Module D.

(7.2%). Table 7 presents the embodied carbon percentage distribution across categories.

The relative weight of these hotspots varied by project while remaining within this same set of categories (as shown in Figure 4). Case 4 was dominated by office furniture and AV and IT equipment, which together account for 61.6% of embodied carbon emissions (33.9% and 27.6%, respectively), with floor finishes the next substantive component (11%). Case 3 exhibited a similar pattern but with a stronger contribution from partition walls (14.1%). Case 2 presented a distinct profile in which HVAC equipment emerges as a leading hotspot (16.9%), alongside office furniture (22.5%), AV andIT equipment (18.1%) and floor finishes (13.3%). Case 1 showed a more even distribution across office furniture (24.0%), casework/joinery (14.0%), partitions (12.6%), ceiling finishes (11.0%) and floor finishes (10.3%). Taken together, these results confirmed that office furniture was the dominant embodied carbon category across all four case studies. AV and IT equipment

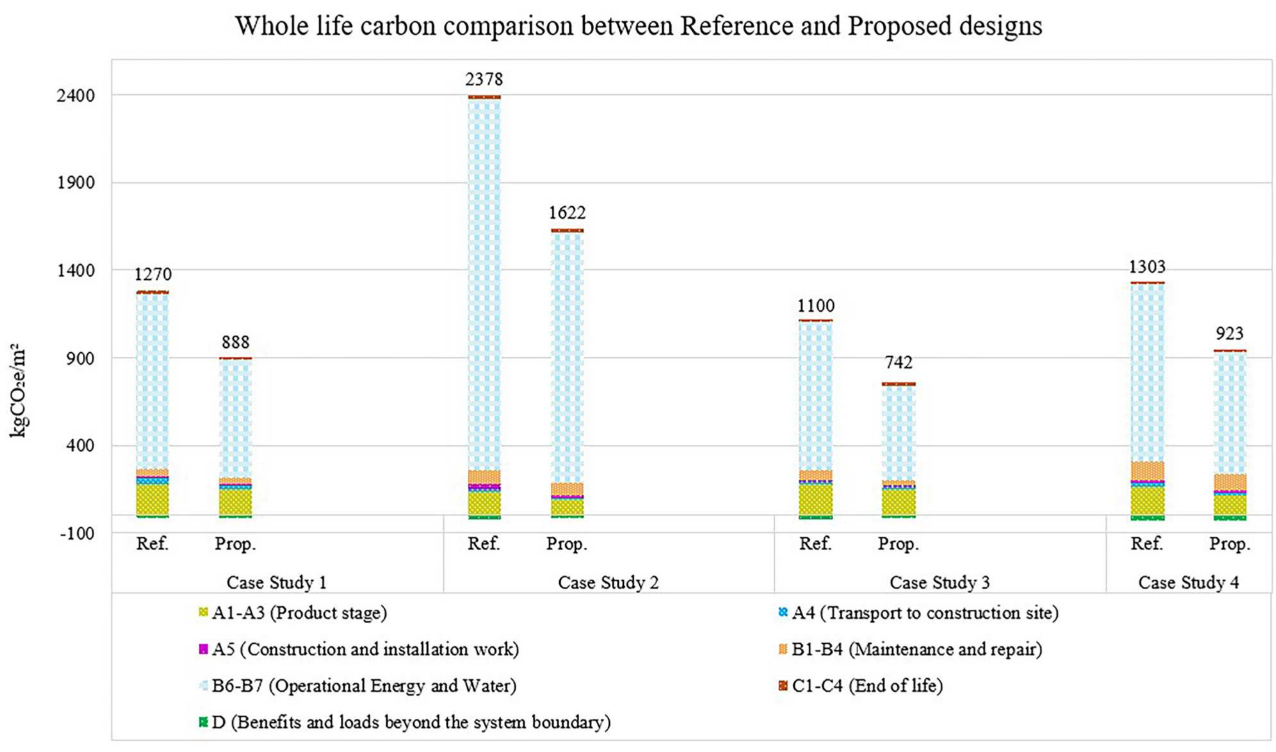

Figure 3. Whole life carbon comparison between Reference and Proposed designs. *Note:* Ref. = Reference design ($kgCO_2e/m^2$); Prop. = Proposed design ($kgCO_2e/m^2$).

Table 6. The detailed breakdown of the saving percentages for each model across cases.

	Case 1			Case 2			Case 3			Case 4		
Modules	Ref.	Prop.	Sav.	Ref.	Prop.	Sav.	Ref.	Prop.	Sav.	Ref.	Prop.	Sav.
A1-A3	175	152	13	138	90	35	175	150	14	167	115	32
A4	38	22	42	14	7	50	21	17	19	16	13	19
A5	10	6	40	24	15	38	5	4	20	18	14	22
B1-B4	44	31	30	80	71	11	56	31	45	106	93	13
B6-B7	994	676	32	2120	1435	32	845	537	36	1011	701	31
C1-C4	26	17	35	23	21	9	19	21	−11	15	14	7
D	−17	−16	6	−21	−17	19	−21	−18	14	−28	−27	7

Note: Ref. = Reference design ($kgCO_2e/m^2$); Prop. = Proposed design ($kgCO_2e/m^2$); Sav. = Savings percentages (%)

and finishes formed the next tier of contributors, and where relevant to the brief and patterns of use, other equipment providing secondary contributions.

Strategies for reducing embodied carbon emissions

Across the four case studies, the hotspot analysis directly informed strategies to reduce WLC emissions. Priority actions focused on retain, reduce and reuse interventions for furniture, ceiling and floor finishes, and existing services, AV and IT equipment, thereby avoiding or minimizing A1–A5 burdens where feasible. These measures were complemented by targeted specification upgrades to lower-carbon products. At the project level, the cumulative embodied carbon reductions attributable to these measures were 21.56% (Case 1), 26.91% (Case 2), 19.19% (Case 3) and 22.51% (Case 4), as shown in Table 8.

Within the retain principle, preservation of high-impact finishes avoided upstream production and installation burdens (A1–A5), with retained ceilings contributing 7.66% (Case 1), 3.24% (Case 3) and 5.52% (Case 4) embodied reductions and retained floor finishes adding 4.64% (Case 1) and 0.42% (Case 4). Strategies that reduced the quantity of new materials and equipment (most notably an exposed-ceiling approach) delivered measurable embodied savings, including 6.96% in Case 2. In parallel, rationalizing equipment quantities (e.g. monitor counts) achieved 6.50% in Case 2 and 8.21% in Case 4, reflecting avoided production and installation burdens (A1–A5). Complementing reduction, the reuse principle extended service life and displaced new manufacture and transport, with reused furniture and equipment contributing 4.33% (Case 2), 9.48% (Case 3) and 4.59% (Case 4) carbon reductions.

Overall, retain, reduce and reuse emerge as the highest-leverage first-line strategies for embodied carbon abatement and should be prioritized at the earliest design stages, when retaining existing elements and minimizi new scope can secure the largest share of carbon savings. Material-selection improvements targeted product carbon intensity, durability, end-of-life pathways, recycled content and low-carbon performance. These interventions delivered embodied-carbon reductions of 2.80% (Case 1), 9.12% (Case 2), 6.47% (Case 3) and 3.69% (Case 4), with additional efficient materials and systems contributing a further 1.20% in Case 1. All material improvements were supported by verified EPDs, ensuring greater transparency, consistency and comparability in the assessment of design alternatives.

Table 7. The embodied carbon percentage distribution for each category.

Category	Case 1	Case 2	Case 3	Case 4
Appliances (i.e. dishwasher, refrigeration)	0.3%	0.5%	0.9%	0.0%
Hydraulic services (i.e. HWS, Zip Tap)	0.0%	0.1%	0.0%	0.1%
Casework (i.e. joinery, kitchen cabinet)	14.0%	0.4%	2.5%	0.4%
Communication systems	0.5%	0.4%	0.5%	0.4%
Lighting fixtures	0.4%	0.0%	0.4%	0.4%
Miscellaneous (i.e. cleaner, demolition EoL)	3.8%	1.4%	3.9%	1.2%
Fire services	1.7%	1.6%	1.6%	1.3%
Electrical services	2.3%	2.8%	2.4%	2.4%
Ceiling suspension systems	0.0%	3.0%	2.5%	7.1%
Interior doors & windows	2.6%	1.0%	2.1%	4.5%
HVAC equipment	5.6%	16.9%	3.5%	2.9%
Wall finishes	4.7%	5.4%	5.1%	3.0%
Partition walls (i.e. framing, insultation)	12.6%	6.0%	14.1%	1.5%
Ceiling finishes	11.0%	6.5%	5.3%	2.3%
Floor finishes	10.3%	13.3%	7.8%	11%
AV and IT equipment	6.4%	18.1%	13.2%	27.6%
Office furniture	24.0%	22.5%	34.2%	33.9%

Operational carbon hotspots

Across the four case studies, operational demand was dominated by a small number of end-uses including lighting, HVAC, AV and IT equipment, with appliances as a secondary contributor and water loads comparatively minor. Table 9 illustrates the operational carbon percentage distribution across categories.

As shown in Figure 5, Case 1, AV and IT equipment represented 35.3% of operational carbon emissions, followed by lighting (30.4%) and HVAC (23.6%), with appliances at 10.2% and water services together below 0.7%. Case 2 is markedly HVAC-intensive, with

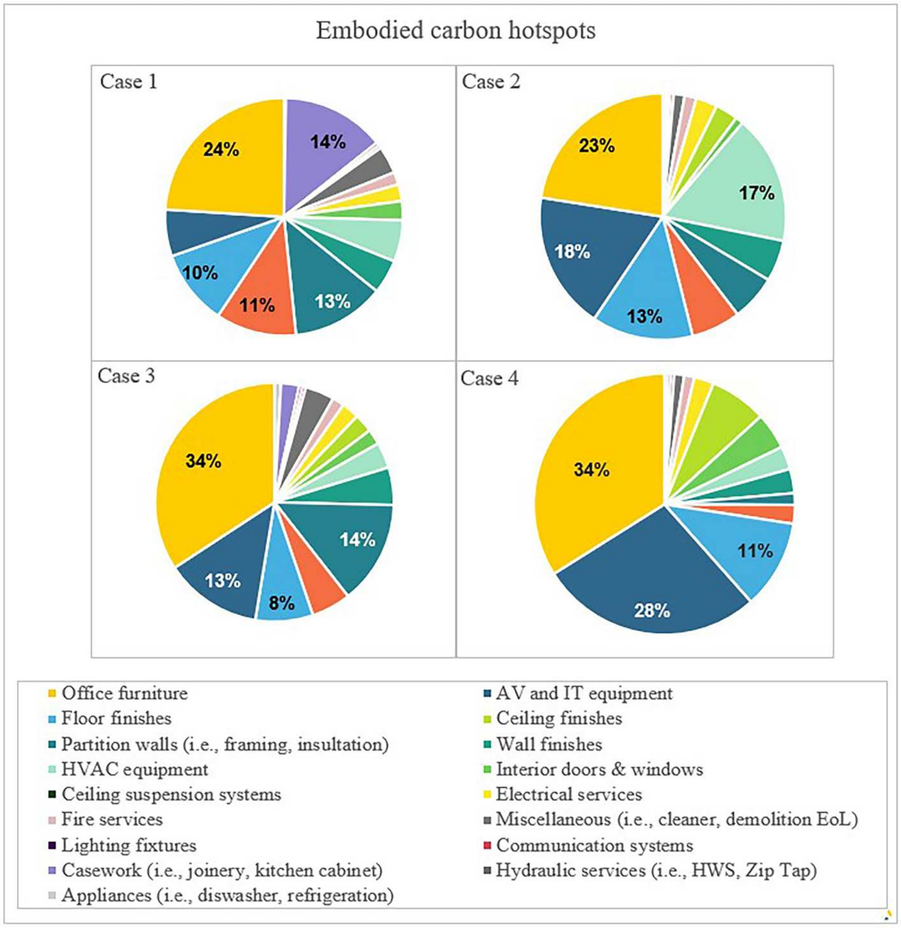

Figure 4. Embodied carbon hotspots (embodied carbon impact per product category).

HVAC accounting for 74.5% of operational demand, followed by lighting (15.8%) and AV and IT equipment (8.3%), while all other end-uses remain below 2%; this elevated HVAC share is associated with project-specific communication/IT support rooms, which increase cooling and air-handling requirements relative to the other case studies. Case 3 exhibited a more balanced profile with lighting (44.2%), HVAC (25.1%), AV and IT equipment (25.1%), appliances (5.5%) and water loads below 0.1%, while Case 4 again showed a three-way split between lighting (37.7%), HVAC (26.9%) and AV and IT (24.5%), with appliances (9.7%) and domestic water heating (1.1%) comprising the remainder.

Case-level differences were instructive for targeting operational carbon reduction strategies. A project with an HVAC-heavy profile (Case 2) prioritized high-efficiency, right-sizing, controls optimization and load reduction measures. Whereas a profile dominated by lighting and AV and IT (Case 1) emphasized high-efficacy luminaires, daylight and occupancy control regimes. In the balanced profiles (Cases 3 and 4), gains were distributed across these domains, with domestic

Table 8. Embodied carbon and WLC reduction achieved by different improvement strategies across cases.

		Embodied carbon reduction % (Modules A1–A5, B1–B4, C1–C4)				WLC reduction % (Modules A–C)			
Strategy principle	Strategy implemented	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Retain	Retain existing ceiling	7.66	n/a	3.24	5.52	1.74	n/a	0.80	1.33
	Retain existing floor finish	4.64	n/a	n/a	0.42	1.05	n/a	n/a	0.10
Reduce	Exposed ceiling	n/a	6.96	n/a	n/a	n/a	0.81	n/a	n/a
	Reduce equipment quantity	n/a	6.50	n/a	8.21	n/a	0.75	n/a	1.97
Reuse	Reuse existing furniture and equipment	n/a	4.33	9.48	4.59	n/a	0.50	2.33	1.11
Improve	Low-carbon materials	2.80	9.12	6.47	3.69	0.64	1.05	1.58	0.89
	High-quality furniture	1.20	n/a	n/a	n/a	0.27	n/a	n/a	n/a
	Operationally-efficient equipment and services	5.26*	-	-	0.07*	25.89	28.51	27.46	23.26
Cumulative impact reduction		21.56	26.91	19.19	22.51	29.59	31.64	32.17	28.68

Note: *Reflects embodied savings derived from HVAC system reconfiguration.

Table 9. The operational carbon percentage distribution for each category.

Category	Case 1	Case 2	Case 3	Case 4
AV and IT equipment	35.3%	8.3%	25.1%	24.5%
Lighting	30.4%	15.8%	44.2%	37.7%
HVAC	23.6%	74.5%	25.1%	26.9%
Appliances	10.2%	0.4%	5.5%	9.7%
Hydraulic services	0.0%	0.9%	0.0%	1.1%
Water Removal and Treatment	0.4%	0.1%	0.1%	0.1%
Water Supply	0.2%	0.0%	0.0%	0.0%

water heating a small but non-negligible opportunity in Case 4. While causal attributions required more detailed building-physics and scheduling data, the end-use shares alone provided a robust basis for sequencing interventions: address the largest loads first, then pursue incremental improvements in secondary end-uses.

Strategies for reducing operational carbon emissions

Operational energy enhancements were implemented and evaluated across all four case studies, with the intervention mix aligned to the end-use hotspots observed in B6–B7 modules. The strategy set focused on the energy performance of fitout equipment and building services, comprising (i) specification of energy-efficient appliances and IT equipment, (ii) optimized lighting design with high-efficiency luminaires, daylight and occupancy controls and (iii) high-efficiency HVAC systems, including right-sizing and set-point and scheduling optimization.

The impact of these interventions on whole life performance was significant, achieving reductions of 25.89% in Case 1, 28.51% in Case 2, 27.46% in Case 3 and 23.26% in Case 4. Among the strategies implemented, energy-efficient lighting systems and improved HVAC performance emerged as the most influential contributors to operational impact reduction, given their direct effect on long-term energy demand.

The scope of water efficiency measures across the four fitouts was limited to consumption associated with new taps installed in kitchens and breakout spaces, as well as dishwashers. Consequently, the focus was on specifying taps with high WELS ratings, including 5 stars (flow rate between 4.5 and 6 L/min) and 6 stars (flow rate of 4 L/min or less) and dishwashers with high WELS ratings and low water consumption per cycle, ensuring optimal water savings during operation. Improvements in water efficiency were not reflected in this LCA study, as WLC assessment indicated negligible reductions from these measures. Consequently, the analysis focused on embodied and operational energy impacts, which represent the dominant contributors to life cycle emissions. However, water reduction initiatives were successfully implemented and claimed under Credit 18 of the Green Star Interiors v1.3 rating across all case studies.

Discussion

Life cycle carbon emissions of office fitouts

In line with the literature, this study recognizes that hotspot analysis is a critical tool for identifying and managing the most impactful product categories (Barthel et al., 2015; Sousa Zomer et al., 2024). However, the study findings highlight the value of hotspot analysis as a practical decision-support tool for reducing WLC emissions in office fitouts. The carbon hotspot analysis across the four case studies enabled the identification of the components and end-uses with the greatest contribution to WLC emissions. By quantifying category-level shares for embodied modules and end-use shares for operational modules, the analysis established a clear hierarchy of impacts and translated this hierarchy into a practical basis for design decision-making.

It is evident that embodied carbon impacts were concentrated in several product categories, with office furniture accounting for an average of 29% of total

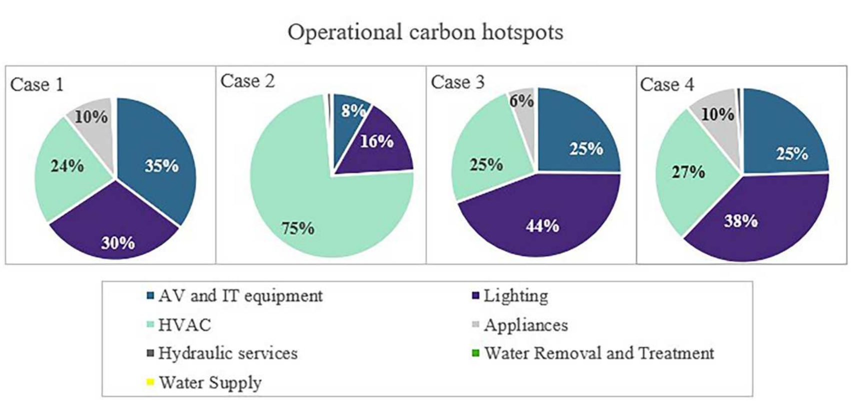

Figure 5. Operational carbon hotspots (operational carbon impacts per product category).

embodied carbon emissions across the four cases. This is consistent with previous studies where office furniture appeared as the largest contributor (Hoxha & Jusselme, 2017). In terms of operational carbon impacts, hotspots were concentrated in a few end-uses: lighting, HVAC, AV and IT equipment. These end-uses consistently dominate operational carbon impacts, with HVAC often the largest source (Kamazani et al., 2025; Pushpakumara & Jayasinghe, 2024). Together, the findings demonstrate that the greatest reduction potential lies in targeting furniture, equipment and finishes for embodied carbon emissions and lighting, HVAC, AV and IT systems for operational carbon emissions. The magnitude of these contributions varies with building function, material selection and the interaction between demand reduction, system efficiency and controls. These results underscore the importance of integrated LCA in interior design, ensuring that improvements in one domain do not lead to unintended trade-offs in the other.

The findings of this study support existing knowledge identified earlier in the literature review while extending it by demonstrating the practical implications of decarbonization strategies for fitout projects. These strategies prioritize extending the service life of interior components, retaining materials across refurbishment cycles and reusing or refurbishing furniture, complemented by upgrades to efficient services equipment and the diversion of furniture and fittings from landfill. This study emphasizes that the retaining and reusing existing materials and components are the most consistently effective means of lowering embodied carbon emissions because they avoid A1–A5 burdens associated with new production and transport. The strategic selection of components and materials is also critical. Wherever feasible, high-impact materials should be avoided or substituted with lower-carbon alternatives that meet functional and performance requirements. In addition, product-specific EPDs can be prioritized to ensure that the most accurate and project-relevant environmental data informs decision-making. Finally, optimizing material quantities has proven highly effective, as reducing resource consumption often delivers greater carbon savings than material substitution alone (Tozan et al., 2025). Taken together, these decarbonization strategies not only contribute to lowering carbon emissions but also align closely with circular economy principles by narrowing, slowing and closing resource loops (Nußholz et al., 2023). Future research should explore regenerative design strategies for office fitouts, examining how interior design can shift from reducing impacts to generating net-positive environmental and social outcomes.

Challenges and considerations

Modelling assumptions of retained and reused materials and products

This study underscores substantial carbon-reduction benefits that arise from retaining and reusing existing fitout components. It does, however, raise important methodological questions regarding how to account for the impact of these elements correctly. Reflecting on the literature, it is acknowledged that the assumptions applied in this study present broader methodological limitations in current LCA practice. The allocation of environmental burdens across multiple life cycles remains highly contested, and no single method has achieved universal acceptance. Existing approaches include (a) EN 15804/15978 cut-off approach, (b) Circular Footprint Formula (CFF), (c) 50:50 approach, (d) linearly degressive (LD) approach and (e) new CE-LD method which was designed to better align allocation procedures with circularity objectives (Eberhardt et al., 2020). Given these variations, this study recommends that future work undertake systematic sensitivity analyses comparing carbon-reduction outcomes for retained and reused elements using various allocation methods. Although several improved methodologies are emerging in academic research, their application in practice will require agreement, standardization and clear instructions across industry and regulatory bodies. For example, such methodologies could be integrated into GBRSs and national policies, allowing the use of best practices across various projects. Consequently, this study reinforces the need for a harmonized LCA approach for fitout and refurbishment projects across different scopes, where recurrent interventions and multi-cycle material flows are especially prevalent.

Data availability and accuracy

The use of EPDs. EPDs provide transparent data on environmental impacts of a product throughout its lifecycle. However, this study showcases some important considerations when using EPDs in the LCA studies. Firstly, it was observed that the market offers a wide range of EPDs developed under different Product Category Rules (PCRs), such as ISO 21930 and EN 15804. This variation can lead to inconsistencies and significant differences in results across LCA models underlying the EPDs (AzariJafari et al., 2021; Konradsen et al., 2024). Thus, it is recommended that practitioners should exercise caution regarding PCR specifications such as impact categories, indicators, units, characterization factors, system boundaries, allocation rules and data quality requirements (ISO, 2010; CEN, 2013; CEN, 2019) when selecting, comparing and interpreting EPDs for design improvement scenarios.

Secondly, the study results indicate that EPDs, when used correctly, can offer the most robust data for the A1–A3 product stage. However, impacts in modules A4 (e.g. transport modes and distances), A5 (e.g. people and equipment), C (e.g. end-of-life scenarios) and D (e.g. benefits and loads beyond the system boundary calculated based on different end-of-life scenarios) can vary noticeably due to regional differences in transport networks, construction practices, energy grids and waste management systems. For example, the default transport-distance assumptions reported in EPDs used for the case studies ranged from approximately 700 km to more than 7000 km, depending on whether materials were transported locally, regionally, or internationally. Regions with highly renewable electricity mix such as New Zealand can substantially reduce installation impacts compared to regions like Australia. Likewise, Module C data reported in European EPDs is not representative of Australian end-of-life scenarios as recycling rate and disposal scenarios depend on the local practices. Previous studies have raised similar concerns regarding the reliability and variability of EPD data, as well as the lack of harmonization (Alaux et al., 2024; Del Rosario et al., 2021). However, practical guidance on how to address these challenges in specific building project contexts remains limited.

This study recommends an alternative modelling approach in which EPD-derived impacts are used for modules A1–A3, while modules A4, A5 and C are modelled using country-specific assumptions and applying conservative (worst-case) scenarios wherever practical uncertainties exist. This involves prioritizing A1–A3 data for product comparisons and ensuring that EPDs follow the same standard and PCR to maintain consistency. Transport assumptions should be verified to reflect the actual distance to the project site. If discrepancies exist, additional transport impacts should be included in Module A4. For A5 and subsequent modules, default industrial-average assumptions based on the project location should be applied when detailed data is unavailable. Accuracy can be improved by using regional EPDs whenever possible, and comparability should be ensured by selecting similar products and applying a consistent LCA framework across all comparisons. In other cases, practitioners should carefully review the assumptions, product origins, data sources and methodological choices presented in EPDs to ensure that any claimed benefits are representative of the regional context in which the products are used.

Lack of generic data for fitout materials and products. Insights from this study echo those in the literature, highlighting persistent challenges related to generic data availability and accuracy. Although progress has been made in developing standardized LCI datasets such as Ecoinvent's alignment with EN 15804, significant gaps remain in regional coverage and representation of specific building components (Anyanya et al., 2025). Variations in data reliability also persist due to differences in verification processes and methodological choices across LCA software and database providers (Konradsen et al., 2024; Somerset et al., 2025). For example, the eTool platform used in this study applies regionalization to background LCI datasets sourced from Ecoinvent when region-specific data is not available. Key parameters such as electricity grid mixes, transport distances and waste-treatment processes are adjusted to reflect the specific conditions of the region, improving the geographical relevance of results (Cerclos, n.d.-c). However, it is important to note the limitation of supply-chain variations not being fully captured. Therefore, caution is necessary when modelling and interpreting LCA results.

Furthermore, this study indicates that most available LCA datasets are designed primarily for base-building applications with limited coverage for office fitouts. Thus, key interior components are frequently absent or represented only by coarse proxies – furniture systems and workstations, loose office equipment, tenant-side services equipment (terminal HVAC devices, diffusers, small air handlers, controls), luminaires and lighting controls, and plug-load devices such as appliances, IT and audiovisual equipment. This under-representation constrains model fidelity, increases reliance on generic factors, and can systematically understate interior impacts and their variability across products and suppliers. Although manufacturers and suppliers may provide environmental impact information for their products, these data are frequently not presented in the form of an EPD, reducing their reliability. EPDs therefore remain the most robust source when available. However, high-quality EPDs are still lacking for many fitout components, requiring careful interpretation.

These gaps complicate the WLC assessment in case studies, as additional time and effort must be spent sourcing alternative data, ultimately lowering confidence in the results. Such challenges mirror those encountered by project teams undertaking carbon assessments in real-world projects and represent a barrier to integrating carbon assessment into the design process. Future work should expand LCA datasets to include a broader range of fitout elements and work towards establishing a reliable data source to improve assessment accuracy.

Low-carbon and indoor environmental quality (IEQ) design implications

Findings from this study offer insights into low-carbon and indoor environmental quality (IEQ) design implications. Low-carbon strategies examined were assessed not only for emission reductions but also for their impacts on IEQ. Across four case studies, design decisions were developed within Green Star Interiors requirements, requiring alignment with criteria for TVOC emissions, formaldehyde content and best-practice PVC avoidance. This was particularly relevant for low-carbon material substitutions, which required both favourable embodied carbon performance and supporting documentation, including test certificates and compliance evidence. Material specification was therefore guided by a dual objective: reducing carbon emissions while maintaining acceptable indoor pollutant thresholds and broader health criteria. For instance, Green Star Interiors requires 95% of paints, adhesives, sealants and carpets to meet stringent TVOC limits, while engineered wood products must comply with low formaldehyde emission standards. Similarly, products such as formwork, pipework and flooring must avoid PVC or meet best-practice criteria. Trade-offs were also evident, particularly where material-reduction strategies, such as exposed ceilings, created potential implications for acoustic performance and indoor comfort. These issues were addressed through complementary low-emission products, such as low-VOC acoustic finishes. Collectively, the findings show that low-carbon strategies in office fitouts cannot be evaluated through a carbon lens alone but must be understood within a broader performance framework that simultaneously considers life cycle carbon emissions, IAQ and occupant health and wellbeing, as well as the constraints and trade-offs that shape holistic design outcomes.

Iterative LCA modelling process

This study reinforces the existing knowledge that the LCA process is inherently iterative, with multiple feedback loops linking its various phases. Because building design itself evolves iteratively (Nielsen et al., 2016), LCA modelling must similarly be revisited at successive project stages. LCA can be undertaken from concept design through developed and detailed design, and later during construction and as-built stages. However, early-stage modelling is strongly recommended. Ideally, LCA should be embedded throughout the design process to support optioneering and inform decision-making. In this study, LCA was conducted from design to as-built stages not only to meet Green Star requirements but also to provide rigorous support for sustainable design decisions as the project progressed. Iterative assessments enabled the project team to identify and demonstrate design improvements over time in pursuit of carbon-reduction targets. Furthermore, design templates and lessons learned from previous fitout LCAs can feed forward into future projects, helping to improve consistency and outcomes. However, completing full comparative LCAs repeatedly across project stages can be resource-intensive, requiring significant time and cost from the project team. As LCA tools become more user-friendly and datasets more refined and comprehensive, this iterative process is expected to become more manageable, reducing the burden on practitioners.

Conclusion

This study investigated the potential of office fitouts to reduce life cycle carbon emissions through four real-life case studies of Green Star Interiors certified projects in Australia. The results generate new insights into how LCA theory translates into practice, illuminating both the opportunities and challenges of implementing LCA in real-world fitout projects. It advances theoretical understanding by identifying gaps and proposing methodological improvements, while also offering practical guidance for practitioners seeking to apply LCA for office fitouts more effectively.

The findings demonstrate that the effective decarbonization of office fitouts requires targeted strategies for both embodied and operational emissions. On the embodied side, a retain-first, reduce-second, reuse-and-improve hierarchy consistently captures the most certain abatements. On the operational side, interventions are aligned to end-use hotspots (principally HVAC, lighting, AV and IT), combining demand reduction with high-efficiency systems and controls to curb long-term energy use. In practice, WLC performance improves most when embodied and operational measures are balanced and when trade-offs were tested explicitly within the WLC loop at each design gate. This study also highlighted LCA methodologies and data limitations as well as modelling process and design considerations particular to interiors projects. These include modelling assumptions of retained and reused materials and products, data availability and accuracy, low-carbon and IEQ design implications, and iterative LCA modelling processes. Together, the study provides recommendations to enhance future LCA studies of office fitouts, enabling more effective methodological enhancement in theory and design decision-making in practice.

In the context of increasing legislative requirements and mandatory disclosure obligations, both internationally and in Australia, this work has significant relevance for policy and practice. The built environment is being required to upskill in the measurement and disclosure of embodied carbon emissions in buildings, on a pathway to minimum standards for these emissions under the NCC. Whilst fitouts are currently excluded under changes to the NCC, the mandatory disclosure obligations on the commercial property sector will increasingly drive demand for this data from landlords and tenants. This suggests the need for building regulation and mandatory disclosure legislation to better align, with industry standard tools being made appropriate for the fitout sector, which is responsible for significant life cycle carbon emissions. Furthermore, in advancing the methodology not only for quantifying life cycle carbon emissions of office fitouts, but also that of identifying hotspots to target reduction in emissions, and strategies for addressing these hotspots, this work supports practitioners as the use of LCA as a decision-making and auditing tool becomes more prevalent.

However, this study is limited to sensitivity and uncertainty analyses. In particular, the assumed 10-year reference study period, while aligned with Green Star Interiors v1.3, actual fitout cycles may be shorter. Shorter service lives would increase the relative contribution of embodied carbon emissions due to more frequent replacements, potentially shifting the balance between embodied and operational impacts and influencing the prioritization of design strategies. Future research should therefore explore the sensitivity of results to different reference study periods, alongside broader uncertainty analyses considering carbon uncertainty factors, multicycle allocation methods, as well as material and grid decarbonization scenarios to better reflect variability and support more robust decision-making.

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Declaration of generative AI and AI-assisted technologies in the writing process

Generative AI – Microsoft Copilot was used solely for minor editing to improve readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Data availability statement

Data are not publicly available due to commercial restrictions. However, some data will be made available upon reasonable request from the corresponding author.

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