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INTERIORS IN FLUX

The coexistence of existing building stock and mass timber through adaptive reuse for environmental sustainability and user well-being.

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Date:	28 June 2024

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Declaration of Originality (University of Pretoria, 2024):

I declare that this mini-dissertation, "INTERIORS IN FLUX – The coexistence of existing building stock and mass timber through adaptive reuse for environmental sustainability and user well-being.", which has been submitted in fulfilment of part of the requirements for the module of DIT 803, at the University of Pretoria, is my own work and has not previously been submitted by me for any degree at the University of Pretoria or any other tertiary institution.

I declare that I obtained the applicable research ethics approval in order to conduct the research that has been described in this dissertation.

I declare that I have observed the ethical standards required in terms of the University of Pretoria's ethics code for researchers and have followed the policy guidelines for responsible research.

2024.06.28

Acknowledgments

Christo van der Hoven
The answer to all our questions… and problems.
•
I am grateful for my supervisor, Christo van der Hoven, for his invaluable patience, feedback, guidance and endless optimism.

York Timbers
The backbone to our research.
•
It was a great privilege to be funded by FP&M SETA 2024 Funding, in partnership with York Timbers.

Family, Paws and Friends
Keeping up the spirits.
•
This mini dissertation would not have been possible without my support system's love and endless belief in me.

Abstract

People spend the majority of their time indoors. People, nature and buildings constantly change. People grow tired of their everyday routine and environment, resulting in periodical spatial changes within the spaces they occupy. Cyclical renovations of interiors occur frequently, responsible for the cumulation of extensive greenhouse gas emissions, a high carbon footprint and concerning amount of construction and demolition waste. This results in prematurely discarded *structures*, *skins*, *services*, *space plans* and *stuffs*, as per Stewart Brand's six shearing layers of change and longevity. Sustainable alternative materials should be sought to replace carbon-intensive and extractive materials like concrete and steel, especially during deep renovations to decarbonise existing building stock. Mass engineered timber renders a viable sustainable alternative to not only reduce the anthropogenic impact on the environment by significantly reducing greenhouse gas emissions and sequestering carbon. Mass timber also presents the potential to improve indoor environmental quality, indoor air quality, human health and well-being. Adaptive reuse can function as implementation tool for mass timber integration in internal applications. The environmental impact of cyclical interiors was investigated through a case study conducted by industry professionals. Comparisons were made between the Global Warming Potential (kg-CO_2e) of different materials to display the potential benefits of mass timber on indoor environmental quality and well-being.

Key Terminology

Existing Building Stock | Mass Timber | Adaptive Reuse | Cyclical Interiors | Environmental Impact | Well-being

CONTENTS

List of Figures

List of Tables

LIST OF KEY ABBREVIATIONS

TERMINOLOGY	DEFINITION
AEC	Architecture, Engineering and Construction
C&DW	Construction and Demolition Waste
DfD	Design for Disassembly
DfMA	Design for Manufacture and Assembly
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
LCA	Life Cycle Assessment
MT	Mass Timber

KEY TERMINOLOGY AND DEFINITIONS

The key terminology used throughout this study is outlined in Table 1 below:

Table 1: Key terminology and definitions (Author, 2024)

TERMINOLOGY	DEFINITION
Adaptive Reuse	In short, adaptation for a new use (The Burra Charter, 2013). The term "… implies a change of function, of a building whose previous use is now obsolete and therefore is changed to accommodate a new function, with new occupiers with different needs and priorities." (Stone, 2019:4)
Cyclical Interiors	Periodic renovations of building interiors - enclosed (differing degrees of enclosure) environments protected from external elements, in which people spend most of their time.
Demolition	"Where a site is cleared of its building by the most expedient means." (Josefsson, 2019:17).
Existing Building Stock	In this study it refers to building stock that has already been built and completed, but with a lack of proper use and function or a need for renovation. It includes housing, urban heritage and building stock in the general sense whether in use or vacant.
Life Cycle Assessment	A life cycle assessment (LCA) offers insight into the environmental performance of a product at a specific point in time. Typically, LCA studies are context-specific and case-related. (Crawford & Cadorel, 2017:840).
Mass (Engineered) Timber	Large-scale structural engineered wood products (Abed *et al.*, 2022:2) with a high strength-to-weight ratio (Trinh & Zhang, 2021:21). It sequesters carbon, resulting in an environmentally sustainable alternative material to steel and concrete. Products include cross-laminated timber (CLT) and glue-laminated timber (Glulam) (Abed *et al.*, 2022:2,3).
System Hybridisation	System hybridisation, or architectural hybridity, refers to architectural systems (such as construction processes, methods or materials) composed of elements from different origins (Belabid *et al*., 2022:7). Hybridity can therefore refer to the relationship between heterogeneous elements.
Well-being	Jarden and Roache (2023:3) define well-being as a "… sense of tranquility resulting from inner peace and harmonious interactions with the external environment" which is largely overlooked in literature related to well-being. Well-being can be subjective and objective.

1. PROLOGUE

1.1 (IM)PERMANENCE

For centuries, humankind was, and still is, obsessed with the philosophical phenomena of continuity, endless durability, immutability and timelessness. Ever since, the dichotomy between permanence and change prevailed.

"All architects want to live beyond their deaths" by making a mark and leaving behind a built legacy (Long, 2016:1). The first in Vitruvius' trinity of architectural principles, *Firmitas*, is widely associated with the ideology of permanence (Touw, 2006:iii). Louis Kahn's monumental mass and solidity epitomise architectural endurance that can stand the test of time. Frank Gehry believes that "*architecture should speak of its time and place, but yearn for timelessness*".

Aristotelian philosophy argued that change is distinct from time, as change occurs at varying rates whereas time remains constant (Mortensen, 2020). His argument relates to Stewart Brand's six shearing layers of change and longevity (Figure 1) in which all parts of a building are subject to change, but at different rates (Brand, 1994:12).

"The only constant is change." – Heraclitus

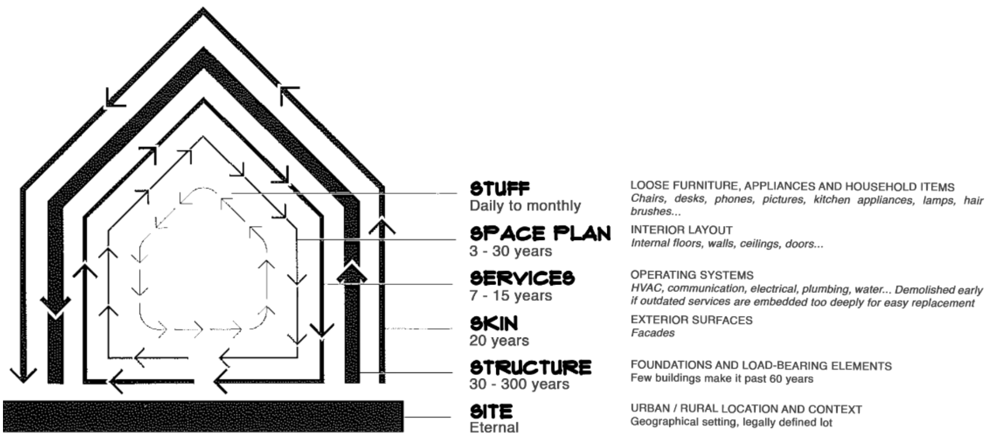

Figure 1: Shearing layers of change and longevity (Adapted from Brand, 1994:13).

Site is eternal; *structure* persists and dominates; *skin* is mutable; *services* are the working guts of a building; the *space plan* is the human comedy and *stuff* just keeps moving… (Brand, 1994:14-22).

Soon the ideal of leaving an everlasting mark were superseded by deeper meanings. The current architectural discourse is starting to realise the value of permanent temporality, where longevity is found within adaptability.

2. INTRODUCTION

People spend approximately 90% of their lives indoors (Ashour *et al.*, 2022:2) in increasing airtight buildings (Gonzalez-Martín *et al.*, 2024:1) whether at home, work or leisure. The life expectancy of a South African is currently 65.10 years (Macrotrends, 2024), translating to 58.59 years indoors and 6.51 years outdoors (Figure 2). One might suspect that this changed after being confined to our homes during the COVID-19 pandemic, but the home improvement industry grew substantially during this period of lockdown to create more desirable spaces for entertainment and remote working (Garcia, 2023).

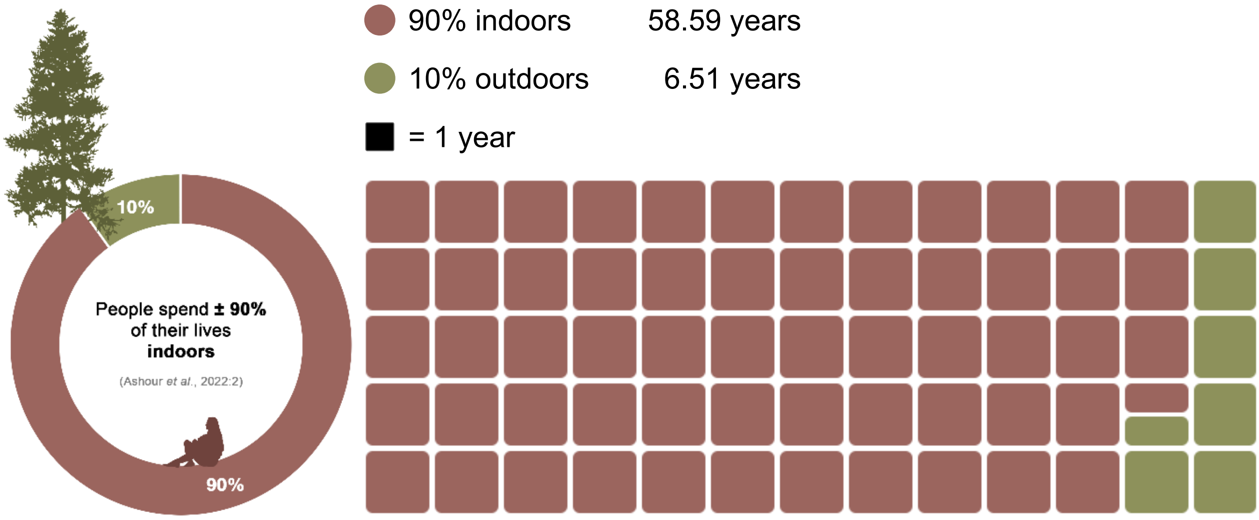

Figure 2: Years spent indoors and outdoors (Author, 2024).

Brand's building layers of *space plan* and *stuff* are the most flexible and temporary in nature – both with shorter lifespans than the other four *S's* (Figure 1). These two internal layers shape the environment in which people spend most of their time, resulting in the spaces where change occurs the most. Renovations, restorations, revamps and refurbishing are typical methods of spatial change. *Space plan* refers to the spatial layout of a building's interior which includes elements such as internal floors, walls, ceilings and doors (Brand, 1994:13). *Stuff* comprises loose items and furniture (*mobilia* in Italian for good reason) that change location or gets replaced on a daily to monthly basis (Brand, 1994:13).

> *"The Space plan and Stuff are what building users have to look at and deal with all day, and they rapidly grow bored, frustrated, or embarrassed by what they see. Between constant tinkering and wholesale renovation, few interiors stay the same for even ten years."*
>
> *– Brand (1994:20)*

2.1 RESEARCH GAP

According to LMN (2022) and multiple others, renovation cycles in hospitality, retail and office spaces occur as frequently as every five years. As people spend most of their time indoors, it is only natural that cyclical renovations of interiors occur so frequently (Table 2). However, literature on the environmental impact of cyclical interior renovations, including the quantification of indoor air quality (IAQ) and construction and demolition waste (C&DW) generated, is a scarce topic in current research. Continuous renovations of interiors may contribute to a higher amount of indoor air pollution, C&DW and an embodied carbon footprint than existing buildings and/or the construction of a new building. This requires attention because if designed unsustainably, interiors can pose even greater risks to human health and environmental sustainability. Our existing building stock, *space plan* and *stuff* should be re-evaluated for potential reuse. Renovations, adaptive reuse strategies and advancements in material technology offer opportunities to decarbonise existing buildings.

Table 2: Recommended periods of cyclical renovations for interiors (Author, 2024).

Occupancy Type	Recommended Cycle (years)	Average (years)	Sources
Residential	3 – 5 – 10	6	Bowdon, 2024; Property24, 2017
Living Rooms	3 – 5	4	McShannon, 2023
Dining Rooms	5	5	McShannon, 2023
Kitchens	10 – 15	12.5	Calder, 2023
Bathrooms	4 – 5	4.5	Mamedov, 2022
Paint	5 – 10	7.5	Buco, 2019
Offices	5 – 10	7.5	Zentura, 2023
Hotels	6 – 7	6.5	Suite Renovations, 2024; Rockfon, 2022
Retail	5 – 10	7.5	KRS, 2024
Restaurants	5 – 10	7.5	Usman, 2023
Hospitals	10 – 15	12.5	Collins, 2019

Table 2 provides recommended periods of cyclical renovations for interiors. Note that the data is based on professional opinions due to insufficient figures in peer-reviewed research. The suggested cycles are not set in stone, as multiple factors influence the lifespan of interiors. It is, however, clear that interiors typically have shorter lifespans than buildings themselves (Figure 1), greatly impacting sustainable practice.

2.2 RESEARCH OBJECTIVES

This study aims to highlight why the environmental impact of interiors should be regulated to reduce the built environment's carbon footprint. It is necessary to understand why the reuse of existing building stock is important in a technologically advanced century where it is difficult to provide for future generations due to rapid urban growth, resource depletion and limited land availability for newly built structures. Therefore, it is intended to provide an overarching view of current issues within the built environment regarding urbanisation, existing building stock, emerging mass timber technologies and future demand. The study indicates how multi-scalar adaptive reuse can be exploited as implementation tool for circularity on a macro (cities), meso (buildings) and micro (components) scale. As both the existing and the emerging can contribute to reduced GHG emissions, system hybridisation will be encouraged. Finally, this study will stress why hybridity contributes not only to environmental well-being, but also user well-being.

2.3 RESEARCH QUESTIONS

2.3.1 Primary Question

What is the environmental impact of cyclical renovations of interiors and how can mass timber integration provide carbon footprint relief within existing buildings to promote decarbonisation, environmental sustainability and human well-being?

2.3.2 Sub-question 1

What is the impact of cyclical interior renovations on environment sustainability?

2.3.3 Sub-question 2

How can mass timber integration enhance indoor air quality and comfort to improve human well-being within interiors?

2.3.4 Sub-question 3

How can adaptive reuse strategies facilitate the integration of mass timber in building interiors?

2.3.5 Sub-question 4

How can system hybridisation accelerate the adoption of mass timber in the built environment?

2.4 LIMITATIONS, DELINEATION AND ASSUMPTIONS

2.4.1 Limitations

Literature on urbanisation, urban sprawl and urban densification is predominantly quantitative in nature with data focused on housing demand. Other types of building demand such as businesses, entrepreneurial establishments, offices and leisure are generally not included in these statistics, which is problematic with regards to an accurate anticipated total building stock demand. The same applies to statistics on demolition. Unlike building demolition, there is a lack of statistics regarding the waste generated and greenhouse gases (GHG) emitted from cyclical renovations of interiors. Due to this, data based on professional opinions were sourced where peer-reviewed research lacked numerical information. Therefore, it is important to note that these companies may base their findings on subjective bias to promote their own product. In addition to this, it is difficult to find numerical data on existing building stock appropriate for structural reuse – especially structures which are vacant or of historical significance. As Skrede and Andersen (2022:253) point out, the qualitative dimension namely social well-being of urban-orientated literature, is an unusual subject within urban research. Therefore, this literature realm does not typically include data specifically revolving around the well-being of urbanites.

2.4.2 Delineation

This study considered only mass timber as emerging building technology. Interior applications and analyses took priority above external applications. Factors influencing mass timber's environmental impact, performance and advantages during each life cycle stage will not be outlined. Examples include the timber density, production scale, storage, material size, indoor environmental quality (IEQ), maintenance, transport distance, fuel type and disposal management. For reference, a thorough study was undertaken by Crawford and Cadorel (2017:842).

2.4.3 Assumptions

This study will not delve into the causes and consequences of urbanisation, urban densification and urban sprawl since this is a well-covered topic in the ongoing architectural discourse. The quantitative statistics regarding local population growth and density will not receive attention, as this is not the main focus of the research. Some numbers are provided, only to support the importance of why the reuse of existing building stock is necessary. It is important to note that this study is not a life cycle assessment (LCA).

3. THEORETICAL FRAMEWORK

Lemos and Donoso (2023:8) states that although sustainability has become increasingly prominent in recent times, the belief still persists that an old, yet functional product is always inferior to a newer one. Lemos & Donoso concludes that this leads to the disposal of perfectly good and usable resources for the sake of "updating", causing significant environmental disturbances. Lemos and Donoso coupled this mentality to civil construction. It can therefore be linked to new construction and cyclical interior renovations. Often the quickest, cheapest and least labour-intensive practices are employed due to high disassembly and low disposal costs (Hulsbeek, 2022:3) as well as time demands associated with restoration and repair of existing building elements. This typically results in the demolition of *structure*, *skin*, *services*, *space plan* and *stuff* to make way for the new and "superior".

This often inherent and unconscious attitude towards existing buildings and new construction is gaining ground in present architectural research on adaptive reuse, which is the process of restoring or repairing existing buildings for continued or new use (Plevoets & Van Cleempoel, 2019:i). Existing and heritage buildings still hold value to ensure the environmental, social and economic function of the urban stock (Lemos & Donoso, 2023:8). By extending the lifespan of existing buildings, material usage and embodied carbon is reduced (Lemos & Donoso, 2023:2,4,7) and therefore decreases the environmental impact of the architecture, engineering and construction (AEC) sector. Sustainable construction materials and technologies that can bridge the gap between traditional and emerging building methods while reducing the AEC's environmental impact, should be sought out to accelerate the adoption of circular construction practices such as deconstruction, design for manufacture and assembly (DfMA), design for disassembly (DfD), adaptive reuse and non-extractive, renewable materials like mass engineered timber. An example can include the adaptive reuse of an existing building by integrating innovative building technologies such as digital computation and prefabricated engineered timber when adding an extension to the old. Hulsbeek (2022:3) points out that buildings were, and often still are, not designed for disassembly, which can be excessive, resulting in demolition. Unfortunately, this results in an increase in landfill waste.

3.1 CONSTRUCTION AND DEMOLITION WASTE

In 2018, the United States generated six hundred million tonnes of construction and demolition waste (C&DW) of which 455 million tonnes were directed to next use (mainly aggregate) while 144 million tonnes ended up in landfill – over 71 million tonnes were solely concrete (EPA, 2020:22). Germany demolished 280 000 m^2 of residential buildings and 5 471 000 m^2 of non-residential buildings in 2022 (De Querol Cumbrera, 2023). 50 000 buildings are demolished per year in the United Kingdom alone (Cox, 2021). South Africans generate 122 million tonnes of waste per year, of which only 10% is recycled or recovered for repurposing (3SMedia, 2023). It is predicted that 516 million tonnes of construction waste will be reached in 2050 across the African continent of which more than 90% are deposited in unsupervised dumpsites and landfills (Jonathan, 2023).

There are 193 member countries of the United Nations and two recognised independent nations (Worldometer, 2024)*. How much does each contribute to C&DW?*

According to Rodriguez-Morales *et al.* (2024:2), demolition waste accounts for 90% of the global C&DW while the remaining 10% is from construction. Rodriguez-Morales *et al.* further states that demolition waste is typically more difficult to recycle due to its heterogenous nature and potentially hazardous waste such as paints, coatings and lighting. However, over 75% of the waste generated by the construction industry has residual value but is not currently reused or recycled, due to the lack of an integrated waste management framework (Purchase *et al.,* 2022:1). Considering the already excessive levels of greenhouse gas emissions (GHG) associated with the AEC sector (Abed *et al*., 2022:2), it is crucial to prioritise and shift towards more circular and sustainable material management strategies.

3.2 PREDICTED CONSTRUCTION ACTIVITY

Unsurprisingly, the built environment is the primary greenhouse gas emitter, producing at least 37% of the global GHG emissions (UNEP, 2023:ix) and approximately 40% of global energy and industrial-related carbon dioxide (CO_2) emissions (IFC, 2023:6). New construction developments require new land which is rapidly decreasing in availability (Abdrabo *et al*., 2021:1). On a global scale, it is estimated that the current 233 billion m^2 building stock will escalate to 415 billion m^2 in 2050, by rising an average of 5.5 billion m^2 annually (Laski & Burrows, 2017).

Interestingly, interiors are not as popular when discussing newly built construction for an anticipated building stock of 415 billion m^2 in 2050. Interiors are typically renovated every five years (Property24, 2019) – whether professionally or by means of a *DIY* project – which is much more frequent than the construction of new building stock reaching completion… if ever. This might imply that interior redo's may cumulatively account for more GHG emissions and C&DW than existing buildings and new constructions.

Yes, cities must undeniably modernise and new constructions will surface. However, existing building stock, including *space plan* and *stuff*, should be re-evaluated for potential reuse. Existing and obsolete buildings can be maintained and altered for continued or new use (Plevoets & Van Cleempoel, 2019:i) instead of undergoing demolition.

> *"Each unused or underutilized building that becomes useful means one less need for construction. Therefore, adaptive reuse by itself already represents a sustainable action."*
>
> *– Lemos & Donoso (2023:8)*

3.3 ADOPTION OF EMERGING BUILDING TECHNOLOGIES

Emerging building technologies (EBTs), also referred to as innovative building technologies (IBTs), are avant-garde building methods that differ from current mainstream practices in a particular region. They are in a transitional phase, moving towards wider acceptance and implementation. Identification is based on time, context and inherent value leading to the expansion of current building practices. Examples include building information modelling (BIM), additive manufacturing, robotics, augmented and virtual reality (AR; VR), unmanned aerial vehicles (UAV), autonomous construction vehicles and mass timber (MT) (McCoy & Yeganeh, 2021), as well as artificial intelligence (AI).

EBTs are opening doors to lower the anthropogenic impact on the environment, mitigate climate change, increase productivity, minimise material waste and decarbonise existing buildings.

3.3.1 Opportunities

The construction industry's uptake of new technological advancements is rather slow (Khudzari *et al*., 2023:1), especially in developing countries (Jaafar *et al*., 2024:2). The construction industry heavily relies on human labour, but there is a significant opportunity to boost productivity through technological innovations such as the utilisation of robots, especially in tasks where human labour is dangerous or demanding (Jaafar *et al*., 2024:4). McCoy and Yeganeh (2021:12) refer to single-task robots such as demolition robots which can enhance labour productivity, improve construction quality, increase workplace safety, expand operational methods and minimise material waste. For the purposes of this study, it is noteworthy that a demolition robot could further encourage the demolition of existing buildings, accelerating and facilitating the demolition process while increasing non-recyclable C&DW ending up in landfills. Therefore, it is of vital importance that buildings are designed to facilitate circularity throughout their life cycles, enabling innovative technologies to follow suit. When buildings are designed for disassembly, and with *cradle-to-cradle* materials like MT, demolition robots could rather become *dismantling* robots. Another example includes off-site prefabrication of engineered wooden buildings which can facilitate DfMA and DfD and stimulate the local bioeconomy while expediting the project timeline (by approximately 20% compared to cast-in-place concrete systems according to McCoy & Yeganeh (2021:11), increasing accuracy and improving performance.

When advanced building methods and sustainable materials are not adopted by practitioners, various risks arise.

3.3.2 Risks

Risks are associated with constructing new buildings using purely extractive and carbon-intensive materials like concrete and steel (Belabid *et al*., 2022:7), combined with the standard approach of demolishing obsolete buildings. If conventional construction practices are upheld, the AEC industry will continue to have a negative impact on the environment (Abed *et al*., 2022:2).

Mid- to high-rise buildings are mostly built of concrete and steel (Crawford & Cadorel, 2017:839). The production processes for concrete and steel are highly energy-intensive and generate concerning amounts of GHG emissions (Abed *et al*., 2022:2). Abed *et al.* further highlights that both these materials contribute to 94-95% of the estimated 82-87% of total GHG emissions produced by building materials.

Concrete is currently the most used and commercialised building material in construction due to its strength, durability, freedom of architectural form and affordability (Belabid *et al*., 2022:2; Rodriguez-Morales *et al*., 2024:1). Annual global concrete production amounts to 30 billion tonnes (Monteiro *et al*., 2017:698), requiring more than 4100 million metric tonnes of Portland cement – globally the most common type of general-use cement as a basic ingredient of concrete, mortar, stucco and non-specialty grout (Menchaca-Ballinas & Escalante-Garcia, 2019:1). It is projected that global Portland cement will reach 4692 million metric tonnes in 2050 (Khozin *et al*., 2020:2,3). After the automobile industry and coal-fired power stations, cement is the third largest producer of CO_2 (Crawford & Cadorel, 2017:839), accounting for more than eight per cent of global CO_2 emissions ascribable to anthropogenic activities (Abed *et al*., 2022:2). One tonne of cement produces one tonne of CO_2 (Abed *et al*., 2022:2). One tonne of steel produces 1.85 tonnes of CO_2, responsible for approximately seven to eight per cent of global CO_2 emissions (Abed *et al.*, 2022:2). Crawford and Cadorel (2017:838,839) call attention to the concerning production processes of conventional construction materials like concrete, steel, glass and aluminium which are extractive in nature – contributing to GHG emissions and the consumption of raw materials, energy and water.

Despite significant improvements to the environmental performance of concrete and steel, these materials still produce elevated levels of CO_2 emissions (Trinh & Zhang, 2021:1) and are still manufactured using non-renewable raw materials, leading to the depletion of natural resources (Crawford and Cadorel, 2017:839). To mitigate human-induced environmental damage, Crawford and Cadorel remark that it will eventually be necessary to develop alternative modes of construction, such as cellulose building materials like bamboo or MT, to replace these extractive conventional materials. This is an environmental imperative, given that steel and concrete have consistently outperformed other materials in large-scale construction projects across various criteria, including cost-effectiveness, fire resistance and structural integrity (Crawford & Cadorel, 2017:839).

To alleviate the alarming carbon footprint of concrete and steel production, it is vital to use sustainable material alternatives to achieve a net-zero built environment (Abed *et al*., 2022:2). To tackle the unsustainable nature of current building practices, there is an increasing recognition that buildings should incorporate a significantly greater number of renewable materials (Crawford & Cadorel, 2017:839).

To accelerate the adoption of circular construction practices such as deconstruction, DfMA, DfD and adaptive reuse for a more productive, decarbonised and non-extractive circular economy (CE), a fusion between traditional and emerging building techniques, processes and materials should be promoted.

3.3.3 System Hybridisation

> *Sub-question 4: How can system hybridisation accelerate the adoption of mass timber in the built environment?*

System hybridisation is not merely the adoption of new technological advancements for the sake of keeping up with technological developments. It holds numerous benefits to lower the AEC's environmental impact. Belabid *et al*. (2022:7) stresses that when traditional and modern materials or processes are combined, lifespans of existing buildings are extended as their performance is improved and their carbon footprint is minimised.

A balance should be sought when adopting modern technologies over established ones. System hybridisation, or architectural hybridity, refers to architectural systems (such as construction processes, methods or materials) composed of elements from different origins (Belabid *et al*., 2022:7). Louw's (2021:265-270) understanding of hybridity is uniquely investigated from a Southern perspective. Louw weighed up seminal and more recent definitions to clarify what hybridity in the practice of making or architecture entails. He contextualises hybridity with specific reference to Critical Regionalism and tectonics. A synthesis of these definitions can be derived from his comparisons between the literary works he refers to:

Hybrid architecture goes beyond a collage of different architectural elements and systems. Hybridisation is a design approach that integrates local traditions and global innovations, creating new configurations that reflect both historical significance and contemporary relevance, aiming for an equitable synthesis of global and local elements to promote social, environmental and economic sustainability. Global materials, forms, construction techniques and ornamentation should not be reinforced at the expense of the local and vice versa. Both realms should have similar weighting, especially when the North represents the global and the South the local. Hybridity is the union of technology and culture.

Interiors might significantly contribute to the reduction of the construction sector's carbon footprint by adopting sustainable material alternatives to concrete and steel, such as engineered timber as structural material for internal use (*space plan* and *stuff*) in adaptive reuse projects. The utilisation of system hybridisation across AEC departments will allow for multi-disciplinary involvement and skills (architects, interior designers and engineers) which may also expedite the regional recognition and adoption of MT in the South African context.

3.4 MASS ENGINEERED TIMBER

Mass timber (MT) is large-scale structural engineered wood products (Abed *et al.*, 2022:2) with a high strength-to-weight ratio (Trinh & Zhang, 2021:21). It is manufactured by binding wooden boards together with adhesives to create composite panels of diverse sizes (McCoy & Yeganeh, 2021:11). As illustrated in Figure 3, products include cross-laminated timber (CLT), glue-laminated timber (Glulam), nail laminated timber (NLT), dowel laminated timber (DLT), laminated stand lumber (LSL), laminated veneer lumber (LVL), parallel strand lumber (PSL) and mass plywood panels (MPP) (Abed *et al.*, 2022:2,3; Stenson *et al.*, 2019:1). CLT and Glulam are currently attracting the most publicity in engineered timber research. CLT combines the advantages of wood construction with those of steel and concrete, offering strength while reducing material usage and labour costs (McCoy & Yeganeh, 2021:11). It sequesters carbon, resulting in an environmentally sustainable alternative to traditional, extractive construction materials such as steel and concrete (Abed *et al.*, 2022:2,19; Crawford & Cadorel, 2017:839).

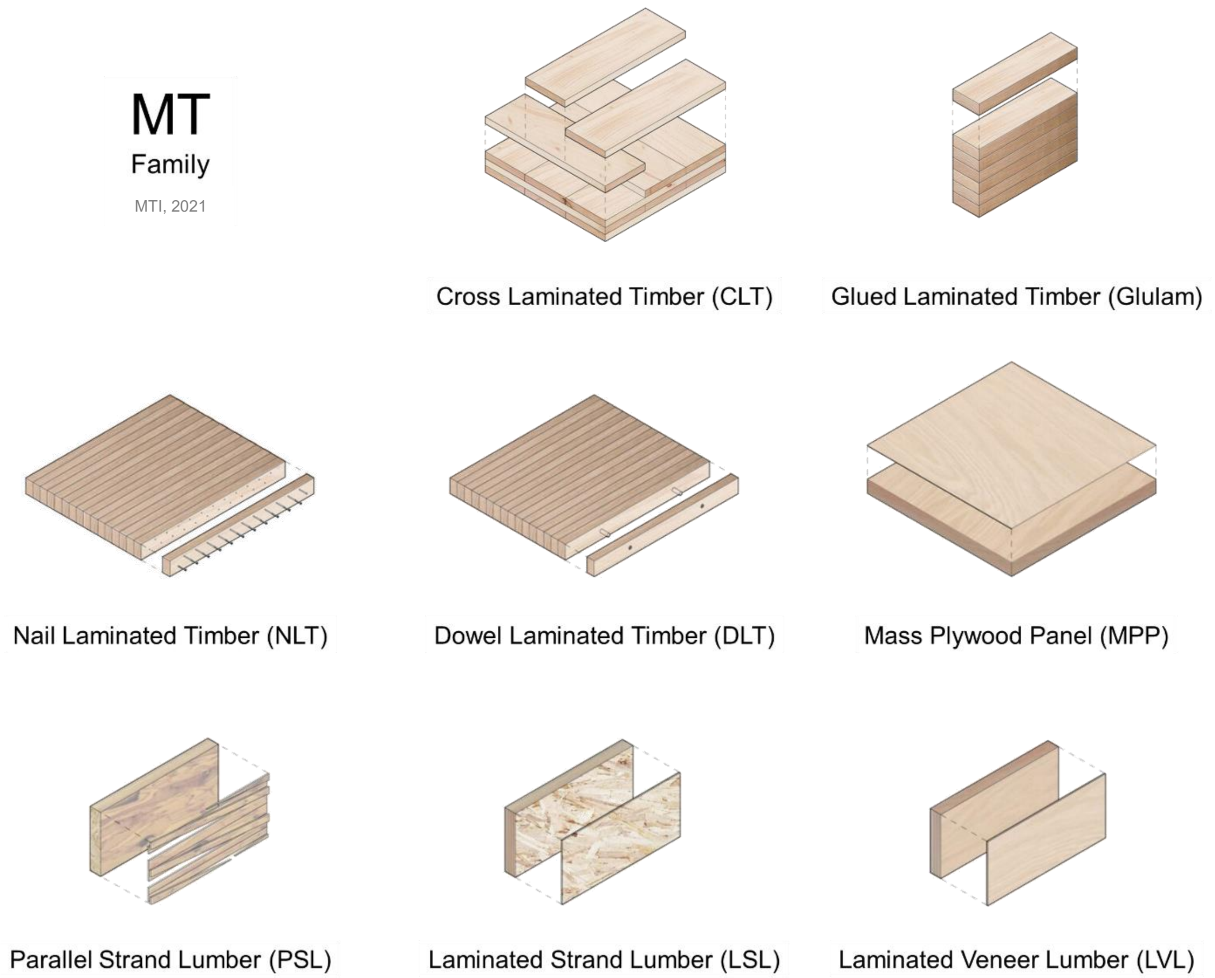

Figure 3: Mass timber products (Adapted from MTI, 2021)

3.4.1 Environmental Impact

Multiple factors should be considered to fully comprehend the potential relief of MT on the environment. Greenhouse gas (GHG) emissions, end-of-life scenarios and forestry management will be discussed. It is important to note that these factors are not limited to the previous mentioned as several others influence the sustainability of MT, including installation, use, maintenance, repair, replacement, refurbishment and adhesives used.

a. Greenhouse Gas Emissions

While conventional materials like concrete and steel emit significant amounts of CO_2 during production, trees naturally absorb about two tonnes of CO_2 from the atmosphere to produce one tonne of their own dry mass (Abed *et al*., 2022:7). By weight, dry wood contains approximately 50% carbon, indicating that MT buildings store significant amounts of carbon (Harte, 2017:122). Therefore, as Abed *et al*. concludes, when MT products are used in buildings, the carbon sequestered during production remains stored throughout their lifespan. This is important to consider during the material selection of interiors, whether new or renovated. MT can significantly contribute to the reduction of embodied, construction and operational emissions (Abed *et al*., 2022:7) as well as the decarbonisation of existing buildings when specified during deep renovations (LMN, 2022). In addition to this, Abed *et al*. states that MT can potentially reduce construction and operational emissions of buildings. MT is typically manufactured by means of off-site prefabrication, minimising noise and dust pollution as well as site waste, due to manageable on-site assembly and limited machinery required during assembly (Harte, 2017:122). Interiors might significantly benefit from these feasible processes together with on-site assembly being mainly dry construction and not wet construction like concrete or brick and mortar. Prefabricated timber can significantly reduce transport-generated emissions when compared to conventional materials (Abed *et al*., 2022:7).

According to McCoy and Yeganeh (2021:11), CLT's environmental benefits include the reduction in carbon emissions and the use of renewable construction materials. Compared to reinforced concrete, MT production requires thirty times less water per cubic meter (Abed *et al*., 2022:7). McCoy and Yeganeh further states that CO_2 emissions can be reduced by 15-20% when replacing steel with CLT. Timber is one of the few renewable building materials that not only reduces carbon emissions but also generates negative emissions through carbon sequestration (Abed *et al*., 2022:2). Browning *et al*. (2022:4) adds to this by stating that the MT elements of a building could offset surrounding materials' carbon footprint, showing promise for internal use.

Even though MT has a high level of airtightness to improve building performance and energy efficiency, the impact of MT's natural airtight qualities on indoor air quality (IAQ) has been questioned in relation to human health (Kremer, 2023:6), as current research is lacking the quantification thereof. Kremer highlights that it might just encourage the construction industry's transition from traditional materials towards MT construction, if proved to be beneficial.

b. End of Life

Even though carbon sequestered during production remains stored throughout the lifespan of MT products, it releases the stored CO_2 back into the environment when burnt or decomposed (Abed *et al*., 2022:9). Therefore, to ensure that MT buildings are truly sustainable, it is crucial to maximise their environmental benefits through material recovery and recycling. Once disassembled, the MT products can be repurposed (the preferred option), combusted as wood fuel for biomass energy conversion (generating a fossil fuel offset) or disposed to landfill (the least desirable option)

(Ramage *et al*., 2017:352). To promote the reuse of MT (either used for similar functions or downcycled), panel adaptation for secondary use is a viable option (Abed *et al*., 2022:9) to ensure that the longevity of the material is restored at all stages of the value chain, creating a closed loop to achieve a CE. Lower-grade timber can be repurposed for non-structural applications (Abed *et al*., 2022:9), enhancing the opportunity for interiors to utilise and minimise material waste, prolong the service lifespan of the timber and store the sequestered carbon for a longer period, decreasing the demand for new wood and reducing production emissions (Ramage *et al*., 2017:351). Interiors thus has a remarkable role in the circularity of MT to fulfil its cradle-to-cradle attributes. Designed by William McDonough + Partners, the Apex Plaza in Charlottesville, Virginia, is a 17373 square meter mixed-use building constructed with exposed MT and materials with low embodied carbon. The MT used is FSC-certified (Forest Stewardship Council) and sourced from Nordic Structures in Quebec. Nordic offers the first cradle-to-cradle certified MT products on the market in North America, meeting criteria for material health, material reutilisation, renewable energy and carbon management, water stewardship and social fairness (Alter, 2022).

c. (Un)sustainable Forestry Management

Ramage *et al*. (2017:339) reassures that regulated timber provenance ensures sustainable forest management, alleviating concerns regarding deforestation. However, this concern should be raised and considered as unsustainable forestry harvesting is a reality and should be avoided (Abed *et al*., 2022:8). Timber can become a non-renewable resource when depleted or sourced from poorly managed forests. Sustainable forest verification and certification schemes include organisations like the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). Detailed research on the full life cycle assessment (LCA) of MT products and buildings are currently lacking to assess the material's full impact per life cycle stage during its service lifetime, jeopardising MT's current environmental benefits to concrete and steel as it might render as unreliable, prohibiting confidence in the use of MT (Crawford & Cadorel, 2017:845).

d. Conclusion

The construction industry's highly risk-averse attitude towards the adoption of innovative building methods requires substantial research to validate that these disruptive technologies can meet engineering requirements (Abed *et al*., 2022:2-3). Despite the numerous social, environmental and economic benefits that MT presents to the built environment, the AEC industry continues to extensively use non-circular, non-renewable and extractive materials, like reinforced concrete and steel. Abed *et al*. explains that the slow uptake of MT is largely due to the current lack in knowledge and uncertainty surrounding the risks associated with MT practices (Abed *et al*., 2022:2-3).

3.4.2 (Un)certainty and (Un)familiarity

Timber can trigger both positive and negative perceptions (Frunzio *et al*., 2023:133), which is why it is important to inform professionals and practitioners on all aspects and benefits of MT architecture to guide informed decision-making during the selection of materials for both external and internal applications.

People (particularly clients and users) base their choice of preference on social, cultural, economic and psychological aspects in addition to aesthetics, well-being and respect for the environment (Frunzio *et al*., 2023:134). An end-user's first response to a material is emotional, unlike industry specialists whose responses are primarily technical. The end-user, who will ultimately inhabit the space, is usually the most uninformed party – familiar with only the recognised brick-and-mortar status quo. By focusing marketing efforts solely on companies concerned with the technical aspects and demand for the material, clients and end-users remain unaware of new technological advancements and their environmental and health benefits. Including end-users in the marketing of MT can considerably assist in increasing the demand of wood by eliminating the misconceptions currently associated with the material.

Thousands of years ago, timber was used as primary source for construction (Martin & Lopez, 2023:1). However, timber was gradually abandoned over the years as main construction material due to wood's susceptibility to rot, burn and decay including its lack in structural strength (Macnamara, 2020). These *then* reasonable concerns resulted in the replacement of wood with modern-day traditional materials such as masonry, steel, glass and concrete. Today, engineered wood is overcoming these *now* misconceptions regarding wood. Over the years, these concerns also evoked unusual misperceptions about wood… *Knock-knock, wood's there*? Superstitions surrounding the quality of wood range from all types of peculiarity. People tend to knock on wood to apparently "hear" the quality of the wood.

However limited, research on consumer viewpoints toward timber as a construction material is expanding. "Soft" factors like aesthetics, well-being and environmental respect are important when evaluating timber spaces (Frunzio *et al*., 2023:133). People's expectations and experiences – an important determinant in interior architecture – should not be discarded to the background but rather understood to drive bioeconomy-driven business strategies (Frunzio *et al*., 2023:130). Frunzio *et al.* further states that consumer acceptance of new bio-based products plays a key role in the transition towards the forest bioeconomy. The youth appreciate the aesthetics and comfortable environment of wooden interiors but simultaneously question its environmental sustainability and cost-effectiveness (Frunzio *et al*., 2023:134). The familiarity of using wood can contribute to a successful bioeconomy in the urban context for both young and environmentally conscious consumers (Frunzio *et al.*, 2023:134).

a. Regional Relevance

MT architecture is relatively new to the South African built environment, considering that less than one per cent of new houses are built with timber as primary construction material (Southey, 2024). However, CLT received a SANS code which permits the use of MT in construction without the requirement of special conditions (WoodBiz Africa, 2023:6). The supply of CLT is currently limited to manufacturers XLAM South Africa and Mass Timber Technologies (MTT). MT, specifically CLT and Glulam, proposes a sustainable alternative to extractive construction materials like masonry, concrete and steel which are still the preferred modus operandi in the South African construction industry.

Given its unfamiliarity in the southern hemisphere, innovative methods can be employed to introduce MT to the South African workforce and end-user. As discussed in section *3.3.3 System Hybridisation*, material hybridity can accelerate adoption of MT through the adaptive reuse of existing buildings when adding new construction (that is MT). Adaptive reuse acts as a foundation for system hybridisation. Herdt and Jonkman (2023:2-3) mentions that local resistance to climate mitigation projects might arise when it seems out of place in terms of place identity and character. Therefore, it is important to find a middle ground between the existing South African building typologies and projects involving MT additions in the South African built environment where MT might seem incongruous. System hybridity can function as negotiator between the two.

Different-scaled projects can facilitate different degrees of visual and physical interaction with the material (Figure 4), enhancing familiarity and enabling skills transfer to professionals, specialists and builders. It can range from small Glulam sculptures to temporary CLT pavilions to residential extensions to mass timber skyscrapers... Utilising system hybridity and different scales of application will allow for multi-disciplinary involvement and skills (architects, interior designers and engineers) which may also expedite the recognition and adoption of MT on home soil.

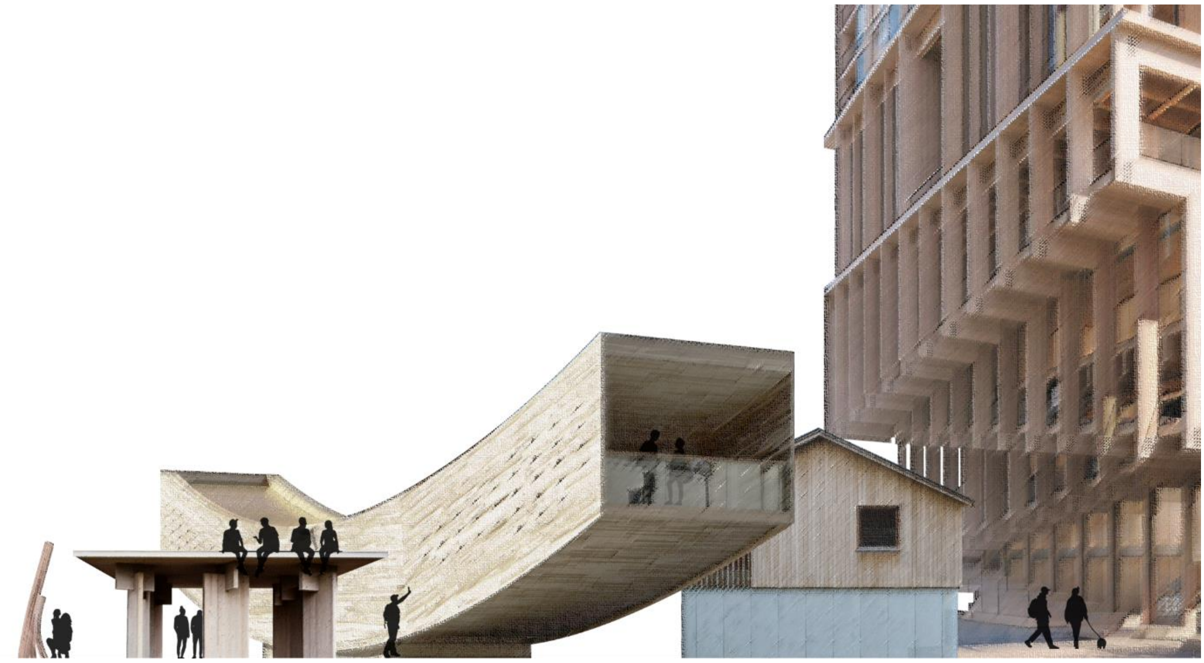

Figure 4: Multi-scalar applications of MT (Collage by Author, 2024).

MT shows promise towards a more productive, decarbonised and non-extractive circular economy (CE). By integrating this technological advancement into existing construction practices, a hybrid system is created which may motivate the use of MT to reduce the construction sector's environmental impact and to stimulate the local bioeconomy.

3.4.3 Well-being and Health

a. Well-being

According to Kremer (2023:5,6), research in MT construction currently lacks knowledge concerning the quantification and long-term effects of biophilia on human health over extended periods.

> *"If you look up from this [dissertation], what you almost certainly see is the inside of a building. Glance out a window and the main thing you notice is the outside of another building."*
>
> *– Brand (1994:2)*

As previously mentioned, people spend their time predominantly indoors. Janisch (2018:9) notes that people seek nature as an escape or retreat, rather than the urbanscape. A simple, yet complex relationship between the built environment, people and nature exists. Reitmann (2021:5) states that phenomenological philosophy, biomimicry principles and biophilic theories substantiate that this relationship can sustainably improve the health and well-being of both people and the natural environment.

The term, biophilia, was coined by renowned psychologist Erich Fromm, but it was further developed by Harvard biologist Edward Wilson through his book, *Biophilia*, in which he describes the term as "… *the innate tendency to focus on life and lifelike processes*" (Wilson, 1984:1). Reitmann (2021:80) refers to biophilia as the innate human tendency to seek connections with nature to contribute to their health and well-being. When spaces are directly or indirectly connected to nature, an individual's health and well-being improves (Konchev, 2021:8).

Jarden and Roache (2023:3) define well-being as a "… sense of tranquillity resulting from inner peace and harmonious interactions with the external environment" which is largely overlooked in literature related to well-being. Well-being can be experienced subjectively or objectively. Petermans and Pohlmeyer (2014:209) defines subjective well-being (SWB) as an individual's personal-reported evaluations of their lives. The classic definition of SWB was defined by Diener (2000:34) as: "… people's cognitive and affective evaluations of their lives". Petermans and Pohlmeyer (2014:208) define objective well-being (OWB) as the extent to which external conditions, which can be objectively assessed, are conducive to a high quality of life.

To put the impact of urban densification on current housing, living conditions and quality of life into perspective, the National Housing Code (NHC) 2009 defines sufficient housing as a space encompassing around $40m^2$ of gross floor area (Naidoo *et al*. 2023). The average household size in South Africa is 3.4 people per household as calculated in 2023 (ArcGIS, 2023). As per SANS 10400 Part C, the minimum required height of a standard habitable space is 2.4m (SANS, 2016:6). Therefore, the national adequate housing building volume equals to $28m^3$ per capita (Figure 5):

$$\text{Adequate housing building volume per person} = \frac{(40\text{m}^2 \text{ housing area})(2.4\text{m house height})}{3.4}$$

$$= 28.24\text{m}^3 \text{ per capita}$$

According to Naidoo *et al*. (2023), the lack of adequate housing in Gauteng has led to dire living conditions with approximately 49% of households restricted to only $10m^3$ of space to dwell in (equivalent to a space of 2m x 2m x 2.5m), as seen in Figure 6.

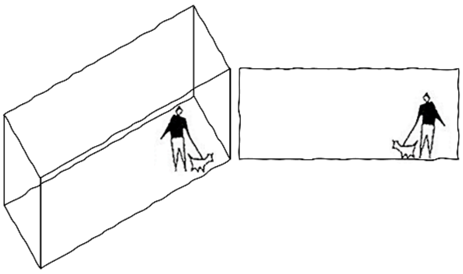

Figure 5:
A visual representation of a 28m^3 space, equivalent to 2m x 6m x 2.4m. (Author, 2024)

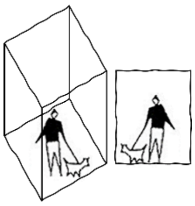

Figure 6:
A visual representation of a 10m^3 space, equivalent to 2m x 2m x 2.5m. (Author, 2024)

With the current rise in urbanisation and urban densification, land availability becomes increasingly minimal with limited dwelling space for new, good and healthy design interventions. With remote working options on the rise, especially after the COVID-19 pandemic, homes are simultaneously serving as residences, offices and leisure spaces. Designers are challenged to improve these boxed-in-all-purpose homes by softening the boundaries between indoors and outdoors through innovative methods, such as biophilic design principles. Biophilic design strengthens these indoor-outdoor connections through direct, indirect or spatial design elements (Reitmann, 2021:80), resulting in lower stress levels, improved cognitive performance, enhanced moods and greater preference for timber spaces (Browning *et al*., 2022:4). Studies found that healing outcomes among hospital patients were better when they had a view to nature (Browning *et al*., 2022:4). These benefits suggest that even a space of 10m^3 can be improved using natural materials in interiors to blur the (in)direct boundaries between outside and inside, improving well-being.

The use of wood triggers a biophilic response where the brain subconsciously connects the material to trees, trees to nature and nature to life (Browning *et al*., 2022:10), as implied in Figure 7. The application of wood improves the relation between people and places, as timber is perceived as warm and natural (Frunzio *et al*., 2023:130). Frunzio *et al.* states that timber as an interior finish, optimistically influence the perceived comfort of a space. Unlike synthetic materials, natural materials like wood exhibits its honest characteristics, age and history. *Let timber be timber!*

Figure 7: (In)tangibility of timber (Collage by Author, 2024; Left photo by LoloStock; Right photo by Fabrizio Verrecchia)

Interesting studies were undertaken in Japan and Korea, investigating the concept of *Shinrin-yoku*, or forest bathing (Browning *et al*., 2022:6). Forest bathing refers to guided walks through forests, leading to a reduction in the stress hormone, cortisol, lasting for hours after the walk. Can internal applications of timber evoke similar lasting experiences? The genius-loci of a building can significantly affect its inhabitants, making them feel either tense and depressed or comfortable and happy (Janisch, 2018:9). Janisch concludes that if our buildings were more tranquil and inspiring like the natural environment, people's daily well-being and experiences would improve.

"I firmly believe that nature brings solace in all troubles."

– Anne Frank

Interior architecture and interior spaces contribute to the health and well-being of people by means of biophilic design.

b. Health

Research on well-being, post-occupancy evaluation behaviour and IAQ in conjunction with MT's natural airtight qualities might encourage the shift from modern-day traditional materials to MT construction (Kremer, 2023:6), if research provides evidence that is satisfactory.

Given the fact that the indoor environment shapes most of our lives, interiors play a vital role in human health, well-being and environmental sustainability. Concentrations of indoor carbon dioxide (CO_2), indoor air pollutants and multiple volatile organic compounds (VOCs) are consistently higher indoors than outdoors with air pollutants twice as high (Irga *et al*., 2024:1) and VOCs up to ten times higher indoors than outdoors (Gonzalez-Martín *et al*., 2024:1). Indoor air quality (IAQ) is largely affected by air pollution. This raises the question whether MT can reduce these indoor concentrations of polluting emissions.

3.5 ADAPTIVE REUSE AS IMPLEMENTATION TOOL

This section builds on sections *3.3.3 System Hybridisation* and *3.4.2 (Un)certainty and (Un)familiarity*.

3.5.1 Adaptive Reuse Defined

The Burra Charter (2013:7) simply defines adaptive reuse as "adaptation for a new use". Adaptation describes any spatial change to suit an existing or proposed use. It can include additions, new services, increased safety and security measures or a new function. In the case of heritage buildings, alternative methods should be considered prior to adaptive reuse, which is acceptable where minimal impact is ensured. Stone (2019:4) states that the term "… implies a change of function, of a building whose previous use is now obsolete and therefore is changed to accommodate a new function, with new occupiers with different needs and priorities." A modern definition of the term is provided by Pérez (2024:53) which goes beyond the past strategies of erasure and overwriting:

> *"The term nowadays is redefined as transforming an unused or underused building into one that serves a new use. This not only includes the reuse of existing structures, but exponentially expands the definition to include other tangible and intangible elements such as materials, transformative interventions, continuation of cultural phenomena through built infrastructure, connections across the fabric of time and space and the preservation of memory."*
>
> *– Pérez, 2024:53*

3.5.2 Adaptive Reuse and the Social Dimension

It is evident that the user plays a remarkable role in the built environment, influencing pertinent design decisions. Interior architecture revolves around the user, hence known as human-centered design (HCD). This study proposes a *seventh S* to Stewart Brand's six S's, namely the *social dimension* or *society* (Figure 8) which refers to the human aspect present in the built and natural environment. Even though Brand briefly proposes human *souls* as the seventh S (Brand, 1994:17), it is not frequently referred to as part of his layers of change. Brand (1994:17) does however mention how the architectural layers relate to people. *Stuff* interacts directly with individuals (*social dimension*), while *space plan* shapes the home of the tenant or user (*social dimension*). The landlord (*social dimension*) is responsible for the maintenance of *services*. The *skin* acts as entry point and interface between the public (*social dimension*) and the building. Both *structure* and *site* are governed by decisions taken by the community (*social dimension*) through the city or county, determining the building footprint and land restrictions. Human beings are present in all six layers, influencing alterations and adaptability. Therefore, the *site*, *structure*, *skin*, *services*, *space plan* and *stuff* are centered around the *social dimension* of the built and natural environment. Architects and designer can design spaces with specific functions and zones in mind, but the user will adapt it to their preferences and changing needs. For buildings to remain functional and useful, buildings should respond to and adapt as generational needs change over time. Otherwise, the building will become obsolete and will not stand the test of time.

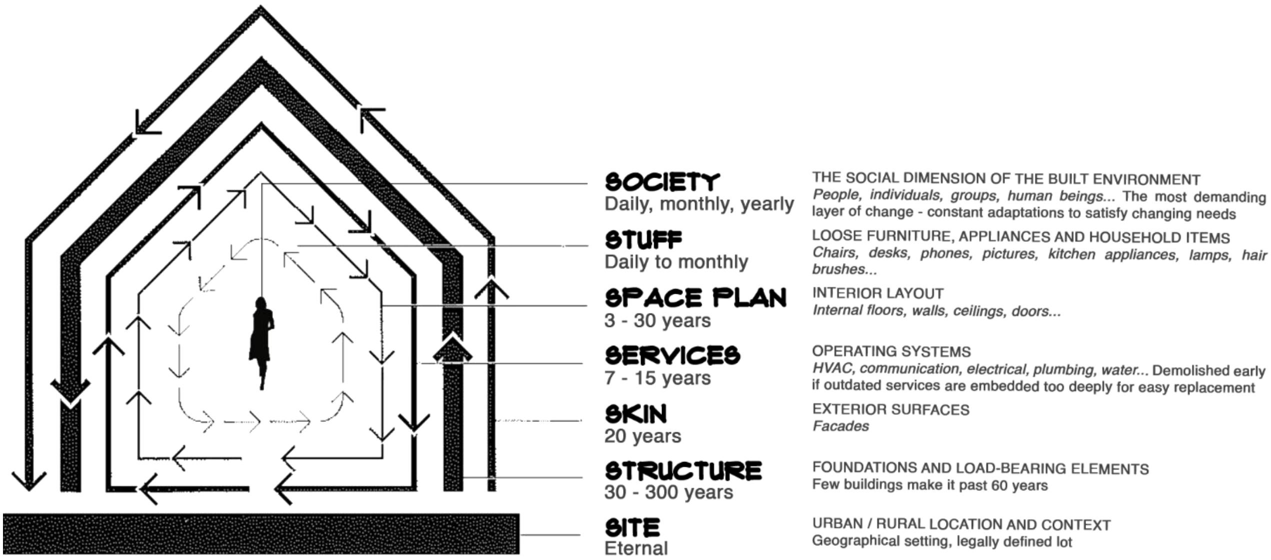

Figure 8: Seventh shearing layer of change and longevity (Adapted from Brand, 1994:13).

3.5.3 Adaptive Reuse Strategies

Sub-question 3: How can adaptive reuse strategies facilitate the integration of mass timber in building interiors?

Brooker and Stone (2018:6) identified three pertinent adaptive reuse strategies in which most adaptation projects fall: *installation*, *insertion* and *intervention* (Figures 8, 9, 10, 11 and 12). Immense potential lies in these strategies for introducing MT products to interior spaces. The following three definitions will be defined with existing building stock as the *old* and MT as the *new*. *Installation* is the most temporary in nature. The existing and new exist independently (Brooker & Stone, 2018:6). The MT design is placed within the perimeters of the existing building, which may be influenced by the existing. The fit, however, is not exact. Thus, when removed, the existing building would return to its original state (Brooker & Stone, 2018:6). If the MT elements are designed to fit, its dimensions are entirely dictated by the old when placed into the confines of the existing building (Brooker & Stone, 2018:6). This strategy is referred to as *insertion*, which is semi-permanent. The third principle is the most permanent of the three. *Intervention* is when the MT design is completely intertwined with the old – both can no longer exist independently (Brooker & Stone, 2018:6).

Figure 9: Wohnungsfrage (Ferrari, 2015)

Figure 10: Predikherenklooster (Paula, 2020)

Figure 11: Reconversion Church in Lampernisse (Divisare, 2022)

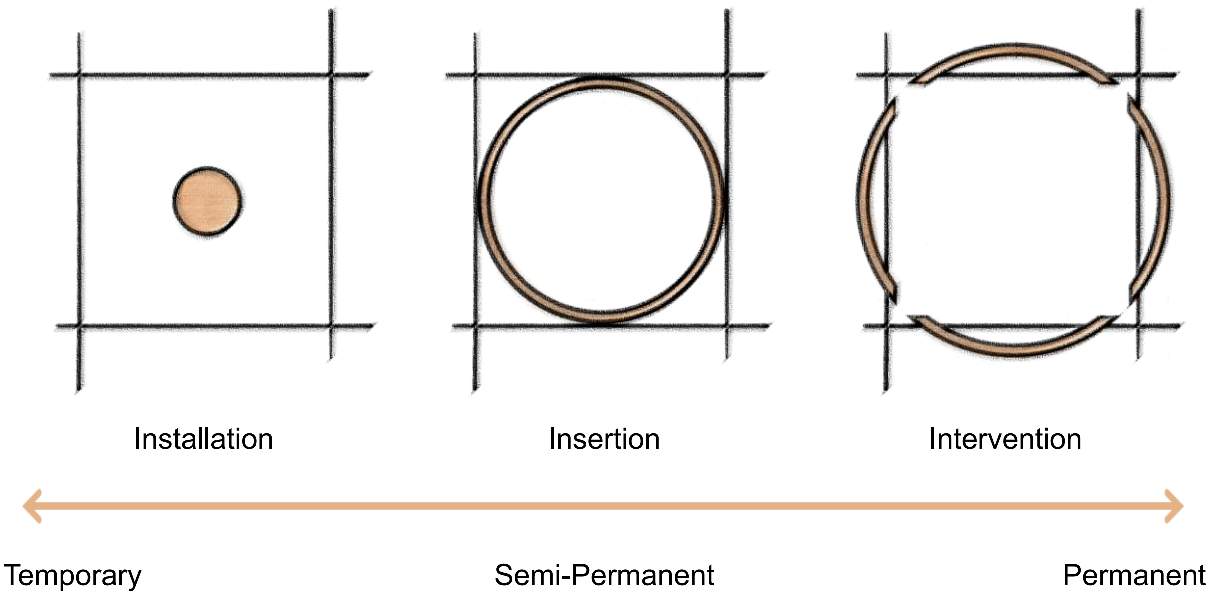

Figure 12: Adaptive reuse strategies (Adapted from Myburgh, 2010:104)

> "*As mounting demographic, economic, and ecological challenges limit opportunities for new construction, architects increasingly focus on transforming and adapting existing buildings… to rethink and redesign existing buildings – a skill that is becoming more and more important.*"
>
> *– Plevoets and Van Cleempoel (2019:i)*

3.5.4 Multi-scalar Adaptive Reuse

It is evident that the reuse of existing building stock should take priority over demolition, where possible. In this study, existing building stock focuses on buildings that has already been built and completed, but with a lack of proper use and function or a need for renovation. It includes housing, urban heritage and buildings in the general sense whether in use or vacant.

Buildings can be adaptively reused as a whole or in parts. Adaptive reuse of building stock can imply that the reuse of buildings occurs on a micro (material), meso (architectural) and macro (urban) scale.

a. Micro – Buildings as Material Depots

Micro could refer to the concept of urban mining, which is the reuse of building materials (Ruben *et al*., 2020:223). According to Aldebei & Dombi (2021:6), the recovery of materials surpasses the process of mining landfills. By designing for disassembly (DfD), the immediate reuse of materials could facilitate deconstruction initiatives to support the construction and demolition sectors' transition to a CE. DfD can promote sustainable interior renovations of structural and non-structural elements. Digital deconstruction (DDC) is possible through technological solutions like RBIM (Reversible Building Information Modelling), a tool that assesses the reversibility potential of buildings in their entirety – thus, buildings as material banks. A colour-coded circularity meter and 3D viewer (Figure 13) are used to determine the reuse potential, either direct reuse, reuse by repair or recycling, and circularity of materials within a building (Bergstra, 2023). RBIM provides quantities of potential carbon emissions captured for on-site reuse, reuse, recycle and waste if an existing building was to be deconstructed for reuse – minimising waste.

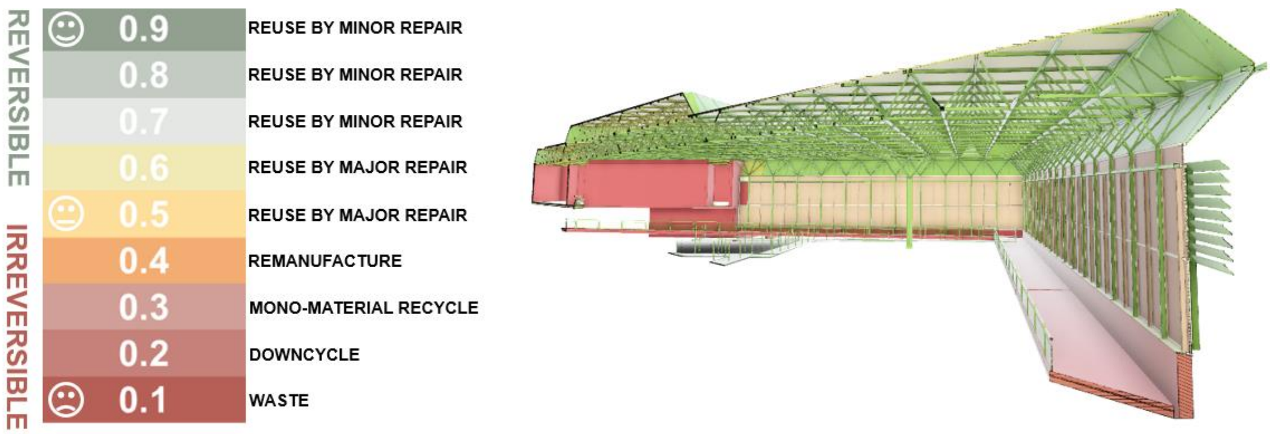

Figure 13: Application of RBIM on an existing building (Adapted from Bergstra, 2023; Cilliers, 2023)

b. Meso – Buildings as Canvases

Meso can involve utilising adaptive reuse strategies to repurpose a building in its entirety. In adaptive reuse projects, buildings can be seen as *blank canvases*, others as *black canvases*. What both have in common, is a canvas as base – the building shell or *structure*. However, each canvas remains as is – whether rectangular, square or circular; new, old or torn. Adaptive reuse projects, specifically in interior architecture, will always have to work within the boundaries of the existing building and context – a point of departure.

To prevent a blank canvas from remaining blank, well… one should get creative and start painting! The potential lies within the emptiness of the space. Blank canvases allow interior architects to reuse the space without additional constraints other than the existing footprint and context – the base. Adaptations can be bold and daring, without being too precious about conserving the original state of the building. This typically involves the introduction of a new programme and function – *tabula rasa!*

Not all adaptive reuse projects have the freedom to "start over". Black canvases require a more cautious approach towards the existing traces of paint. On the one hand, the base might be torn but of significant heritage value, which should be preserved and conserved as much as possible. However, adaptations should be made to prevent the canvas from being disposed of. In the case where urban heritage needs saviour to avoid demolition, adaptations can be made to prevent the building from becoming obsolete. This can involve adaptations for either a new or continued use in programme. On the other hand, the painting on the canvas might be nearly complete, but requires something extra. Perhaps embroidery mending the torn canvas while dangling outside the lines? Adaptive reuse projects are not limited to the interior of the building's perimeters. A project can add an extension to the existing building, whether heritage or not, acting as foundation for the new.

Mass Timber Technologies (MTT), a timber prefabrication company specialising in the manufacture and supply of MT products in Johannesburg, South Africa, is introducing MT to the South African built environment. House Taylor (Figure 14) is a $50m^2$ first-floor addition to an existing residence in Johannesburg. The CLT addition was placed on top without the need to reinforce the existing building (MTT, 2022). The volume of timber amounted to $17m^3$, capturing 17 tonnes of CO_2 emissions (MTT, 2022). House Taylor is a regional prototype of a low-impact, high-value approach to adaptive reuse with CLT.

Figure 14: House Taylor, CLT addition (MTT, 2023)

c. Macro – Buildings as Cities

Finally, one can envision that on a macro scale, a whole city can be reused when the lifespan of its existing building stock is prolonged.

4. RESEARCH FRAMEWORK

This study investigates the potential that mass engineered timber has to offer the built environment to promote system hybridisation within interiors to decarbonise existing building stock. As illustrated in Figure 15, the study was conducted in the form of an IMRAD report, within a "basic" research context, referring to theory-driven research in the academia environment to improve our understanding of real-world problems faced by architects in industry and practice (Du Toit, 2021:5). Both quantitative and qualitative research methodologies were combined to solve a particular, real-world research problem within a pragmatic research paradigm (Du Toit, 2021:12).

However limited, quantitative data captures the potential carbon footprint relief of cyclical renovations by integrating MT into existing buildings. It will be discussed by analysing case studies and comparing numerical data of multiple materials' GHG emissions. Quantitative data represents the impact of MT on the health and well-being of the social dimension of the built environment, namely its users. Desktop studies were undertaken as the predominate method of investigation.

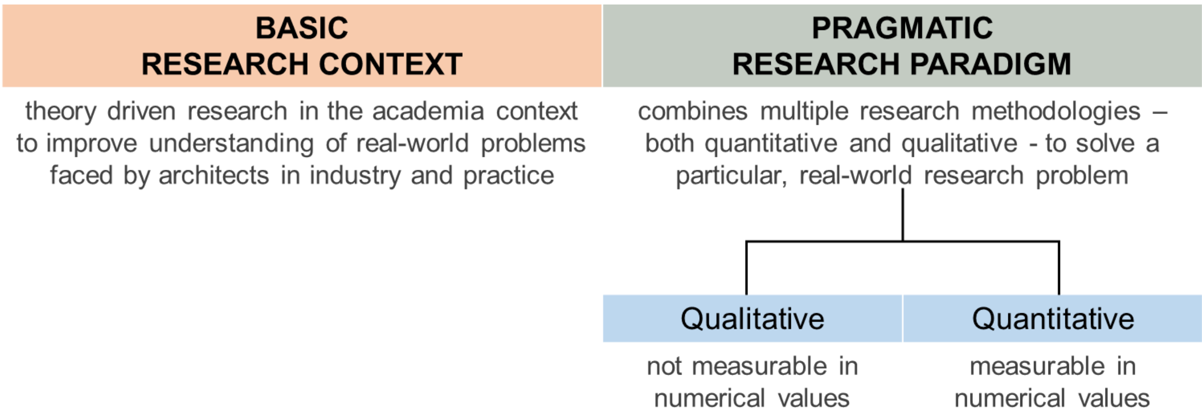

Figure 15: Research framework (Adapted from Cilliers, 2023)

5. METHODOLOGY

Multiple sources of literature were investigated primarily through a desktop study. An iterative process of elimination clarified the research focus and statement. The broader impact of MT on the built environment was investigated to formulate possible applications for regional relevance. At first, the search output resulted in a limited amount of relevant peer-reviewed literature. However, as the research progressed, refined key terminology improved search results on platforms like ResearchGate, ScienceDirect, Google Scholar, Academia and the University of Pretoria's library databases. Bibliographies of literature works proved to be useful to attain additional research resources.

Company reports, conference papers and newspaper articles were included to a limited extent for specific and the latest statistical data where peer-reviewed literature lacked the relevant content. Boolean operators, used in conjunction with search filters, narrowed down results further to more recent publications of the last five to ten years. Older publications were used in the case of limited statistical data and for comparisons between seminal concepts or definitions. Only English articles were sourced. Artificially Intelligent (AI) Natural Language Processing Tools (NLPT), such as ChatGPT, were used to rephrase sentences and improve sentence structures, grammar and spelling.

This methodological approach identified multiple gaps in current research, specifically regarding a lack of information of the environmental impact of cyclical renovations and material application. Case studies and precedents specifically addressing the environmental impact of MT in interiors were limited to professional opinions based on companies' own studies on relevant products.

6. RESULTS

The following case study, conducted by LMN Architects, and embodied carbon quantities were analysed to provide possible answers for sub-questions 1 and 2 as stated in section *2.3 Research Questions*. It is important to note that companies undertook these case studies to analyse their own product's performance, which may include bias. It is however important to look at these quantified estimates to visualise the potential impact that interiors have on the built and natural environment. This realisation should encourage the development of truly "green" frameworks that can mitigate the negative impact of interiors.

The findings were analysed with a focus on the interior architectural layers of Steward Brand's six shearing layers of change and longevity: *space plan* and *stuff* (Brand, 1994:14-22), together with the proposed 7th S, namely the *social dimension*.

6.1 EXTERNAL CASE STUDY 1: ENVIRONMENTAL IMPACT OF CYCLICAL RENOVATIONS OF INTERIORS LMN ARCHITECTS, 2022

LMN architects conducted a case study on their office (Figure 16) to analyse the possible impact of interiors on whole-building embodied carbon estimates. LMN's office is located in the Norton Building in Seattle, Washington, United States. The study commenced early 2019, with the aim to quantify the total embodied carbon footprint of the office over its entire lifespan, specifically paying attention to the cyclical renovations that occurred during this period. The Norton Building opened in 1959 and the office in 1984. All renovations that took place since the office opened, formed part of the data analysis. The study was extended to 1959 to provide a context of a whole building life cycle spanning across 60 years, since the Norton Building opened. The study was based on LMN's first-hand knowledge of materials and furniture, fixtures and equipment (FF&E) quantities specified for the office's latest renovation that occurred during 2013 to 2015.

Figure 16: Interior of LMN architects' office (LMN, 2022)

6.1.1 Context Scope

The Carbon Leadership Forum's (CLF) tenant improvement life cycle assessment (TI LCA) was used as a template to process the data gathered. Thus, input data may have been limited to CLF's available options when data override was not possible. The TI LCA tool requires information surrounding spatial improvements and EPDs (Environmental Product Declarations). EPDs are transparency labels which show the Global Warming Potential (GWP, expressed in kg-CO_2e) of finishing material products (LMN, 2022). They provide important quantifiable carbon data, enabling the comparison of the carbon impact per product to promote informed decision-making processes related to low carbon design (LMN, 2022).

Figure 17 provides an overview of the availability of EPDs for typical products and materials used in a building's *structure*, *skin* (envelope), *space plan* and *stuff* (interior renovations). The specified quantities were based on LMN's own 2013-2015 renovation. Surprisingly, the *space plan* and *stuff* account for most of the specifications (up to 10 and 3.3 times higher than the *structure* and *skin* respectively) but have the least available EPD information.

How many materials are you specifying?

	Number of Products/Materials on a Typical Project		EPD availability
Structure	**<5**	Steel, Concrete, Wood, Fireproofing.	widely available, except for wood products
Envelope	**<15**	Cladding, Insulation, Studs, Air and Water Barriers, Supports, Windows and Frames, flashing, sealants	major categories available for high volume items
Interior Renovations	**>50**	Drywall, studs, ceilings, wallcoverings, tiles, carpeting, base, trim, doors, hardware, glazing, paint, fixtures, desks, chairs, rugs, tables, equipment, bathroom partitions, dispensers, shelving, lighting, ductwork, plumbing, and electrical distribution, A/V components and wiring, more.	many categories have few or no EPDs available. Products change regularly, most have small total buys per project, and many products are made of many materials.

Figure 17: Availability of EPDs (LMN, 2022)

LMN determined that the office renovations thus far, each of different complexity, included three major office renovations (1995, 2000 and 2013), two additional partial floor renovations (1997 and 2015), one glazing replacement (2000) and one bathroom remodel in 2009. Additional and temporary remodelling that accommodated displaced employees during the major renovations were excluded. Specifications, floor plans, wall elevations and furniture elevations assisted in assessing the scope of each renovation. Note that assumptions were necessary in some cases due to the lack of specific information, such as the thickness of internal glass replaced, cabinetry details and when reconfigurable metal partitions were removed.

The *structure*, *skin*, *space plan* and *stuff* were included in the study. The *structure* and *skin* are made up of steel columns with pre-stressed concrete beams. The concrete core consists partially of concrete masonry units (CMU). *Space plan* and *stuff* comprised of products such as ceilings, acoustic wall panels, partitions, internal glazing, floors, carpets, paint, doors, custom display tables and furniture. Product-specific EPDs were used as far as possible. When it was not available, industry average EPDs were used or comparisons were made between equivalent products with EPDs. Due to a lack of EPD-specific data available at the time of the study, items like window treatments, wall bases, various ancillary furniture and trims were not assessed. *Services* like mechanical, electrical and plumbing (MEP) systems, lighting and office equipment were also excluded, as well as LMN's fabrication shop, loading dock, lobby and shared facilities like storage and showers.

For the interior renovations, only LCA stages A1 (raw material extraction and processing), A2 (transportation to manufacturer) and A3 (manufacturing) of the building's lifespan (Figure 18) were considered, as the product stage offered the most quantifiable opportunities for interior products.

For the building's *structure* and *skin* calculations, LCA stages A1 to A4 (product and construction process), B2 to B5 (usage), C (end of life) and D (circularity) were used in conjunction with a Tally model. The embodied carbon results of the *structure*, *skin*, *space plan* and *stuff* were grouped into five-year intervals. All the embodied carbon estimates were normalised across LMN's rental space in 2019, consisting of 2.4 floors.

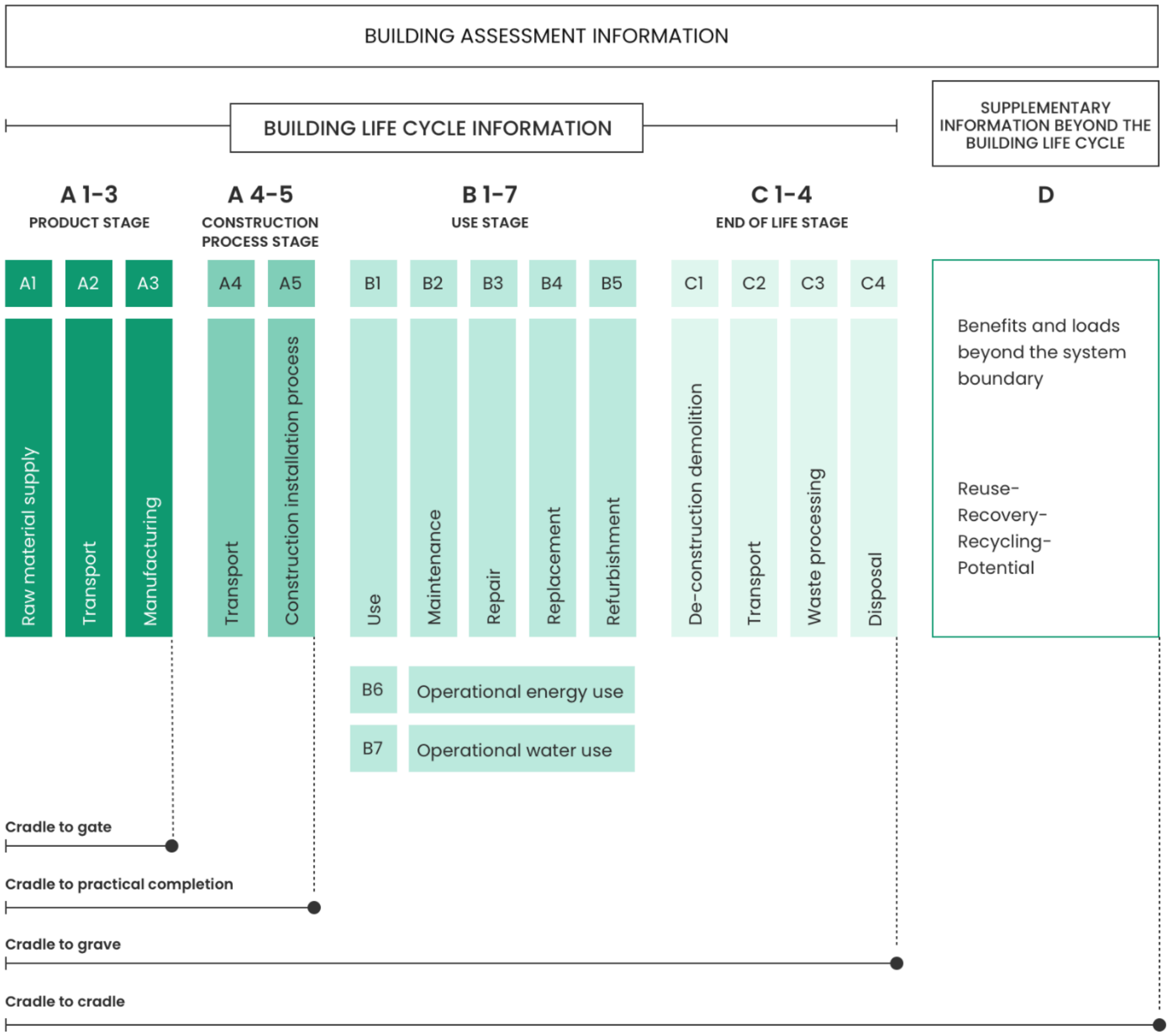

Figure 18: Carbon timeline study (One Click LCA, 2021:15)

6.1.2 Results

As shown in Figure 18, LMN included an additional renovation that most likely occurred between the openings of the building and the office – between 1959 and 1984. For comparison, the results also incorporated a 30% embodied carbon reduction to accommodate for technological advancements in concrete used in a modern-day building. The cyclical tenant improvement study estimated that the office's internal cyclical renovations accumulated more embodied carbon over the 60 years than the *structure* and *skin* **combined** (Figure 18).

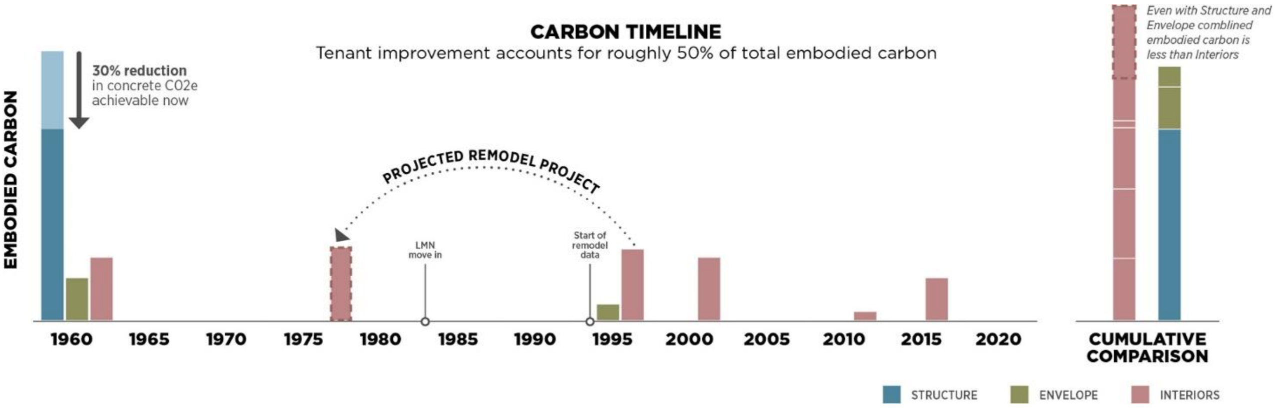

Figure 19: Carbon timeline study (LMN, 2022)

The results are consistent with CLF's TI LCA study (LMN, 2022). The TI LCA sorts data in three categories of carbon impact: low (45 kg-CO_2e/m^2), medium (90 kg-CO_2e/m^2) and high (135 kg-CO_2e/m^2). The office indicated a 36-52 kg-CO_2e/m^2 impact per renovation, meaning a low carbon impact per renovation (LMN, 2022). However, the data is estimates with multiple factors excluded from the data inputs. If EPDs were available and these factors included, the carbon impact per renovation cycle would increase. Figure 20 indicates the embodied carbon of the major contributors. Figure 21 illustrates the office's 2013-2015 redo's embodied carbon, based on the available data used during the study. The furniture contributed the most to the latest renovation's total embodied carbon, close to 50%.

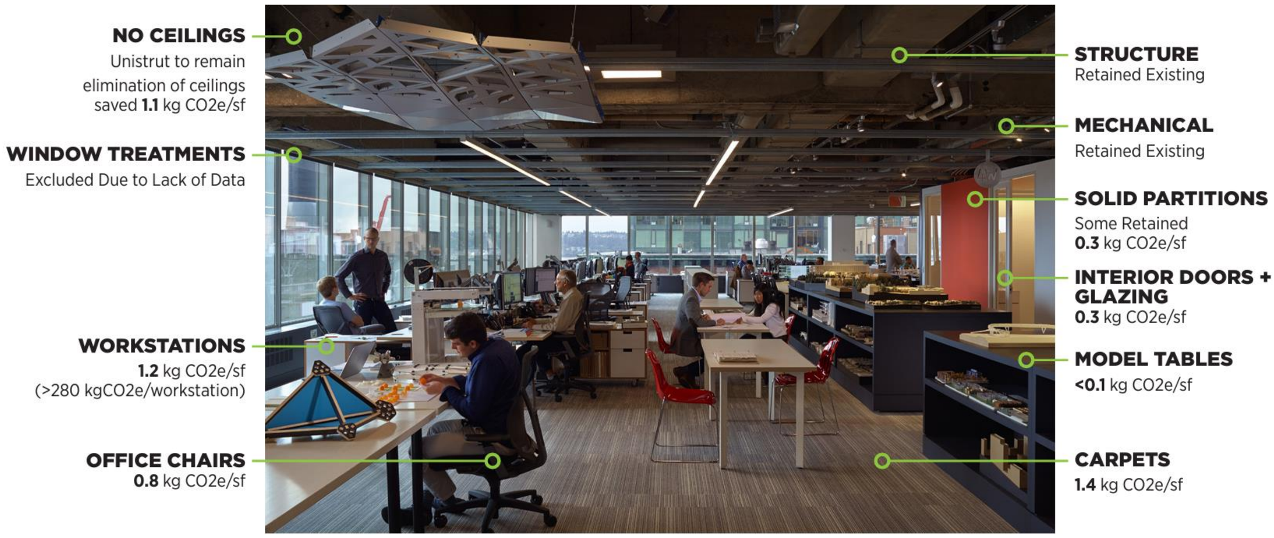

Figure 20: Embodied carbon of the major contributors (LMN, 2022)

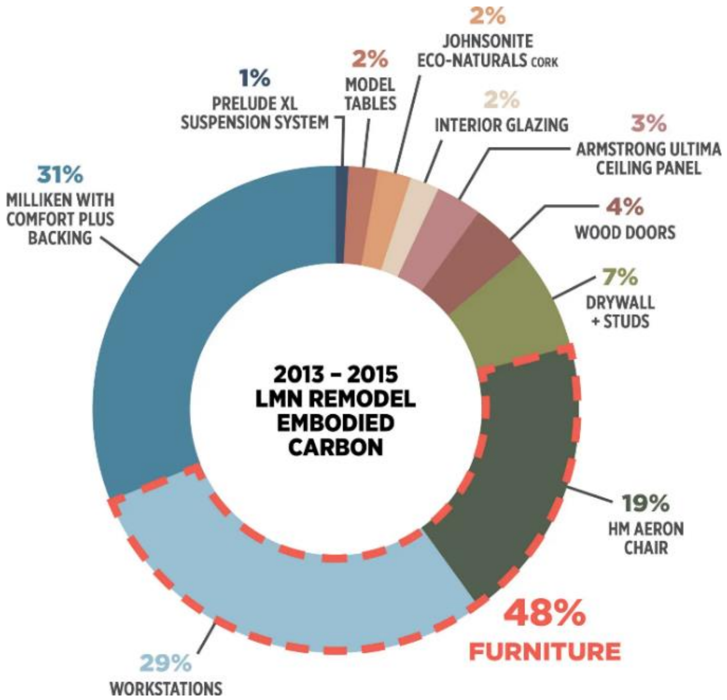

Figure 21: Carbon timeline study (LMN, 2022)

As seen in Figure 22, LMN proposed two scenarios to the latest renovation. The renovation baseline indicates that more than 75% of the total embodied carbon was attributable to *stuff*, namely chairs, workstations and carpet tiles. Scenario 1 adds acoustic ceilings throughout the office, covering the current exposed structure's surface. A closed ceiling would have increased the embodied carbon by 3 kg-CO_2e/m^2. Scenario 2 captures the aggressive reduction in embodied carbon if high-quality, low-carbon alternatives from the 2021 market would have been used during the renovation. The embodied carbon would have been reduced by 50%.

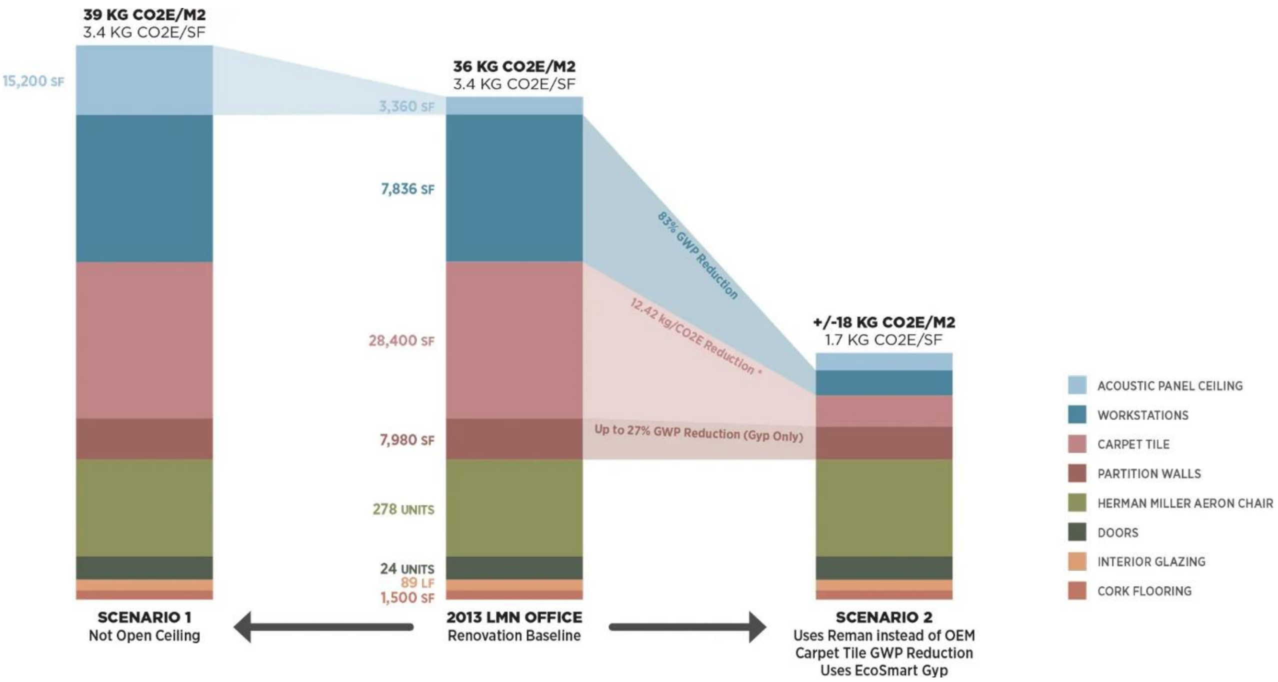

Figure 22: Embodied carbon scenarios (LMN, 2022)

6.2 EXTERNAL CASE STUDY 2: MASS TIMBER INDOOR AIR QUALITY AND COMFORT EMBODIED CARBON COMPARISONS

Concentrations of indoor carbon dioxide (CO_2), indoor air pollutants and multiple volatile organic compounds (VOCs) are consistently higher indoors than outdoors with air pollutants twice as high (Irga *et al*., 2024:1) and VOCs up to ten times higher indoors than outdoors (Gonzalez-Martín *et al*., 2024:1). As the IEQ is largely affected by the IAQ of a building, air pollutants play a significant role in quantifying the quality of indoor spaces.

It is important to distinguish between indoor air pollution, household air pollution and ambient air pollution. Indoor air pollution has typically received less attention than outdoor air pollution. It is, however, gaining interest as indoor air pollution levels are commonly twice as high than outdoor levels (Irga *et al.,* 2024:1), resulting in diseases and deaths attributable to particulate matter (PM), biological pollutants (allergens, bacteria, mould, fungi and spores), physical agents (temperature and electromagnetic fields), volatile inorganic compounds (VICs such as CO, NOx and O3) and VOCs (benzene, toluene, ethylbenzene, xylenes, naphthalene, formaldehyde, trichloroethylene, α-pinene and limonene) (Gonzalez-Martín *et al*., 2024:3). According to the World Health Organisation (WHO, n.d.), household air pollution is a specific type of indoor air pollution generated by the insufficient combustion of solid fuels used for heating and cooking indoors. Globally, 2.3 million people cook by means of open fires or inadequate stoves fuelled by kerosene, coal and biomass (wood, crop waste and livestock manure) responsible for 3.2 million premature deaths annually (WHO, 2023). The poor in low- and middle-income countries (LMIC) suffer the most (WHO, 2023). Ambient air pollution refers to outdoor air pollution capable of entering the interiors of buildings (WHO, n.d.).

MT is often left exposed as interior finished surfaces, altering the surface-to-air volume ratio of interior materials and potentially affecting indoor environmental quality (IEQ) (Stenson *et al*., 2019:1,2). Stenson *et al.* explains that IEQ affects occupant health and well-being, considering factors like indoor air quality (IAQ) as well as thermal, acoustic and visual comfort. Occupant productivity and satisfaction are common metrics for evaluating IEQ (Stenson *et al*., 2019:2).

This section will focus on embodied carbon present in frequently specified construction materials for indoor use, as the responsibility typically lies with the architect to propose and recommend safe, healthy and environmentally sustainable materials in an attempt to mitigate the construction sector's impact in an era of Climate Change. Irga *et al*. (2024:1) states that an accumulation of indoor VOCs has been associated with Sick Building Syndrome (SBS), which is defined by Igwe *et* *al.* (2023:3) as a condition where poor air quality within an enclosed space, i.e. poor IAQ, causes occupants to feel unwell while inside. Symptoms include shortness of breath, cough, dry eyes, nasal irritation, headaches, itchy skin, aggravated asthma, sensitivity to odours, fever and nausea (Igwe *et al*., 2023:3). SBS can be experienced in old, new and renovated buildings. However, these symptoms are often more pronounced in newly painted or furnished buildings due to the presence of chemical components from paints or furnishings. Additionally, buildings are becoming more airtight to improve building performance, energy efficiency, cost-effectiveness and thermal comfort (Kempton *et al*., 2022). Current research, however, is questioning the impact of increasing airtightness on IAQ (Kempton *et al*., 2022). The level of a building's airtightness is often controlled by the construction methods employed during new construction or deep renovation.

Several studies discuss the contribution of wood in the creation of healthy environments, many of which rely on occupant feedback rather than quantitative monitoring data, while most quantitative IEQ studies are limited to measurements in laboratory environments or unoccupied buildings (Stenson *et al*., 2019:2). This raises the question whether MT can reduce these indoor concentrations of polluting emissions.

Average embodied carbon emissions of typical construction materials for external and internal application were compared in Table 3 below. It is important to note that the kg-CO2e values and units differ across sources, depending on what life cycle stage is being assessed. In addition to this, time of publication varies, which may render some values as outdated, especially where technological advancements and improvements were made. Therefore, it is currently difficult to accurately compare the embodied carbon of products.

Table 3: Embodied carbon comparisons (Author, 2024)

	Embodied Carbon (GWP, expressed in kg-CO_2e)					
Material	**kg-CO_2e / kg**	**Source**	**kg-CO_2e / m^2**	**Source**	**kg-CO_2e / m^3**	**Source**
Wood and Bamboo						
Mass Timber			198	Hemmati *et al*., 2024		
CLT	0.25	Place *et al*., 2021; ARUP, 2023			87.64	Oh *et al*., 2023
Glulam	0.28	Place *et al*., 2021; ARUP, 2023			87.64 197.97	Oh *et al*., 2023 TSW, 2022
General	0.46	Sabnis *et al*., 2015:4				
Plywood	0.81	Sabnis *et al*., 2015:4				
Soft Wood (Spruce and Pine)	0.263	Place *et al*., 2021			110	Pliteq, 2022
Bamboo (Moso)			18.7	TSW, 2022		

	Embodied Carbon (GWP, expressed in kg-CO_2e)					
Material	**kg-CO_2e / kg**	**Source**	**kg-CO_2e / m^2**	**Source**	**kg-CO_2e / m^3**	**Source**
Concrete and Cement						
Plain	0.13	Sabnis *et al.*, 2015:4			258.58	Oh *et al.*, 2023
Cement (Portland)	0.73	Sabnis *et al.*, 2015:4				
Reinforced	0.148	Sabnis *et al.*, 2015:4			635	Pliteq, 2022
Precast	0.215	Sabnis *et al.*, 2015:4				
Bricks						
General	0.22	Sabnis *et al.*, 2015:4			503	TSW, 2022
CMU					260	
Clay					345	Pliteq, 2022
Steel						
General	1.77	Sabnis *et al.*, 2015:4	243	Hemmati *et al.*, 2024	12 090	Pliteq, 2022
Rebar					3 562.60 6 972	Oh *et al.*, 2023 TSW, 2022
Aluminium	8.24	Sabnis *et al.*, 2015:4			18 009	Pliteq, 2022
Glass						
General	0.85	Sabnis *et al.*, 2015:4				
Rammed Earth					48	Pliteq, 2022
Stone	0.056	Sabnis *et al.*, 2015:4			237	Pliteq, 2022
Marble Tiles	0.187	Sabnis *et al.*, 2015:4				
Adhesives						
CLT						
MUF	1.518	ARUP, 2023				
EPI	2.964 (USA) 3.6 (ICE)	ARUP, 2023				
Polyurethane	0.88	ARUP, 2023				
Glulam						
MUF	1.518	ARUP, 2023				
EPI	2.964 (USA) 3.6 (ICE)	ARUP, 2023				
MF	5.275 (USA) 4.19 (ICE)	ARUP, 2023				
PRF	2.708	ARUP, 2023				

	Embodied Carbon (GWP, expressed in kg-CO_2e)					
Material	**kg-CO_2e / kg**	**Source**	**kg-CO_2e / m^2**	**Source**	**kg-CO_2e / m^3**	**Source**
Insulation						
Fiberglass			0.46	TSW, 2022		
Cellulose			0.59	TSW, 2022		
Expanded Polystyrene			2.63	TSW, 2022		
Extruded Polystyrene			25.36	TSW, 2022		
Spray Foam (closed cell)			3.83	TSW, 2022		
Mineral wool			2.63	TSW, 2022		
Hempcrete (blocks)			0.194	TSW, 2022		

7. DISCUSSION

The findings of Case Study 1 and Case Study 2, as well as their relevance to mass timber (MT), will be discussed.

7.1 EXTERNAL CASE STUDY 1

Approximately 80% of the buildings expected to exist in developed nations by 2050 have already been built (LMN, 2022), meaning that the carbon emissions from their *structure*, *skin* and major *services* such as mechanical, electrical and plumbing (MEP) systems have already been released into the atmosphere. These buildings are likely to undergo multiple interior renovations before then, ranging from updates to furniture, fixtures and equipment (FF&E), in other words *stuff*, as well as finish materials to major revisions in *space planning*, MEP *services*, deep energy retrofits and lighting. Due to the cyclical nature of interior renovations, they have a significant carbon impact. However, interiors – specifically the *space plan* and *stuff* layers – present opportunities for the decarbonisation of existing buildings. Current research is stating that existing buildings should be renovated to decarbonise the existing built environment (LMN, 2022). This should be done sustainably, which can be achieved through sustainable interior renovations that use alternative, circular materials like MT to minimise the building's carbon footprint.

7.1.1 Environmental Product Declarations

It is devastatingly clear that EPDs for the *space plan* and *stuff* are highly limited, while the number of materials used during renovations are more than the materials required for the *structure* and *skin,* respectively (Figure 16). EPDs are readily available for some material categories, such as carpet tiles and acoustic ceiling tiles. However, capturing the whole scope of the interiors' impact is difficult due to the substantial number of unique material types spanning many specification sections and the number of manufacturers competing in each material category. In addition, the complexity of each product's composition, supply chain, demand for a wide variety of new products and performance attributes make it difficult for manufacturers to provide third party verified carbon data in a consistent format. The industry is already aware of this when looking for transparency on health and toxicity: larger manufacturers and popular product lines are more likely to provide EPDs and other transparency labels, while the cost of compiling and publishing this data often challenge smaller manufacturers.

With regards to wood, EPDs are not as widely available and the lack of information adds to wood waste being disposed to landfill (Figure 24). EPDs should become high in demand from markets to hinder greenwashing and the manipulation of established green building frameworks. Green building frameworks need to become more robust to ensure honest and accurate sustainability in projects. EPDs are necessary to be made available, especially for new and upcoming technologies like MT, to raise awareness of its material properties and accelerate the adoption thereof. EPDs will allow practitioners and consumers to compare products, based on their environmental impact, benefits and drawbacks. This suggests that further research on the full life cycle assessment (LCA) of engineered wood is necessary, as it is currently lacking (Crawford & Cadorel, 2017:845). LCAs require significant improvement related to accurate quantifiable data throughout the lifecycle of MT, for MT construction to be adopted and used with confidence.

Currently, as the lack of data suggests, interior renovations are unregulated. Interior renovations are performed by both professional and amateur. A robust framework should be developed to track and manage the performance of interior renovations.

7.1.2 Fast Furniture

Similar to "fast fashion", the term "fast furniture" refers to affordable and quickly produced furniture and similar *stuff* (LMN, 2022). "Fast furniture" led furniture to be one of the fastest growing landfill categories. In 2018, the United States generated 12.1 million tonnes of furniture waste, which is an increase of 450% since the 1960s (LMN, 2022). As a result, most of the furniture currently in landfill was made within the last 10 to 15 years (Figure 23). "Fast furniture" is not built to last or easy to repair, making it often cheaper to buy new than to fix or refinish existing furniture. Furniture recycling is also difficult, especially furniture types that are made up of multiple layers of varied materials and those using adhesives, such as upholstered chairs or mattresses. The result of this poor furniture design is that 80% of the furniture is landfilled and nearly all the rest is incinerated (LMN, 2022).

Office furniture is the primary source of furniture waste, accounting for an estimated 8.5 million tonnes per year (LMN, 2022). Most office furniture is meant to last 10 to 15 years or longer, but the average leases are now seven years or lower and tenants do not typically transfer existing furniture to new office locations or reuse furniture when a refresh occurs (LMN, 2022). Busy office managers do not always have the time or expertise to ensure recycling or reuse of FF&E during decommissioning of an office space. Without a plan in place, furniture can easily end up in the landfill. With offices downsizing to accommodate the shift to hybrid work, this volume of furniture waste will likely increase over the next few years (LMN, 2022).

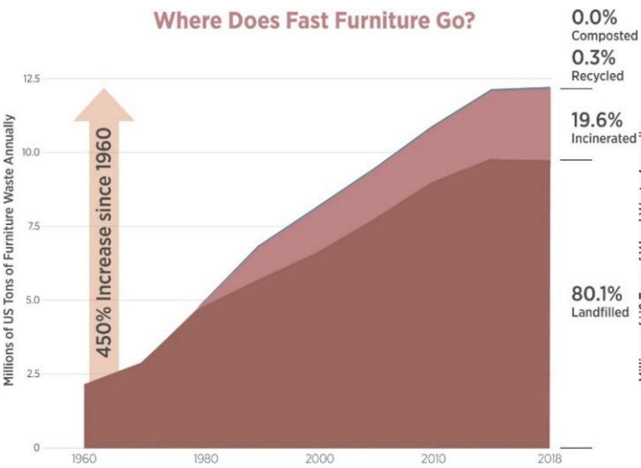

Figure 23: Where fast furniture ends up (LMN, 2022)

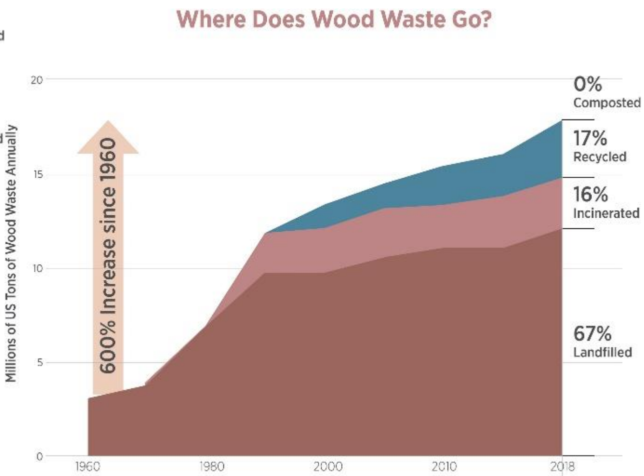

Figure 24: Where wood ends up (LMN, 2022)

7.1.3 Life Cycles and a Circular Economy

The complexity and lack of data means that many additional material categories, including Furniture, Fixtures, and Equipment (FF&E), casework, and lighting, are often omitted from carbon calculations despite having a surprisingly large emissions impact.

Capturing the full picture of the interiors scope is more effort than structure and envelope, and project teams likely do not have the fee and time to address each material. However, there are easy strategies to make big impacts.

While embodied carbon investments in *skin* and *structure* are high, they are also long-lived. Cycles of interior renovations typically occur every 5 years in hospitality, retail and office spaces. Restoration clauses are often included in tenant contracts, requiring the removal of *space plan* and *stuff* of the interior when moving out. The removal of *space plan* elements such as walls, ceilings, lighting, furnishing and fixtures are often disposed to be landfilled. This results in the premature discarding of materials with a decade worth of useful service life still left. A Climate Toolkit for Interior

Design was developed due to the harmful impact that cyclical interiors have on the indoor and outdoor environment.

7.2 EXTERNAL CASE STUDY 2

Even though kg-CO2e values and units differ across sources, depending on what life cycle stage is being assessed, it provides a good basis for comparison between non-biobased and biobased materials. The benefits of MT are clear as stated throughout the study. It is a sustainable alternative to your modern-day traditional materials like reinforced concrete and steel. As mentioned, LCA data should improve. A LCA offers insight into the environmental performance of a product at a specific point in time. Typically, LCA studies are context-specific and case-related. (Crawford & Cadorel, 2017:840). LMN (2022) states that data collection related to the whole scope of interiors' environmental impact is difficult due to the considerable number of unique material types spanning many specification sections, as well as the number of manufacturers competing in each material type category. The carbon emissions of FF&E calculations are typically omitted from LCAs, even though the *stuff* has a significant impact on embodied carbon.

8. FURTHER RESEARCH

Future research can delve into quantifying the frequency of and the environmental impact of cyclical interior renovations to increase accuracy in indoor environmental quality, indoor pollution and predicted C&DW to address relevant mitigation strategies. In addition to this, research on MT will benefit from analysing the potential mitigation strategies and carbon footprint relief of existing interiors and cyclical interior renovations when integrating MT products in interior spaces. The natural airtight qualities of MT can be analysed in more depth, to accurately assess not only its energy efficiency but also its impact on IAQ and human health.

Crawford & Cadorel (2017:) raises the concern regarding the limitations in LCA frameworks. Previous studies on the environmental benefits of MT construction could be considered inconclusive the use of flawed assessment techniques as well as the unavailability of detailed and accurate information from manufacturers on MT products. These studies often exclude indirect but potentially resource and emissions-intensive processes, as process analysis fails to capture these aspects (Crawford & Cadorel, 2017:842).

9. CONCLUSION

Cyclical renovations of interiors result in prematurely demolished and discarded *structures*, *skins*, *services*, *space plans* and *stuffs*. Although interiors currently pose a significant threat to the environment and health of the *social dimension*, it also has terrific opportunity to decarbonise existing buildings and reduce the environmental impact of interiors. Sustainable frameworks should be developed to accurately assess and regulate interior renovations. Sustainable alternative materials should be sought to replace carbon-intensive and extractive materials, especially during cyclical renovations to decarbonise existing buildings. Mass engineered timber offers a viable sustainable alternative to reduce the anthropogenic impact on the environment by significantly reducing greenhouse gas emissions, sequestering carbon and presenting the potential to improve indoor environmental quality, indoor air quality, human health and well-being. Adaptive reuse can function as implementation tool for mass timber integration in internal applications, while accelerating the adoption thereof. It is important to adapt existing buildings to meet current needs. The *social dimension's* cultural meanings, significance, needs and demands change as time passes by. This ensures the survival of the building while extending its lifespan and reducing its environmental impact.

A closed-loop harmony between the *social dimension*, *site*, *structure*, *skin*, *services*, *space plan* and *stuff* will create a resilient *system* (Figure 25) that replenishes raw, non-extractive materials...

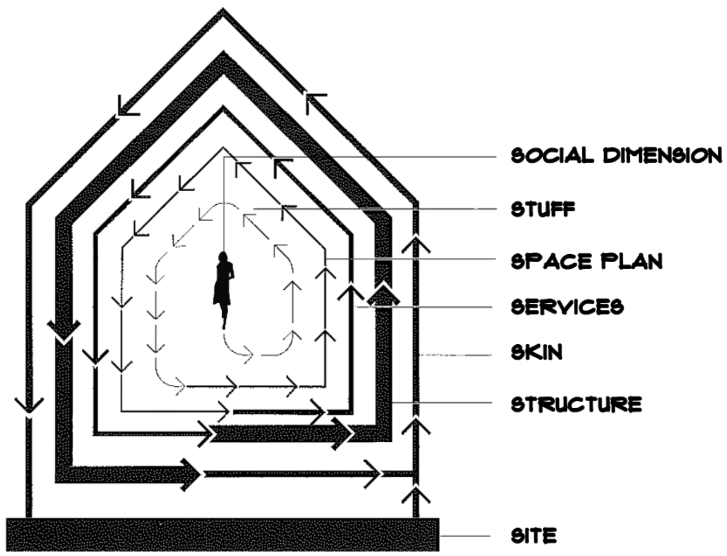

Figure 25: Shearing layer of a circular economy (Adapted from Brand, 1994:13).

10. BIBLIOGRAPHY

1. 3SMedia. 2023. *Great legislation, terrible landfills*. [Online] Available at: https://issuu.com/glen.t/docs/resource_february_2023/s/19449567 [Accessed 16 May 2024].

2. Abdrabo, K.I., Hamed, H., Fouad, K.A., Shehata, M., Kantoush, S.A., Sumi, T., Elboshy, B. & Osman, T. 2021. A methodological approach towards sustainable urban densification for urban sprawl control at the microscale: case study of Tanta, Egypt. *Sustainability*, 13(5360):1-20.

3. Abed, J., Rayburg, S., Rodwell, J. & Neave, M. 2022. A review of the performance and benefits of mass timber as an alternative to concrete and steel for improving the sustainability of structures. *Sustainability,* 14(5570):2-24.

4. Aldebei, F. & Dombi, M. 2021. Mining the built environment: telling the story of urban mining. *Buildings*, 11(388):1-18.

5. Alter, L. *Mass timber goes cradle-to-cradle in Virginia's Apex Plaza*. [Online] Available at: https://www.treehugger.com/apex-plaza-virginia-by-mcdonough-5271268#:~:text=Nordic%20has%20the%20first%20Cradle,water%20stewardship%20and%20social%20fairness. [Accessed 25 June 2024].

6. ArcGIS. 2023. *Average Household Size in South Africa*. [Online] Available at: https://www.arcgis.com/home/item.html?id=582208ececa2424ab6e387d9cdcf01e3#:~:text=Description-,This%20map%20shows%20the%20average%20household%20size%20in%20South%20Africa,household%20population%20by%20total%20households. [Accessed 15 May 2024].

7. ARUP. 2023. *Embodied carbon: timber*. [Online] Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.istructe.org/IStructE/media/Public/Resources/ARUP-Embodied-carbon-timber-v2.pdf [Accessed 25 May 2024].

8. Ashour, M., Mahdiyar, A., Haron, S.H. & Hanafi, M.H. 2022. Barriers to the practice of sustainable interior architecture and design for interior renovations: a parsimonious-cybernetic fuzzy AHP approach. *Journal of Cleaner Production*, 366(September):1-15.

9. Belabid, A., Elminor, H. & Akhzouz, H. 2022. The concept of hybrid construction technology: state of the art and future prospects. *Future Cities and Environment*, 8(1):13,1-16.

10. Bergstra, T. (t.bergstra@gtb-lab.com) 2023. RBIM research graphics. [E-mail to:] Cilliers, M. P. (u18123865@tuks.co.za) 30 August 2023.

11. Bowdon, B. 2024. *Home renovation in 2024: 15 facts & stats to consider before renovating*. [Online] Available at: https://www.gallerykbny.com/post/home-remodeling-myths-and-facts-general-contractors-tell-all [Accessed 15 May 2024].

12. Brand, S. 1994. *How buildings learn: what happens after they're built*. London, UK: Penguin Books.

13. Brooker, G. & Stone. S.H. 2018. *Re-Readings 2: Interior Architecture and the Design Principles of Remodelling Existing Buildings*. London, UK: RIBA.

14. Browning, W.D., Ryan, C.O. & DeMarco, C. 2022. *The nature of wood, an exploration of the science on biophilic responses to wood*. New York, NY: Terrapin Bright Green LLC.

15. Buco, 2019. *How often should you repaint your home*? [Online] Available at: https://www.buco.co.za/blog/home-improvement-trends-and-inspiration/repaint-your-home [Accessed 15 May 2024].

16. Calder, G. 2023. *How often should you do a kitchen renovation*. [Online] Available at: https://bespokedesigns.co.za/how-often-should-you-do-a-kitchen-renovation/ [Accessed 15 May 2024].

17. Cilliers, M.P. 2023. *How can digital material inventories facilitate building deconstruction for elemental circularity*? Unpublished honours literature review. Pretoria: Department of Architecture, University of Pretoria.

18. Collins, S. 2019. *Strategies to improve the human experience during interior renovations*. [Online] Available at: https://www.bdcnetwork.com/blog/strategies-improve-human-experience-during-interior-renovations [Accessed 15 May 2024].

19. Cox, J. 2021. *Demolition - Blight or Blessing?* [Online] Available at: https://www.ryegroup.co.uk/blog/demolition-blight-or-blessing/ [Accessed 15 May 2024].

20. Crawford, R.H. and Cadorel, X. 2017. A framework for assessing the environmental benefits of mass timber construction. *Procedia Engineering*, 196(2017):838-846.

21. De Querol Cumbrera, F. 2023. *Demolition of buildings and parts of buildings in Germany from 2015 to 2022, by area of useful floor space (in 1,000 square meters)*. [Online] Available at: https://www.statista.com/statistics/1294378/demolition-of-buildings-and-parts-of-buildings-in-germany/ [15 May 2024].

22. Diener, E. 2000. Subjective well-being: the science of happiness and a proposal for a national index. *American Psychologist*. 55(1):34-43.

23. Divisare, 2022. *Dhooge & Meganck Reconversion Church in Lampernisse*. [Online] Available at: https://divisare.com/projects/457499-dhooge-meganck-annabelle-stampaert-johnny-umans-reconversion-church-in-lampernisse [Accessed 27 February 2024].

24. Du Toit, J. 2021. *Research Designs for Architecture*. Pretoria: Department of Architecture, University of Pretoria.

25. EPA, 2020. *Advancing sustainable materials management: 2018 fact sheet assessing trends in materials generation and management in the United States*. [Online] Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.epa.gov/sites/default/files/2021-01/documents/2018_ff_fact_sheet_dec_2020_fnl_508.pdf [Accessed 27 February 2024].

26. Ferrari, E. 2015. *Wohnungsfrage*. [Online] Available at: https://www.domusweb.it/it/architettura/2015/10/30/haus_der_kulturen_der_welt_wohnungsfrage.html [Accessed 27 February 2024].

27. Frunzio, G., De Simone, M., Loreto, G., Di Gennaro, L. & Massaro, L. 2023. The use of wood betters the relationship between people and places. *Building Technology Educators' Society*, 1(June):130-133.

28. Garcia, J.S. 2023. *Home renovation facts and statistics (2024)*. Architectural Digest, 7 August. [Online] Available at: https://www.architecturaldigest.com/reviews/home-improvement/home-renovation-facts-statistics [Accessed: 12 January 2024].

29. Gonzalez-Martín, J., Kraakman, N.J.R., Pérez, C., Lebrero, R. & Munoz, R. 2021. A state-of-the-art-art review on indoor air pollution and strategies for indoor air pollution control. Chemosphere, 262(2021):1-16.

30. Harte, A.M. 2017. Mass timber – the emergence of a modern construction material. *Journal of Structural Integrity and Maintenance*, 2(3):121-132.

31. Hemmati, M., Messadi, T., Gu, H., Seddelmeyer, J. & Hemmati, M. 2024. Comparison of embodied carbon footprint of a mass timber building structure with a steel equivalent. *Buildings,* 14(5):1-14.

32. Herdt, T. & Jonker. A.R. 2023. The acceptance of density: Conflicts of public and private interests in public debate on urban densification. *Cities*, 140(June):1-12.

33. Hulsbeek, L.D.J. 2022. *A decision support tool to assist demolition contractors in choosing to reuse, recycle or recover building elements*. Master's thesis. Netherlands, University of Twente. [Online] Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://essay.utwente.nl/92943/1/Hulsbeek_MA_ET.pdf [Accessed 15 March 2023].

34. IFC. 2023. *Building green – sustainable construction in emerging markets*. [Online] Available at: https://www.ifc.org/en/insights-reports/2023/building-green-in-emerging-markets [Accessed 7 April 2024].

35. Igwe, A. E., Ezeobi, A. A., Okeke, F. O., Ibem, E. O. & Ezema, E. C. 2023. Causes and remedies of sick building syndrome: a systematic review. *E3S Web of Conferences*, 434(October):1-10.

36. Irga, P.J., Mullen, G., Fleck, R., Matheson, S., Wilkinson, S.J. & Torpy, F.R. 2024. Volatile organic compounds emitted by humans indoors – a review on the measurement, test conditions, and analysis techniques. *Building and Environment*, 255(May):1-13.

37. Jaafar, M., Salman, A., Ghazali, F.E.M., Zain, M.Z.M., & Kilau, N.M. 2024. The awareness and adoption level of emerging technologies in Fourth Industrial Revolution (4IR) by contractors in Malaysia. *Ain Shams Engineering Journal*, 15(5):1-11.

38. Janisch, A. 2018. *A research and educational centre: exploring the cconnection between the natural environment and architecture: learning from the mysteries of nature*. Published master's thesis. Johannesburg: University of the Witwatersrand. [Online] Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://wiredspace.wits.ac.za/server/api/core/bitstreams/1aaac310-d0e0-4424-8cab-7fdc160e53d8/content [Accessed 28 January 2024].

39. Jarden, A. & Roache, A. 2023. What is wellbeing? *International Journal of Environmental Research and Public Health*, 20(6):2-4.

40. Jonathan, C. 2023. Circular economy in Africa: towards a model for affordability in housing including the craftsmanship of components, involving reusing, and re-purposing. *Open Access Library Journal,* 10(10):1-17.

41. Josefsson, T.A. 2019. *Form follows availability: the reuse revolution*. M.Arch. Thesis. Sweden: Chalmers University of Technology. [Online] Available at: https://odr.chalmers.se/bitstream/20.500.12380/257024/1/257024.pdf [Accessed 13 May 2023].

42. Kempton, L., Daly, D., Kokogiannakis, G & Dewsbury, M. 2022. A rapid review of the impact of increasing airtightness on indoor air quality. *Journal of Building Engineering*, 57(October):1-15.

43. Khozin, V., Khokhryakov, O & Nizamov, R. 2020. *A «carbon footprint» of low water demand cements and cement-based concrete*. Paper presented at Conference: International Scientific Conference on Socio-Technical Construction and Civil Engineering (STCCE - 2020), April – May:29-15, Kazan, Russian Federation. [Online] Available at: https://iopscience.iop.org/article/10.1088/1757-899X/890/1/012105 [Accessed 27 February 2024].

44. Khudzari, F., Rahman, R.A. & Ayer, S.K. 2023. *Critical factors influencing construction technology adoption: a multivariate analysis*. Paper presented at Conference: World Sustainable Construction Conference Series 2021, May:1-15. [Online] Available at: https://www.researchgate.net/publication/370739654_Critical_factors_influencing_construction_technology_adoption_A_multivariate_analysis [Accessed: 24 June 2024].

45. Konchev, A. 2021. *EnvironMental: using biophilia to create a mental health support facility in Johannesburg*. Master's thesis. Johannesburg: University of Witwatersrand.

46. Kremer, P.D. 2023. Filling the knowledge gaps in mass timber construction: where are the missing pieces, what are the research needs? *Mass Timber Construction Journal*, 6(July):1-10.

47. KRS, 2024. *The 5 stages of a successful store remodel - a comprehensive guide to remodeling your store*. [Online] Available at: https://kingrs.com/ourinsight/stages-successful-store-remodel/#:~:text=However%2C%20a%20typical%20store%20renovation,changing%20consumer%20preferences%20and%20competition. [Accessed 15 May 2024].

48. Laski, J. & Burrows, V. 2017. *From thousands to billions coordinated action towards 100% net zero carbon buildings by 2050*. [Online] Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://worldgbc.org/wp-content/uploads/2022/03/From-Thousands-To-Billions-WorldGBC-report_FINAL-issue-310517.compressed.pdf [Accessed: 5 April 2024].

49. Lemos, C.B. & Donoso, M.D. 2023. Reduce, reuse, rethink and preserve: the reuse of historical buildings as a strategy for environmental sustainability and heritage appreciation. *Scientific Journal of Applied Social and Clinical Science*, 3(20):1-9.

50. LMN. 2022. *15 – interiors, cyclical renovations + carbon*. [Online] Available at: https://lmnarchitects.com/lmn-research/15-interiors-cyclical-renovations-carbon [Accessed 15 May 2024].

51. Long, J. 2016. Architecture of (im)permanence. *Byera Hadley Travelling Scholarships Journal Series*, 2016.

52. Louw, P.L. 2021. *The search for hybrid tectonics in contemporary African architecture: encounters between the global and the local*. Doctoral thesis. Cape Town: University of Cape Town.

53. Macnamara, M. 2020. The lure of timber. Timber iQ – Design & Construction, 17 November. [Online] Available at: https://www.timberiq.co.za/2020/11/17/the-lure-of-timber/#:~:text=Most%20people%20believe%20that%20woodexpensive%20to%20build%20and%20maintain [Accessed 19 January 2024].

54. Macrotrends. 2024. *South Africa Life Expectancy 1950-2024*. [Online] Available at: https://www.macrotrends.net/global-metrics/countries/ZAF/south-africa/life-expectancy [Accessed 5 April 2024].

55. Mamedov, E. 2022. *How often should you renovate your bathroom*? [Online] Available at: https://www.danielsconstructionca.com/blog/bathroom/how-often-should-you-renovate-bathroom/ [Accessed 15 May 2024].

56. Martin, J.A. & López, R. 2023. Biological deterioration and natural durability of wood in Europe. *Forests*, 14(283):1-34.

57. McCoy, A.P. & Yeganeh, A. 2021. *An overview of emerging construction technologies*. Published doctoral thesis. Blacksburg, Virginia Tech.

58. McShannon, 2023. *How often should you decorate your living room*. [Online] Available at: https://www.mcshannondecorator.uk/how-often-should-you-decorate-your-living-room#:~:text=For%20instance%2C%20living%20rooms%2C%20being,every%207%20to%2010%20years. [Accessed 15 May 2024].

59. Menchaca-Ballinas, L.E. & Escalante-Garcia, J.I. 2019. Low CO2 emission cements of waste glass activated by CaO and NaOH. *Journal of Cleaner Production*, 239(2019):1-11.

60. Monteiro, P.J.M., Miller, S.A. & Horvath, A. 2017. Towards sustainable concrete. *Nature Materials*, 16(7):698-699.

61. Mortensen, C. 2020. Change and inconsistency. *The Stanford Encyclopedia of Philosophy Archive*.

62. MTI, 2021. *All about mass timber*. [Online] Available at: https://academic.daniels.utoronto.ca/masstimberinstitute/about-mass-timber/ [Accessed 27 February 2024].

63. MTT, 2022. *House Taylor*. [Online] Available at: https://www.masstimbertech.co.za/projects/house-taylor [Accessed 27 February 2024].

64. MTT, 2023. *CLT Addition on site*. [Online] Available at: https://www.linkedin.com/posts/mass-timber-technologies_clt-engineeredtimber-lowimpact-activity-7092513977951240192-DY89?utm_source=share&utm_medium=member_desktop [Accessed 27 February 2024].

65. Myburgh, 2010. *Wood for the trees : a temporary theatre for the performance of 'Circles in a Forest'*. Published master's thesis. Johannesburg: University of the Witwatersrand. [Online] Available at: https://repository.up.ac.za/handle/2263/30282 [Accessed 28 January 2024].

66. Naidoo, L., Ballard, R., Naidoo, Y., Maree, G., Khanyile, S., Lopez, D.P. & Esch, T., 2023. *Building volume per person in Gauteng*. Gauteng City-Region Observatory.

67. Oh, J. W., Park, K. S., Kim, H. S., Kim, I., Pang, S. J., Ahn, K. S. & Oh, J. K. 2023. Comparative CO2 emissions of concrete and timber slabs with equivalent structural performance. *Energy and Buildings*, 281(February):1-10.

68. One Click LCA, 2021. *Life cycle assessment for buildings – why it matters and how to use it*. [Online] Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://143253260.fs1.hubspotusercontent-eu1.net/hubfs/143253260/Life-Cycle-Assessment-for-Buildings-2021.pdf [Accessed 5 April 2024].

69. Paula, P. 2020. *City Library Het Predikheren / Korteknie Stuhlmacher Architecten + Callebaut Architecten + Bureau Bouwtechniek*. [Online] Available at: https://www.archdaily.com/944248/city-library-het-predikheren-korteknie-stuhlmacher-architecten-plus-callebaut-architecten-plus-bureau-bouwtechniek [Accessed 5 April 2024].

70. Pérez, A. J. Y. 2024. Adaptive reuse of urban heritage in contested urban contexts. *Architecture and the Built Environment*, 14(4):1-384.

71. Petermans, A. & Pohlmeyer, A. 2014. Design for subjective well-being in interior architecture. Paper presented at Proceedings of the 6th Symposium of Architectural Research 2014: Designing and Planning the Built Environment for Human Well-Being, October 2014, Oulu, Finland. [Online] Available at: https://www.researchgate.net/publication/267631889_Design_for_subjective_well-being_in_interior_architecture [Accessed: 24 June 2024].

72. Place, T., Perkins, C & Caine, L. 2021. *Mass timber embodied carbon factors*. [Online] Available at: https://www.istructe.org/resources/blog/mass-timber-embodied-carbon-factors/ [Accessed 5 April 2024].

73. Plevoets, B. & Van Cleempoel, K. 2019. Adaptive reuse of the built heritage: concepts and cases of an emerging discipline. New York, NY: Routledge.

74. Pliteq. 2022. *9 building materials and their shocking carbon footprints that will surprise you*. [Online] Available at: https://pliteq.com/news/building-vs-carbon-footprint/ [Accessed 5 April 2024].

75. Property24. 2019. *How often should you update your home*? [Online] Available at: https://www.property24.com/articles/how-often-should-you-update-your-home/28806 [Accessed 22 January 2024].

76. Purchase, C.K., Zulayq, D.M.A., O'Brien, B.T., Kowalewski, M.J., Berenjian, A., Tarighaleslami, T. & Seifan, M. 2021. Circular economy of construction and demolition waste: a literature review on lessons, challenges, and benefits. *Materials*. 15(76):1-25.

77. Ramage, H.M., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, U.D., Wu, G., Fleming, P., Densley-Tingley, D., Allwood, J., Dupree, P., Linden, P.F. & Scherman, O. 2017. The wood from the trees: the use of timber in construction. Renewable and Sustainable Energy Reviews, 68(1):333-359.

78. Reitmann, L. 2021. *Knitting with nature - a chronicle of South Africa's biomes, told through Melville Koppies' Visitors Centre*. Published master's thesis. Johannesburg: University of the Witwatersrand. [Online] Available at: https://wiredspace.wits.ac.za/items/addf4df9-82fe-4523-878c-270c604d9ede/full [Accessed 28 January 2024].

79. Rockfon, 2022. *Renovating a hotel improves guest experience with visual appearance and acoustic conditions*. [Online] Available at: https://www.rockfon.co.uk/about-us/blog/2022/hotel-renovation/#:~:text=Generally%20speaking%2C%20most%20hotels%20should,technology%20to%20meet%20guest%20preferences. [Accessed 15 May 2024].

80. Rodriguez-Morales, J., Burciaga-Diaz, O., Gomez-Zamorano, L.Y. & Escalante-Garcia, J. I. 2024. Transforming construction and demolition waste concrete as a precursor in sustainable cementitious materials: An innovative recycling approach. *Resources, Conservation & Recycling*, 204(2024):2-10.

81. Ruben, P.A., Sileryte, R. & Agugiaro, G. 2020. 3D city models for urban mining: point cloud based semantic enrichment for spectral variation identification in hyperspectral imagery. *ISPRS Annals of The Photogrammetry, Remote Sensing and Spatial Information Sciences*, 5(4):223-230.

82. Sabnis, A.S., Mysore, P. & Anant, S. 2015. *Construction materials-embodied energy footprint-global warming; interaction*. Paper presented at Conference: Structural Engineers World Congress, October 2015:1-7. [Online] Available at: https://www.researchgate.net/publication/310022790_Construction_Materials-Embodied_Energy_Footprint-Global_Warming_Interaction [Accessed: 24 June 2024].

83. SANS. 2016. The application of the National Building Regulations, Part C: Dimensions. Pretoria: SABS Standards Division. (SANS 10400-C:2016).

84. Skrede, J. & Andersen, B. 2022. The emotional element of urban densification. *Local Environment*, 27(2): 251-263.

85. Southey, R. 2024. *Time to build with timber*. [Online] Available at: https://saforestryonline.co.za/articles/time-to-build-with-timber/ [Accessed: 14 May 2024].

86. Stenson, J., Ishaq, S.I., Laguerre, A., Loia, A., MacCrone, G., Mugabo, I., Northcutt, D., Riggio, A., Gall, E.T. & Van Den Wymelenberg, K. 2019. Monitored indoor environmental quality of a mass timber office building: a case study. *Buildings*, 9(142):1-15.

87. Stone, S. H. 2019. *Undoing buildings: adaptive reuse and cultural memory*. New York, NY: Routledge.

88. Suite Renovations, 2024. How Often Do Hotels Need to be Renovated? [Online] Available at: https://suitereno.com.au/how-often-do-hotels-need-to-be-renovated/ [Accessed 15 May 2024].

89. The Burra Charter. 2013. *The Burra Charter - the Australia ICOMOS charter for places of cultural significance*. [Online] Available at: https://australia.icomos.org/publications/burra-charter-practice-notes/ [Accessed 27 February 2024].

90. Touw, K. 2006. *Firmitas re-visited: permanence in contemporary architecture*. Master's thesis. Belgium: University of Waterloo.

91. Trinh, L. & Zhang, H. 2021. *The 200 m timber tower A study of building geometry and construction feasibility*. Published master's thesis. Sweden: Chalmers University of Technology.

92. TSW. 2022. TSW R&D study: embodied carbon content of common building materials. [Online] Available at: https://www.tsw-design.com/tsw-rd-study-embodied-carbon-content-of-common-building-materials/ [Accessed 26 June 2024].

93. UNEP. 2023. *Building materials and the climate: constructing a new future*. [Online] Available at: https://wedocs.unep.org/handle/20.500.11822/43293 [Accessed 6 April 224].

94. Usman, M. 2023. *Renovating a restaurant – a chronological overview*. [Online] Available at: https://www.arrantconstruction.com/renovating-a-restaurant-a-chronological-overview/ [Accessed 15 May 2024].

95. WHO, 2023. *Household air pollution*. [Online] Available at: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health [Accessed 5 April 2024].

96. WHO, n.d. *Exposure & health impacts of air pollution - pollutants not only severely impact health, but also the earth's climate and ecosystems globally*. [Online] Available at: https://www.who.int/teams/environment-climate-change-and-health/air-quality-energy-and-health/health-impacts/exposure-air-pollution [Accessed 5 April 2024].

97. Wilson, O.E. 1984. *Biophilia: the human bond with other species*. Cambridge, US: Harvard University Press.

98. WoodBiz Africa. 2023. *Architects and developers are starting to adopt mass timber technologies*. Napier, South Africa: ForSawn Media.

99. Worldometer, 2024. *How many countries are there in the world? (2024) - total & list*. [Online] Available at: https://www.worldometers.info/geography/how-many-countries-are-there-in-the-world/#:~:text=There%20are%20195%20countries%20in,and%20the%20State%20of%20Palestine. [Accessed 27 February 2024]

100. Zentura, 2023. How Often Do I Need to Refurbish My Office? [Online] Available at: https://www.zenturaworkspace.co.uk/post/office-refurbishment-cycle#:~:text=Every%20week%2C%20we%20speak%20to,every%205%20and%2010%20years. [Accessed 15 May 2024].