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Research Report

Utilising Mass Timber to Unlock the Potential of Adaptive Reuse Projects for Sustainable Human Settlements

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DECLARATION OF ORIGINALITY

I declare that the mini dissertation, "*Utilising Mass Timber to Unlock the Potential of Adaptive Reuse Projects for Human Settlements*", which has been submitted in fulfilment of part of the requirements for the module of DIT 801 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.

Signature: .....

Date: 28-06-2024

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Abstract

This mini-dissertation explores the transformative potential of mass timber (MT) in adaptive reuse (AR) projects to address South Africa's housing crisis in Pretoria's Central Business District (CBD). The research examines perceptions and experiences of construction professionals—engineers, architects, quantity surveyors, and construction managers—regarding MT and AR through detailed questionnaires and interviews. By leveraging the inherent strengths of MT, such as its sustainability, strength, lightweight properties, and rapid construction capabilities, this study aims to present MT as a viable solution to overcome the challenges of AR projects.

The literature review investigates the pressing need for centralised social housing, highlighting the potential of repurposing obsolete buildings in the Pretoria CBD for low-income housing as part of urban renewal strategies. The study also addresses the complexities and benefits of AR, proposing strategies to revitalise dormant structures and integrate MT to create sustainable, efficient, and socially inclusive urban environments.

Key findings indicate that MT facilitates faster construction, reduces environmental impact, and allows vertical extensions of additional stories in high-density urban areas. Despite some challenges, such as the initial cost and limited awareness among industry professionals, the successful implementation of MT in AR projects can significantly contribute to meeting the demand for centralised social housing. The study concludes that strategic collaboration, financial incentives, education initiatives, and industry guidelines are essential to overcoming barriers and promoting the widespread adoption of MT in AR projects.

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Acronyms

AR – Adaptive Reuse

CBD – Central Business District

CLT – Cross Laminated Timber

CNC – Computer Numerical Control

CO^2 – Carbon Dioxide

CoT – City of Tshwane

GDP – Gross Domestic Product

GLT – Glue Laminated Timber

IBT – Innovative Building Technologies

IRR – Internal Rate of Return

LCC – Life Cycle Cost

LVL – Laminated Veneer Lumber

MTC – MT Construction

MSTB – Multi-Storey Timber Building

MT – Mass Timber

RC – Reinforced Concrete

SA – South Africa

Definitions

Adaptive Reuse
Adaptive reuse is renovating a building for a purpose other than what it was originally built or designed for. It involves renovating and modifying a structure to suit a new function while retaining its historic features.

Carbon Sink
Anything, natural or artificial, that absorbs and stores more carbon from the atmosphere than it releases over a given period. This process of absorbing and storing carbon is known as carbon sequestration.

Carbon Footprint
The total amount of greenhouse gas emissions caused directly and indirectly by an individual, organization, event, or product.

Innovative Building Technologies
A construction method or material that is considered new, advanced, or non-traditional compared to conventional building practices.

Life Cycle Cost
the total cost of a building or structure throughout its entire lifespan. This would encompass the initial construction costs and ongoing expenses such as maintenance, repairs, and eventual demolition or deconstruction.

Mass Timber
A category of engineered wood products including glue-laminated timber (GLT) and cross-laminated timber (CLT).

Prefabrication
The practice of assembling components of a structure in a factory or off-site location and then transporting complete assemblies or sub-assemblies to the construction site for installation.

Social Housing
A subsidised rental option provided for households in South Africa earning between R1 850 and R22 000 per month (Capital City, 2024)

Chapter 1 - Introduction:

The research paper investigates the potential capabilities of mass timber (MT) to overcome the barriers facing adaptive reuse (AR) projects for empty buildings in the Pretoria CBD. Perceptions and experiences of construction professionals (engineers, architects, quantity surveyors, and construction managers) regarding mass timber (MT) and adaptive reuse (AR) projects are retrieved through questionnaires and interviews and analysed. By examining these two areas, the research will identify solutions provided by mass timber (MT) to overcome adaptive reuse (AR) project obstacles and suggest strategies to revitalise obsolete buildings.

The literature, bar understanding broader knowledge of MT and AR, will investigate the needs of social housing residents and explore the potential for obsolete buildings in city centres, like the Pretoria Central Business District (CBD), to appropriately house low-income residents in urban renewal strategies. The rich history and multitude of empty buildings in the Pretoria CBD motivated the location for the research, as the increase in crime and degrading infrastructure in the CBD underscores the urgent need for renewal strategies. The paper argues the necessity of including low-income residents in renewal strategies for SA's administration capital.

1.1 Background

A background will be provided to contextualise the reader with the concepts of AR, MT, and social housing – or sustainable human settlements.

1.1.1 Sustainable Human Settlements

The City of Tshwane municipality manages a property portfolio of approximately 369 office buildings. However, it was calculated that if city officials were spread over 135 000sqm of underutilised building space, they would each occupy 35 sqm of space, enough for a one-bedroom apartment. From 1990, private and government headquarters systematically migrated from the business district to surrounding areas of Pretoria (Turok, Seeliger, & Visagie, 2021). This opened the city to crime, vandalism, and poverty and left the buildings occupying the capital city of South Africa (SA) to decay (Botha 2022). Clarke & Corten (2011:888) discovered that developers, like City Property, invested in office spaces during the migration, and at the time of the interview, held a portfolio of up to 700 inner city buildings in Johannesburg and Pretoria. Similarly, the government held its position in the city and prevented a complete property collapse (Clarke & Corten, 2011:887). However, most national departments have since systemically relocated their offices out of the city (Clarke & Corten 2011:887; Bremner, 2000:186). The lack of succinct collaboration between government departments and the private sector results in the slow development of obsolete buildings (Turok, Seeliger, & Visagie, 2021). The HB Philips building, a city-owned building in the CBD's centre, was evacuated due to office relocation and has been abandoned for over five years. A collective vision is urgently needed to revitalise these dormant assets.

Despite Regional Spatial Development Frameworks promoting densification (RSDF, 2018), the government and private sector continue to fuel urban sprawl. With undefined peri-urban areas, developments outside the RSDF force the municipality to provide additional services on the outskirts of metropolitan areas. In contrast, service provision to the city centres is neglected (Sahana et al., 2023:24). Neglect of inner-city service repair and maintenance is exacerbated by the theft, vandalism, or overuse of already damaged services (Turok, Seeliger, & Visagie, 2021:20). Reappropriating empty inner-city buildings promotes the RSDF plans for densification and returns the focus of repair and maintenance on existing services to revitalise Pretoria's infrastructure (Moolla et al., 2011:143). Concentrated service repairs and maintenance promote efficiency by reducing transport costs, increasing readily available labour and materials, and shortening repair turnaround times.

Revitalising Pretoria's CBD through densification and improved service provision will enhance investment opportunities, potentially creating a demand for higher-income markets. However, gentrification often carries a dark secret: the displacement of lower-income groups (Mahlatsi, 2022). The private sector is frequently guilty of developing

areas without concern for the current residents (Wilhelm-Solomon, 2022). National departments have recently fallen into the same trap. Turok, Seeliger, & Visagie (2021:21) found that "the statistics agency was required to build a shelter for 90 street children from the CBD after demolishing two smaller shelters to make way for its new headquarters". Unfortunately, no shelters were built due to disagreements over responsibility. Lower-income groups are not a burden but an asset. Botha (2022:255) iterates how residents of Cosmo City, a spread-out area synonymous with negative perceptions of poverty and crime, continue to contribute meaningfully to SA's gross domestic product (GDP). Therefore, the focus should be on integrating income groups into an inclusive urban fabric through policy, programs, and legislation for responsible gentrification (Cooper et al., 2024).

The current state of social housing often fails to meet the needs of its residents (Olojede et al., 2019). When tenders for social houses are rewarded, they are usually hijacked by corrupt contractors (Mahachi, 2019:12; Moolla et al., 2011) and are often located in existing low-income areas where there are poor services, no access to public infrastructure like schools, hospitals and parks, and little protection against crime (Mahlatsi, 2022). Residents are forced into commutes of up to an hour for job opportunities, making up most of their monthly expenditure (Dallimore et al., 2021). This urban organisation strategy perpetuates the segregation frameworks set up during Apartheid and contributes to social and economic exclusion (Botha, 2022; Landman, 2005). It is vital to protect the income of these residents by locating future social housing closer to cities with services, infrastructure, and job opportunities (Moolla et al., 2011).

1.1.2 Adaptive Reuse

Despite their circularity, sustainability, and cost-saving benefits, AR projects remain rare, potentially due to client demands, complexities arising from heritage legislation, and a need for knowledge and understanding of current technology amongst industry professionals (Clarke & Corten, 2011). However, transforming existing buildings into social housing offers a compelling strategy for socially integrated urban renewal. Traditional construction and building management pose significant obstacles to achieving this vision. Firstly, building plans are notoriously scarce in SA – outdated or missing. Retrieving information on the condition, location, and properties of the existing structure or services can be difficult. This forces the need for rigorous testing and measuring before renovations. Secondly, traditional construction materials are heavy, quickly adding to the foundation load in renovation projects; and require lengthy timeframes to construct, which negatively impacts a dense and congested city. Finally, adapting office blocks into residential units offers numerous opportunities for practitioners, such as reduced live loads on existing structures, but also presents challenges, such as service alteration. These considerations will be thoroughly investigated in the literature and reviewed in the discussion alongside research data.

1.1.3 Mass Timber

As an innovative building technology (IBT), MT offers a promising solution to the limitations of traditional construction methods, emerging as a preferred material technology globally and locally. Trees reduce existing carbon emissions and, when farmed for construction, provide a renewable building material geared towards strength. MT consists of cross-laminated timber (CLT) and glue-laminated timber (GLT), which creates a thick mass of timber that is stronger than singular lumber elements of a similar size (Abed et al., 2022:5). Gonzáles-Retamal et al.'s (2022) study outlines the development of timber to MT, revealing the overwhelming evidence of improved strength, fire resistance, stability, and sustainability as a carbon sink. Rivalling the strength of RC while offering the lightweight advantages of steel (Stazi et al., 2019). The improved benefits of MT have fuelled a global trend for its use even in high-rise buildings (ARUP, 2019), making it an appropriate material for inner-city AR projects.

MTs' innovation extends beyond its physical properties, revolutionising the construction process by necessitating collaboration of all practitioners, early decision-making, and ensuring strict adherence to accelerated schedules and budget (Greyling, 2020:171). Additionally, the relatively lightweight nature of MT also reduces transport costs and

foundation loading and speeds up construction timeframes tremendously (Abed et al., 2022:7,17,18). These qualities position MT as a suitable material for AR projects that transform offices into residential buildings.

Throughout the paper, a clear distinction is made between timber and MT, and it will not be intertwined, as the benefits of MT far surpass that of timber.

1.1.4 Summary

Social housing, MT, and AR projects hold interconnected strategies to address urban challenges. Adaptive reuse of existing buildings, like underutilised office spaces in city centres, offers a sustainable and cost-effective approach to creating social housing. With its strength, lightweight properties, and efficient construction process, MT emerges as an ideal building material for such projects. Combining these approaches makes it possible to revitalise urban areas, provide affordable housing, and promote improved construction practices. However, knowledge gaps and negative perceptions must be addressed to increase implementation.

1.2 Research Problem

Despite the pressing need for centralised social housing in SA, the Pretoria CBD is plagued by a significant number of vacant office buildings. These obsolete structures present an opportunity for office to residential AR projects, alleviating the housing shortage. However, innovative solutions, strategies, or construction methods need to be established to facilitate transitioning these neglected office blocks to habitable spaces.

1.2.1 Objectives

This research aims to investigate the perceptions and experiences of industry professionals on AR projects in terms of their serviceability, structure, economy, and general challenges and opportunities. This study also seeks to provide insights from industry professionals into how AR projects can benefit from using MT to address the need for centralised social housing. The objective of the study is to establish potential solutions, strategies, or construction methods of MT in facilitating the transition from office to residential in AR projects.

1.3 Research Questions

The objective will be achieved by answering the three sub-questions below, which will consequently answer the main research question.

1.3.1 Main Question:

How can mass timber assist in overcoming the challenges facing adaptive reuse projects for sustainable human settlements, according to South African construction industry professionals?

1.3.2 Sub-Questions:

- Are obsolete buildings in the Pretoria CBD appropriate locations for social housing?
- What are the perceptions of engineers, architects, quantity surveyors, and construction managers regarding MT and AR projects?
- What are the challenges of AR projects when transitioning buildings from office to residential, and what are potential solutions provided by MT?

1.4 Limitations and Delineations

Due to the online nature of the questionnaires, researchers were not present when respondents completed them, which could lead to misunderstandings or misconceptions about the questions. To mitigate this risk, the researchers piloted the questionnaire with various professionals before distribution.

Orozco et al. (2023:21) caution readers to verify the data sources, like the interview responses (provided in Appendix A), for further validation, as the possibility of human error, which is common in data collection and entry stages, cannot be entirely eliminated. In filling out the questionnaires, the researchers are reliant on trust and honesty. Therefore, the interviews and questionnaire responses were interpreted with the same nature as a conversation – with critical reflection and clarifying literature.

Restricted time and limited availability of industry professionals necessitated non-probability sampling of convenient participants over probability sampling. Probability sampling, which requires contacting all possible industry professionals and scrutinising their levels of engagement, was not feasible. Although researchers aimed to find an equal number of architects, engineers, quantity surveyors, and construction managers through the questionnaires, there was a reliance on architects' responses due to the authors' and supervisors' known connections in the field. This was mitigated during the interview stage, where all four types of practitioners were included to confirm responses and identify any biases.

1.5 Research Contribution

Despite its benefits, MT remains underutilised in the construction industry, which relies on traditional methods (Botha, 2022). To bridge the gap, fabricators and local manufacturers like MTT host industry-wide workshops and programs for clients and practitioners (van der Hoven, 2024). Understanding the perceived barriers of MT among construction professionals is crucial for fostering innovation and sustainability. The knowledge developed in the study will assist educators, manufacturers, and fabricators to address obstacles preventing widespread adoption.

Additionally, though AR projects are seemingly more frequent than MT, they still face various challenges that limit their implementation. No innovative solutions, strategies, policies, or construction methods are in place to assist construction practitioners in AR projects. Therefore, this study aims to bridge the gap, providing practitioners with strategies, solutions or construction methods that facilitate AR projects, with specifical focus on office to residential conversion.

Chapter 2 - Literature Review

The literature review, in this study, serves as a partial qualitative analysis tool to address the first sub-question regarding social housing, and to provide deeper insights into AR and MT. Thus, the review will identify, analyse, and synthesise relevant literature concerning sustainable human settlements, and specifically social housing in SA, expanding the scope to include local and global literature on AR and MT.

2.1 Sustainable Human Settlements

This section will examine the challenges and shortcomings of social housing programs in South Africa, emphasising the need for centralised social housing in city centres to address issues of segregation, access to opportunities, and affordability of residents.

2.1.1 Social Housing Development Context

The current state of housing in SA is critical, with a backlog of 2.4 million houses and an estimated 23% of households lacking adequate shelter (Mahachi, 2019:3; Olojede et al., 2019:165-166). As a result, most citizens eligible for social housing live in informal settlements while awaiting housing or social grants (Adetooto, Windapo, & Pomponi, 2022; Mahachi, 2019). "The South African housing market is characterised by a severe housing shortage, affordability issues, fragmented housing policy and administrative systems, lack of capacity, non-payment of housing loans and service payment boycotts, lack of end-user finance, insufficient land, and inappropriate standards" (Olojede et al., 2019:164) Despite shifts from quantity to quality in housing delivery, poor quality and size of housing delivery persists (Botha, 2022:248).

Addressing the need for social housing has been declared a priority by the South African government (Mahachi, 2019). Thus, housing programs encompass financial and product interventions (Olojede et al., 2019). Social housing programs include the National Housing Forum (NHF), established during the inception of the South African Housing policy, as a non-governmental body with a focus on the right of citizens to adequate housing (Social Economic Rights Institute, 2018). Additionally, the Social Housing Regulatory Authority (SHRA) aims to achieve 30,000 housing units by the end of 2024 (Department of Government Communications and Information System, 2021:111), and Department of Human Settlements (DHS, 1996), which facilitates the national housing development process, aiming to deliver 180 000 subsidy housing units, and 25 000 rental units (Department of Government Communications and Information System, 2021; Department of Human Settlements, 2019). Furthermore, financial initiatives such as Metro's access loans, the Finance Linked Individual Subsidy (FLISP) and its associated National Housing Finance Corporation (NHFCA) (1996) are "mandated to provide access to affordable housing finance for low-income and middle-income households… "(Botha, 2022:250; Department of Government Communications and Information System, 2021:110). These programs may signify a concerted push towards increased housing development, yet users are widely disappointed with the quality and location of social housing (Moolla et al., 2011: 143; Botha, 2022:255).

2.1.2 Centralised Social Housing

Lower-middle-income cities, like Pretoria and Johannesburg, face the fastest rate of urbanisation – which is expected to almost double by 2030 (5.635 million – 11.573 million in Johannesburg) (United Nations, 2016:4). Low-income groups are drawn to urban areas through pull factors like job accessibility, education, improved services, while push factors from rural areas include poverty, inadequate services, safety concerns, and political instability (Cooper et al., 2024:5). The increase of urbanisation, as Fujita (1989: 12) notes, is due to household residents prioritising their proximity to the CBD. This has caused poverty-stricken citizens and migrants to reside illegally in abandoned buildings, creating informal settlements (synonymous with rural locations) inside inner-city buildings (Wilhelm-Solomon, 2022). The media and government have labelled this consequence as 'hijacking', criminalising, arresting, removing, and deporting some residents without supplying even temporary shelter (Wilhelm-Solomon, 2022). The Inner-City

Federation (ICF) was formed in 2015 by residents continuously inflicted by unconstitutional building raids (Wilhelm-Solomon, 2022). They marched to the City Council in Johannesburg with a memorandum stating, "Our local government does not provide the residents of the inner city with public and social housing; they only talk of evicting non-documented people and taking away basic municipal services from inner-city residents. They act like they were voted to criticise poor people, abuse them, and ignore their right to dignity" (Wilhelm-Solomon, 2022:198).

By 2003, the state had subsidised the construction of over 1.5million RDP houses, named after the government's Reconstruction and Development Programme (Wilhelm-Solomon, 2022:54). But "it was a program plagued with problems, including widespread perceptions of corruption and poor building quality. Also, the houses were built on urban outskirts, often far from places of work" (Wilhelm-Solomon, 2022:54). Low-cost housing is typically placed on the periphery of townships or far from economic centres (Mahlatsi, 2022:486; Turok & Borel-Saladin, 2014:688). These schemes have perpetuated historical segregation and decentralisation in underprivileged communities (Botha, 2022:248; Landman, 2005). An ANC activist and resident in Cosmo City, said that residents of Diepsloot were removed to Cosmo during 1992 Apartheid to make way for high-income gated estates such as Dainfern and Steyn City (Botha, 2022:251; Dainfern 2024). "Therefore, Cosmo City should be viewed as part of the restructured or decentralised post-apartheid Johannesburg as opposed to integration" (Botha, 2022: 251).

Critics at the ANC Land Summit 2018 in Johannesburg highlighted that perpetuating apartheid planning undermines integration-based wealth creation through land and property assets (Botha, 2022:249-250). Furthermore, social housing provided in peri-urban contexts excludes low-income South Africans from accessing essential amenities, infrastructure, and job opportunities (Olojede et al., 2019; Burgoyne, 2008; South African Cities Network, 2014). Providing social housing in peri-urban areas also increases service infrastructure and raises rates and taxes, creating a scenario where subsidised housing is provided, but with increased running costs (Botha, 2022:257).

31% of City of Tshwane (CoT) residents, which includes Pretoria, spend more than 30 minutes on their most frequent trips (Dallimore et al., 2021:44). "...it is of utmost importance that all services and amenities be provided to reduce transport costs for the inhabitants" (Moolla et al., 2011:142) and provide proximity to employment, services, and resources (Cooper et al., 2024). A lack of commitment is given towards theorising alternatives to desegregate apartheid urban frameworks (Landman, 2005; Todes, 2006; Radikedi, 2005; Mahlatsi, 2022). A strategy workshop in Centurion in 2021 saw Deputy Director General Leshabane suggest a shift towards acquiring buildings in the inner city of Pretoria for vertical densification (Botha, 2022: 249).

According to Andersen et al. (2022:7), buildings suitable for AR are vital in areas with a pressing need for housing, like SA's densely populated city centres. Additionally, AR can help distribute the population in overly dense peri-urban regions of Soshanguve, Sunnyside and Arcadia (Naidoo et al., 2023), housing mainly indigent residents, into central zones. By providing centralised social housing for low-income groups in the CBD, the state can provide the benefits of city living, like job opportunities and cost-effective transport, to protect incomes and promote responsible city renewal.

2.2 Centralised Human Settlements in the Pretoria CBD

This section will briefly outline the history of the Pretoria Central Business District (CBD), and subsequent urban migration. It will then explore strategies for revitalising the CBD through densification and adaptive reuse of existing buildings for social housing.

2.2.1 History of Pretoria CBD

Pretoria CBD emerged as a centre of political power (Mabin, 2012) for the Afrikaner region and, in 1910, became the administrative capital of the Union of SA (Turok, Seeliger, & Visagie, 2021). In the 1980s, new commercial cores in the east of Pretoria prompted a migration out of the Pretoria CBD. The systematic abandonment was perpetuated by the dismantling of Apartheid rule - mainly the 1991 repeal of the Groups Areas Act of 1966, which enforced racial

segregation (Bremner, 2000:185-186). In fear of negative influence from differing racial classes, the white and wealthy withdrew into gated office parks and communities (Clarke & Corten, 2011:881; Botha, 2022), abandoning the city to crime, grime, and decay (Turok, Seeliger, & Visagie 2021:20). The government contributed to this with individual government departments removing themselves from the city (Clarke & Corten, 2011:887). Thus, the working poor took residence in vacant residential buildings, and the demographic changed from middle and upper-income whites to low and middle-income blacks (Turok, Seeliger, & Visagie 2021).

The city is thus full of obsolete or ageing office structures (Langston et al., 2008:1710-1711). Zoning laws have maintained a heavy bias towards office space in the inner city despite the market shifting away from demand. The potential, therefore, arises to adapt these offices, seen in green in Figure 1, into mixed residential units and lively commercial activities. "Reconfiguration of the city is needed: This can be achieved through a legislative imperative of social housing being set aside in every existing and new residential development" (Mahlatsi, 2022:486). Russel (2018:4) reveals that Cape Town has already designated 900sqm of space to be rezoned from office to residential in the inner city.

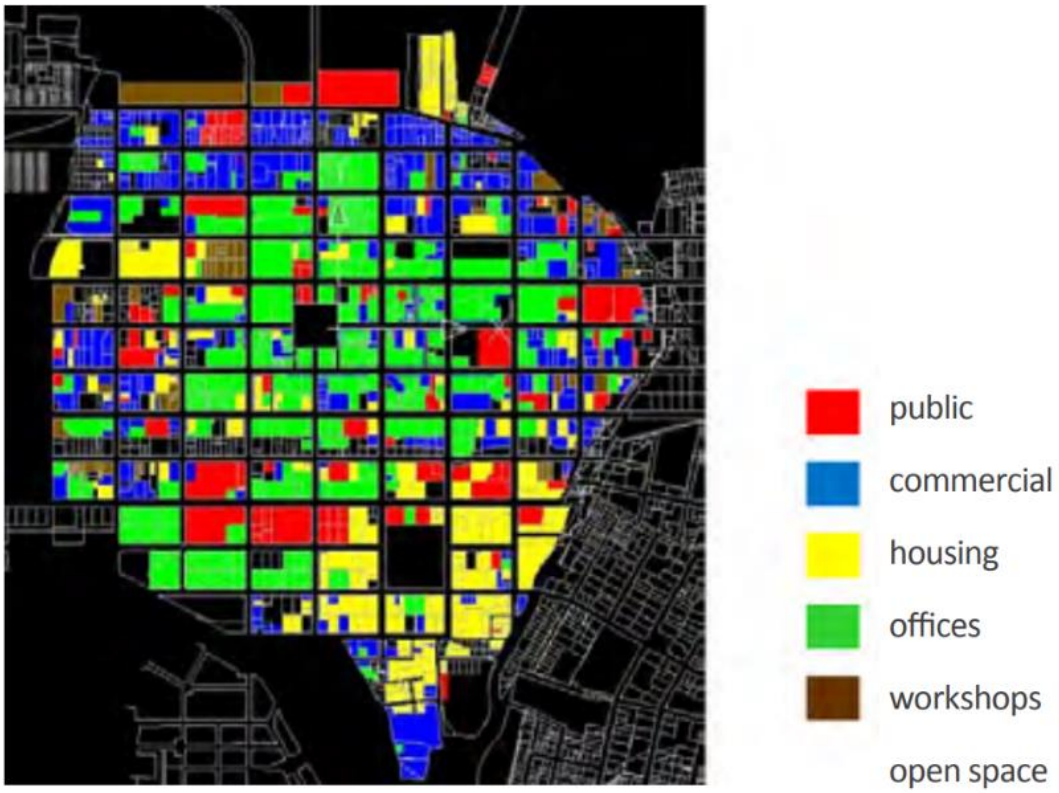


Figure 1: Functions Map. (Corten and van Dun, 2010)

2.2.2 Public and Private Collaboration in Catalytic Projects

Increased rental in the CBD reveals the potential for investment from the Government and Private sectors (Property 24, 2009; Clarke, 2011). Though urban revitalisation is a positive step towards improved investment, gentrification prevents lower-income groups from benefiting from economic development - and could lead to unfortunate evacuations of people with low incomes (Botha, 2022). Unfortunate examples include ninety street children displaced when their shelters were demolished for a new public Statistics Agency building (Turok, Seeliger, & Visagie, 2021:21) or private sectors consistently conducting unconstitutional raids on informal inner-city dwellers to remove (Wilhelm-Solomon, 2022). Therefore, a grassroots approach is vital for the responsible economic and social renewal of the city that incorporates the underprivileged within social housing.

Catalytic projects, started by Minister Lindiwe Sisulu in 2009, are defined as mixed-use, non-racial, and class-integrated projects, joining the fragmented racial and economic groups of SA through flexible socio-economic policy frameworks and housing developments (Botha, 2022; Human Settlements, 2015/16:262-267).

Though the rise of social housing does not reassure developers (Turok, Seeliger, & Visagie, 2021:21), government subsidies can make the social housing market appealing. If 30% to 70% of units contribute to deep down-market reach of rent no higher than R2 500/month, the city can offer approximately 77% capital costs of units targeted towards social housing (Department of Human Settlements, 2009:76). The cost of construction per unit is roughly R426 000 (including land and services) and SHRA administers R328 867 per unit (Social Housing Regulatory Authority, n.d.). Essentially, private development can contribute to socially inclusive and responsible revitalisation that avoids gentrification through mixed-income housing provisions.

2.2.3 Densification Strategies

The proportion of the global population living in cities is expected to rise from 55% to 68% by 2050 (Andersen et al., 2021:1; United Nations, 2018). Urban migration, rapid population, and increased wealth in developing countries will result in the inevitable densification close to economic hubs (Skullestad et al., 2016:113). Sitting in the financial heart of the country, the Pretoria CBD will see an influx of residents (Clarke & Corten, 2011). SA's very own Redbook (Department of Human Settlements, 2019) outlines the need for a city's compactness, walkable neighbourhoods with shared amenities, a variety of housing choices, and public transport, all within a 1-5km walk radius (CSIR & DHS, 2019; van Niekerk et al., 2015).

Including social housing with inner-city densification strategies creates efficiencies for concentrated service provision. Higher density service provision can potentially reduce the cost of installation, repair, and maintenance due to less distance travelled to service more people. Additionally, fewer roads must be managed through densified vertical urban expansion (Parker & Hamman, 2020). Therefore, instead of installing or repairing costly services in new peri-urban areas, it has been argued that it is more cost-effective to repair existing infrastructure to make inner-city buildings liveable (Moolla et al., 2011). Multi-unit apartment buildings also have reduced energy consumption for heating due to building surface to volume ratio and shared walls (Diamond, 1995; Skullestad et al., 2016:113)

Additionally, uncoordination in the mayor's office has led to ad hoc developments, as seen in over densified areas like Sunnyside and Arcadia, neighbouring the Pretoria CBD (Botha, 2022; Clarke & Corten, 2011). Senior municipal politicians acknowledge that "decision-making was slow and urban management is poor" (Turok, Seeliger, & Visagie, 2021:21). The problem is that the population is disproportionately dispersed around Pretoria, with neighbouring city areas like Sunnyside and Arcadia pressuring service provision not conducive for such densification (Botha, 2022:254). In contrast, the CBD infrastructure and services remain virtually unused (Mahlatsi, 2022) and suffer neglect (Botha, 2022:254). Since 2015, a decline in satisfaction with service provision has been seen among Pretorian residents (Dallimore et al., 2021:20-25), with some residential areas taking on "slum characteristics" (Clarke & Corten, 2011:887). Langston et al. (2008:1712) promote the reuse of existing public infrastructure to relieve demands on local authorities.

2.3 Considerations of Adaptive Reuse

This section will outline the benefits and challenges of AR in construction, emphasising its potential for sustainable urban development and revitalisation of existing buildings. It will also discuss the complexities involved in such projects, including structural considerations, service upgrades, and heritage preservation.

2.3.1 Benefits of Adaptive Reuse

Urbanisation leads to a surge in demolition and new construction, with newer buildings often at higher risk of demolition in densely populated areas (Andersen et al., 2022; Andersen et al., 2023). However, this practice is unsustainable as only 36% of materials like concrete and steel are recycled (Andersen et al., 2022:7). By leaving the basic structure intact and changing its use, AR minimises demolition or deconstruction (Langston et al., 2007). Andersen et al. (2023:21) promote the importance of preserving local character, heritage and valuable resources while reducing the need for demolition.

Buildings older than 60 years are deemed heritage artefacts (National Heritage Resources Act, 1999). This is advantageous for developers, as "older buildings are often in advantageous locations in city centres and close to transport making reuse (where appropriate) more viable." - Langston et al., (2008:1712). City Property believes that the "revitalisation of city buildings and the rehabilitation of city centres is plain good business" through accommodating the demand for housing in the City by adapting empty offices in its portfolio into residential accommodation (Clarke & Corten, 2011:889). Finally, AR projects for social housing can extend the lifecycle of buildings, with a 40% reduced environmental impact compared to a new building (Rasmussen & Birgisdottir, 2015).

Russel (2018:41) argues that AR is a more sustainable option, with less disturbance due to hazardous materials, falling materials and excessive dust, resulting in an environmentally unfriendly process (Itard & Klunder, 2007). Additionally, AR generates less waste, uses fewer materials, and uses less energy than rebuilding after demolition (Itard & Klunder, 2007). The construction process is also more convenient, as the existing structure can be used as an enclosure against weather interruptions (Remøy & van der Voordt, 2007:8). Several papers have discussed the opportunities created by AR projects over demolition and redevelopment (Cooper, 2001; Douglas, 2002)

Office buildings carry high conversion potential due to wide spans with few columns, high floors, and high load-bearing capacity (Russel, 2018). Additionally, offices require more elevators and staircases due to increased occupancy capacity and, therefore, offer an abundance of circulation for residential blocks. However, low acoustic insulation, high beams and dense structural grids reduce conversion potential (Russel, 2018).

2.3.2 Challenges of Adaptive Reuse

Altering building components invites complex challenges in AR projects. Façade interventions incur tremendous costs, and cantilevering floors with curtain walls reduce the potential for balconies (Russel, 2018:46-47). Well-maintained façades with a dense grid, large floor plates, and building depth increase conversion potential (Russel, 2018).

Thorough inspections of older buildings are necessary as building plans are not always correct, and the structure and fabric might be in a state of decay (Russel, 2018:37). This issue is exasperated in the Pretoria CBD, where many ex-government buildings lack proper documentation due to historical oversight, requiring costly development of building plans before AR projects can proceed.

Additional services are required for residential buildings, necessitating more vertical shafts for electricity, water, and plumbing compared to offices, which increases costs (Remøy & van der Voordt, 2007:6). Office buildings may not be optimally designed for residential use, and older buildings often do not meet SANS 10400 building standards for safe occupation. De Vrij (2004) has developed a checklist to determine conversion feasibility.

Collaboration with heritage practitioners is vital for developers. City Property was forced to halt the demolition of Marchie Mansions in Pretoria after a cease-and-desist order revealed the building to be a heritage artefact, though some damage had already been done (Clarke & Corten, 2011:889-890). Despite national legislation requiring local, provincial, and national authorities to compile a heritage register by 2009, no such registry exists (Clarke & Corten, 2011:889; National Heritage Resources Act, 1999).

Pedestrian movement and vehicular transportation are vital for inner-city logistics, with congestion affecting infrastructure and economics (Russel, 2018). The government forces inner-city developments to consider site access and adjacent street use in construction to avoid unnecessary congestion (Russel, 2018:41-42). Given South Africa's notoriously long construction schedules and increased delays, innovation is required to shorten construction times.

Parking requirements often impede developments, as parking takes up most of the development space and incurs tremendous costs. Most city ERFs cannot accommodate residential parking requirements, forcing developers to demolish buildings (Williams, 2016). Though the lack of available parking can negatively impact residents of middle- to higher-income groups, students, or citizens in need of social housing likely don't own vehicles and, therefore, don't need parking (Russel, 2018). Decreasing parking requirements for social housing or providing parking incentives can enhance development feasibility by reducing construction costs for below-market units (Russel, 2018).

2.3.3 Vertical Extensions

City planning policies, like the City of Tshwane Integrated Development Plan (2020), are increasingly focused on densification for social, environmental, and economic reasons, shifting away from uncontrolled urban sprawl (City of Tshwane, 2020:158). Raising the height of existing buildings, especially with MT, is a growing global trend to accommodate densification (Kuzmanovska et al., 2018). If a building is designated for renovations, the building owner can take advantage of the existing construction process to add floor space above for rental or sales, mitigating the cost of construction or potentially making a profit (Soikkeli, 2016:817).

Karjalainen et al. (2021:2) argue for the use of renewable materials in AR projects. Therefore, many have considered the potential for MT to be used in AR projects. MT is used globally to add up to three extra storeys of existing residential blocks since it has two-thirds of the design loads of concrete (ARUP, 2019:28). In London's Dalston Lane project, completed in 2017, strict foundation load limits necessitated innovative solutions for building expansion (ARUP, 2019: 30). By choosing lightweight CLT (mass timber) construction over concrete, the project added 15 extra apartments across three additional storeys, with load capacity for 20 extra apartments in the future (ARUP, 2019:30).

No formal live load allocations for office or residential could be found in SANS 10160 for South African standards. However, the total live loads, outlined by the Bangladesh National Building Code (2012:4-5), for a typical office use are between 2.40kn/m^2 (offices) and 4.7kn/m^2 (lobbies and first-floor corridors), where the live loads for a residential block are between 1.44kn/m^2 (Habitable areas) and 1.92kn/m^2 (areas not including stairs and balconies). Therefore, repurposing old office buildings for residential use exponentially reduces the live loads on existing columns and foundations by at least 2.78kn/m^2. This reduction of live loads can be transformed into additional floors above. For concrete buildings, which make up most of the CBD's building stock, this opportunity is even more significant as concrete strengthens with age, allowing existing columns to carry more load (ARUP, 2019:25). However, fire safety measures must be carefully considered to meet requirements for compartmentation, protection, and escape, especially when increasing the building's height (ARUP, 2019: 28).

Subsequently, when considering the incorporation of relatively light-weight MT (which allows for the addition of up to three stories of existing buildings) in an office-residential AR conversion (which provides overall reduced live load), the potential arises for over four stories to be added to existing building stock (Figure 2)

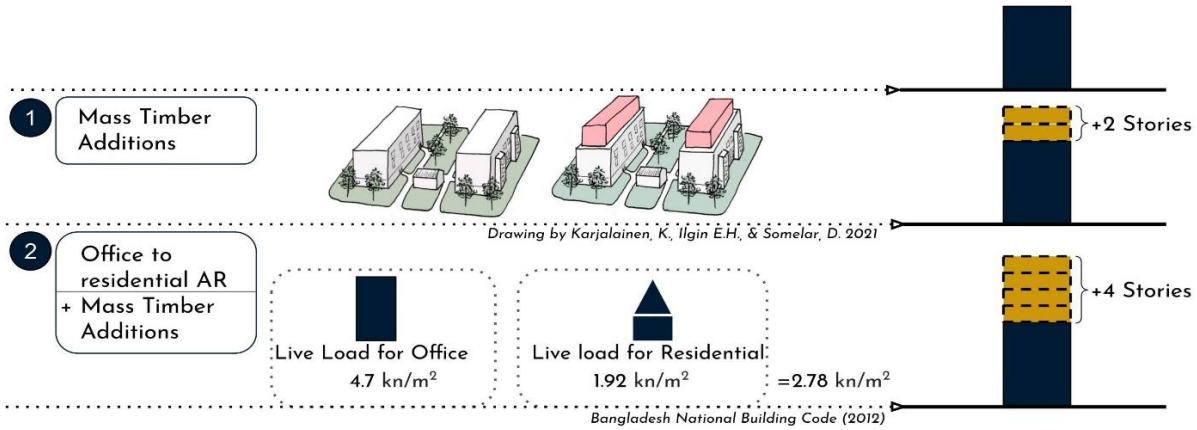


Figure 2: Image adapted from Drawing by Karjalainen et al., 2021, and this paper's author combining attributes of AR conversion from office-to-residential with MT allowing the extension of multiple floors above an existing structure (Author, 2023)

2.4 Considerations of Mass Timber

This section will provide an overview of MT, discussing history, and applications in construction, with a focus on its growing prominence in South Africa. It will also delve into the economic, environmental, and technical aspects of MT, including its cost-effectiveness, sustainability, strength, and fire resistance. Additionally, the section will address the perceptions and challenges surrounding timber SA and MT globally, highlighting the need for education and collaboration to promote its wider use in the construction industry.

2.4.1 Conventional Construction and Innovative Building Technologies

Joseph Monier's (1823 - 1906) invention of reinforced concrete (RC) in 1849 led Francois Hennebiques (1842 – 1921) to develop the reinforced concrete (RC) system we know today (Frampton, 2001). However, current construction practices contribute to over 37% of greenhouse gas (GHG) emissions globally (UN Environment Program, 2023), with the concrete manufacturing process alone contributing 5-8% of worldwide GHG emissions (ARUP, 2019:15; Wikstrom, 2023)

This has annual cost implications for existing buildings, considering SA's Carbon Tax Act of 2019, which demanded that developers pay R120/ton of CO^2, with a yearly increase of inflation + 2% (SARS, 2023). The 2024 carbon tax rate sits at a high of R154/ton of CO^2. Problematically for developers, most high-rise buildings developed during Pretoria's growth included RC and steel structural systems, all materials with high embodied carbon (Skullestad et al., 2016). Concrete's carbon footprint and steel's energy demands have propelled timber to the forefront of discussions on sustainable cities (Goubran, Masson & Walker, 2020), and MT is its pioneer.

Substituting RC with timber can lead to a 60 to 75% less embodied carbon footprint than benchmark RC structures (Baker & Schultz, 2014). Additionally, if MT structures are incinerated at the end of life for energy generation, carbon neutrality or negative carbon footprints can be achieved - a tremendous feat for the construction industry (Skullestad, Bohne, Lohne, 2016:122).

2.4.2 Introduction to Mass Timber

MT, including glue-laminated timber (GLT) and cross-laminated timber (CLT), has developed tremendously since Otto Hetzer's original glulam (GLT) patent in 1906 (ARUP, 2019:66). Additionally, CLT, developed in Europe in the 1990s, has become widely used worldwide (Abed et al., 2022:4).

Glue-laminated timber (GLT) panels are manufactured by layering lumber boards parallel to each other and bonding them with structural adhesives (Image b* in Figure 3). The resulting strength lies predominantly along the wood grain,

making GLT particularly suitable for use in columns and beams. Notably, a GLT column can exhibit greater strength than a solid lumber column of the same dimensions (Abed et al., 2022:5).

In contrast, cross-laminated timber (CLT) panels are constructed by layering and bonding lumber at right angles, using similar structural adhesives (Image a* in Figure 3). This cross-bracing orientation allows the wood grain to run in both directions, providing CLT panels with exceptional two-way span capabilities akin to RC floor slabs (Abed et al., 2022:4).

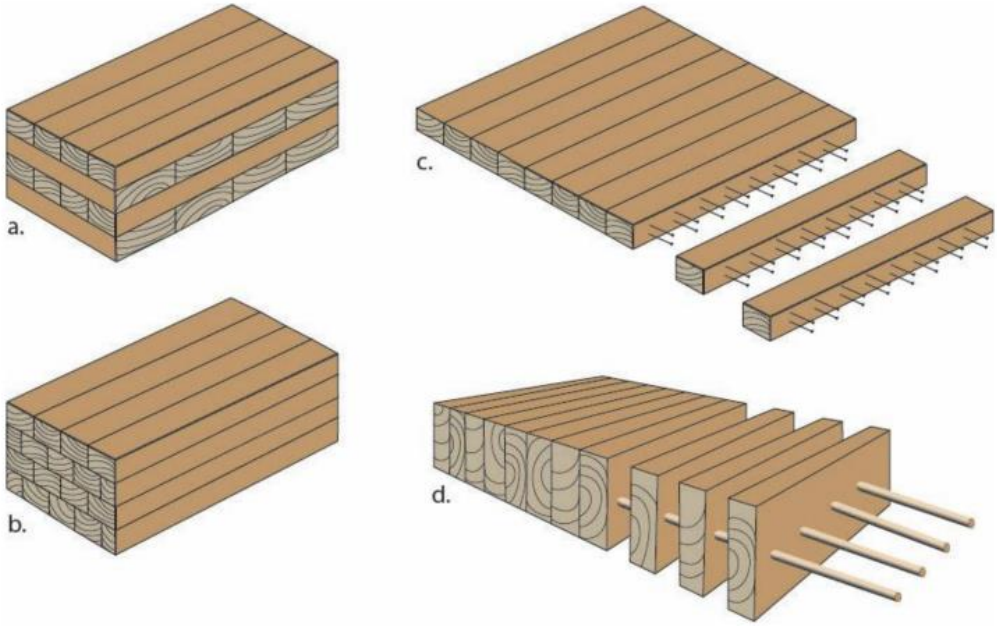


Figure 3: Cross-Laminated Timber (a); Glue Laminated Timber (b); Nail Laminated Timber (c); Dowel Laminated Timber (d) (Abed et al., 2022:4)

2.4.3 History of Mass Timber

Large timber structures have strong routes in history. In the Chronicle of Kings (it is said that "The mansions of the cities (that) reached the clouds were mostly built of wood" (Kalhana, 1148). More famously, the first temple in Jerusalem (957BC) was made of mostly Lebanon's cedar logs (1 Kings 7:2). Historian Lewis Mumford emphasised wood's role in the European machine age, from the 10th to the 18th centuries, in various applications like buildings, bridges, and ships (ARUP, 2019:12). However, Timber structures faced a decline when rapid population growth and ill-considered urban densification resulted in devastating fires like the Great Fire of London (1666), the Great Chicago Fire (1871), and the Boston Fire (1872). These disasters prompted a shift towards non-combustible materials such as bricks, concrete, and steel (Smith & Snow, 2012:505).

However, the recent rise in tall multi-storey timber buildings (MSTB) reflects advancements in engineering and construction sciences of timber to MT. González-Retamal et al. (2022:30) give a comprehensive analysis of over 286 pieces of literature on MT in environmental, sustainable, and economic categories. Over 16 studies suggest that the global implementation of CLT has become economically competitive, and 37 studies promote its environmental sustainability, meeting demands for faster construction and comparable strength and quality (González-Retamal, 2022:6).

2.4.4 Mass Timber, Global to Local Case Studies

The Stadthaus at 24 Murry Grove in England, erected in 2008 by Waugh Thistleton Architects, marked a milestone as the world's first high-rise MT building - Its prefabricated construction reduced build time by 23 weeks (Greyling, 2020:28). Other globally recognised high-rise timber buildings include Wood Innovation and Design Centre in Canada (2014), Fore-Living in Melbourne, Treet in Norway (2015), Brock Commons Tallwood House in Canada (2017), and Hoho Tower in Austria (2017) (Goubran, Masson, & Walker, 2020:101).

Over the past decade, MT developments in South Africa have served as case studies aimed at demonstrating the potential of MT to a cautious industry. A few case studies include the Hout Bay Show House in the Western Cape, built in 23 days, ending in September 2015 (HWZ International, n.d; Greyling, 2020:43). Another example is the dining Hall (Figure 4) and auditorium of the Future Africa campus in Pretoria, completed in 2018 by EarthWorld Architects, which employed pre-fabrication principles (Greyling, 2020:33). Portal frames, constructed from three layers of 22mm plywood boards cut with CNC machines, were assembled off-site and installed within 90 days, by a carpenter who had no construction experience (Greyling, 2020:33).

Despite this progress, the limited number of local MT manufacturers presents a significant obstacle to widespread adoption. MTT, XLAM SA (PTY), and HWZ International are among SA's few MT fabricators. MTT is actively investing in research and development with the University of Pretoria to promote MT within both practice and academia.

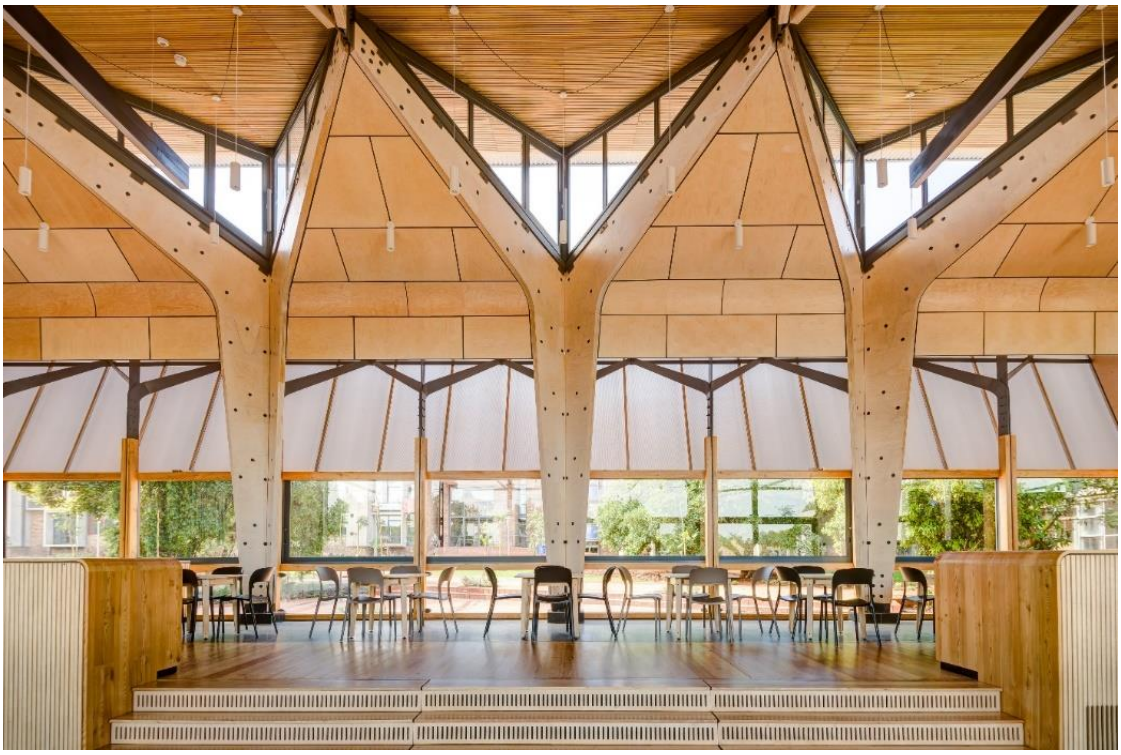


Figure 4: Dining Hall at Future Africa Campus. Designed by Earth World Architects. Pohotograph by FUTUREAFRICA.science

2.4.5 Pre-Fabrication for Inner-City Construction

The use of prefabricated components, particularly MSTB, has become a notable trend (Leskovar & Premrov, 2021:1). This is made possible with computer numerical control (CNC)-based factory processes. CNC manufacturing ensures tight dimensional tolerances within millimetres, drastically mitigating the risk of errors (Greyling, 2020:33,41).

Prefabricated components can be built concurrently with foundations and footings (Abed et al., 2022:17), drastically accelerating construction (Orozco et al., 2023). This front-loaded design and construction process helps mitigate change orders (Greyling 2020:165). Additionally, assembly processes ensure quieter, safer, and less disruptive construction sites with minimised truck deliveries (20% net savings on transport) and reduced onsite waste generation (Abed et al., 2022:24; ARUP, 2019; Leskovar & Premrov, 2021). Coupled with Improved health and safety standards, workforce development, and consistent product performance (ARUP 2019:43), it paved the way for MT to revolutionise construction in inner cities.

2.4.6 Economic Performance

Most of the cost benefits of MT come from its lightweight qualities and speed of construction. CLT & GLT are typically 40–50% lighter than RC structures, resulting in smaller and lighter foundations, which significantly reduces earthworks and foundation costs (Abed et al., 2022:17; Scouse et al., 2020). Studies attribute the accelerated construction pace of MT construction to their lightweight characteristics, enabling larger and fewer lifts, dry jointing of components, and precise sequential packing and delivery (ARUP, 2019:48 This corresponds with Abed et al. (2022:18) in which they found a 61% reduction in timeline compared to concrete and steel.

Westhuyzen and Wium (2021) conducted an in-depth study evaluating the financial feasibility of MSTB and RC structures in SA, revealing through a comprehensive financial model that MSTBs achieve an internal rate of return (IRR) of 20.9%, with a hurdle rate assumed at 15%. Therefore, justifying MSTB as financially justifiable. The study also revealed that the 5-month shorter construction schedule of MT compared to RC frames (Figure 5) led to significant interest savings of R1,220,000 and five extra months of rent income of R4,646,500. However, The Initial capital investment for the MSTB was 10% more than the RC structure, which held an IRR of 25.7%.

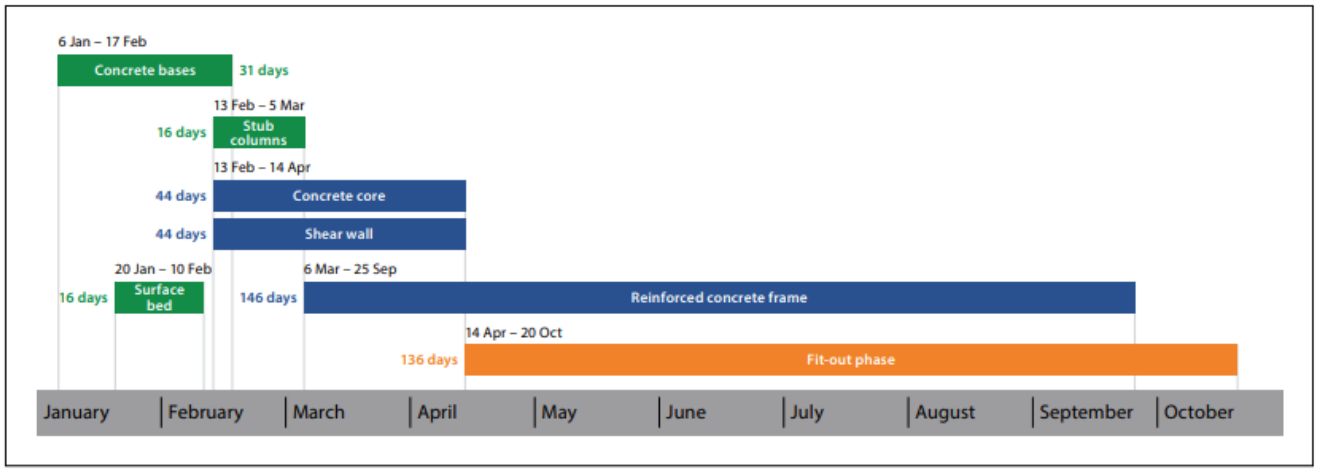


Figure 5: Construction Timeline of RC Building (Westhuyzen & Wium, 2021)

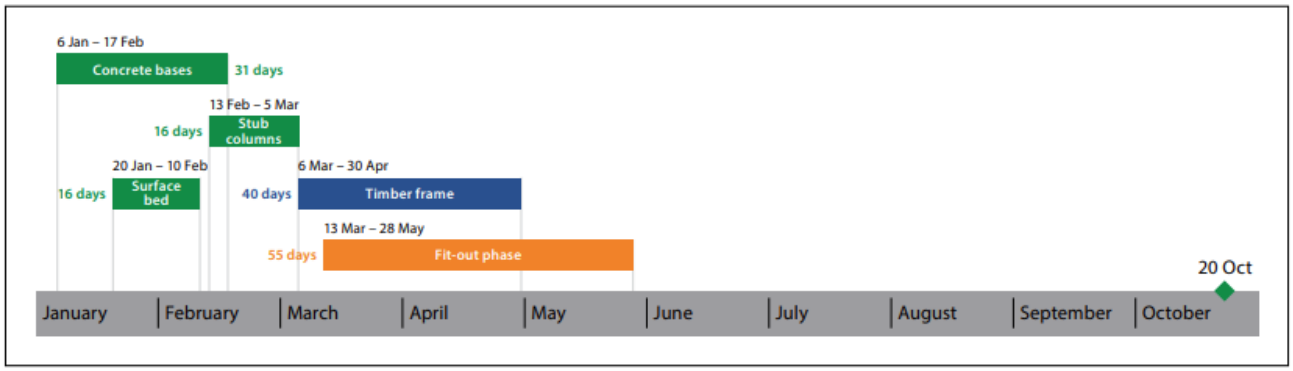


Figure 6: Construction Timeline of MT Building (Westhuyzen & Wium, 2021)

In concrete construction, design changes necessitate a time-consuming rework process, often doubling the time per alteration and accumulating significant project delays (Greyling, 2020). Additionally, the study did not include the annual carbon emissions and, thus, the annual carbon tax incurred on developers over the five years, which will affect the RC structure's IRR.

The perceived higher cost of MT remains a significant concern among industry professionals (Abed et al., 2022:16). Achieving cost competitiveness in SA's MT industry will require concerted efforts from stakeholders across the

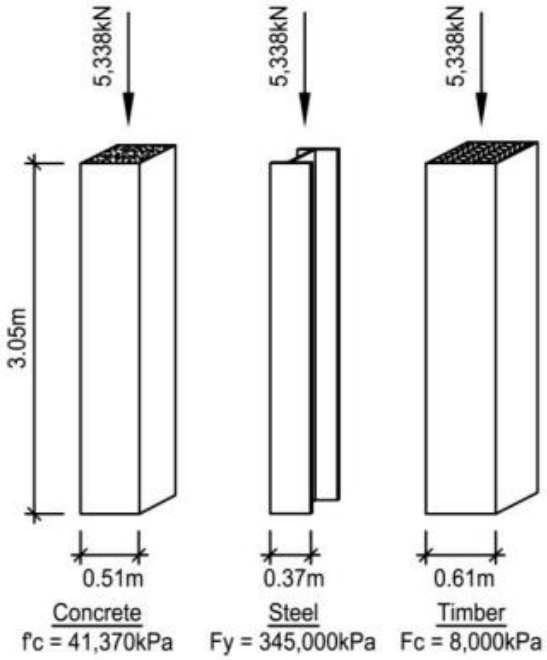
forestry, manufacturing, and construction sectors (Hildebrandt et al., 2017). Despite this, MSTBs have the potential to stimulate local economies by activating real estate and forestry sectors (Hildebrandt et al., 2017).

2.4.7 Availability

Sawmills have the potential to meet the current demand for timber, as it is mainly exported, with rough-sawn and planed pine timber accounting for the majority of IOEC exports in the building materials category (IOECadmin, 2022). The forestry sector in SA encompasses 1.2 million hectares of commercial plantations, covering only 1% of the country's total land mass and showing room for growth if demand requires (Greyling, 2020:18). South African forestry policies are robust and progressive, promoting inclusivity, sustainable practices, fair labour, and economic growth through black ownership initiatives, skills development, and certified fair trade (Ofoegbu & Speranza, 2021).

2.4.8 Strength and Stability

Timber possesses remarkable strength capabilities. Figure 7 shows comparable sizes of concrete, steel, and timber under the same load (Baker & Schultz, 2014). The timber column was 102mm thicker when carrying the same load compared to the concrete column. The strength and durability of timber cannot be understated, with research indicating no correlation between building material and useful lifespan, debunking the notion that timber structures are less durable than concrete or steel counterparts (ARUP, 2019:70).



Material Axial Strength Comparison

Material	Concrete	Steel	Timber
Cross Section	508x508mm	W14x99	610x610mm

Figure 7: Column Strength Comparison (Baker & Schultz, 2014)

3.4.9 Fire Ratings

It is essential to consider the improved fire rating of MT, especially when used in contexts of densified MSTBs. Figure 8 reveals the effect of fire on structural components. Steel members, seen as melted and warped, are fully supported by the remaining timber beam. This underscores the ability of thick timber elements to withstand loads in a fire. Safety considerations, particularly regarding fire performance and design, are extensively addressed in works by Kaufmann et al. (2019), Santana-Sosa et al. (2018, 2019), and Santana-Sosa et al. (2019), highlighting the industry's commitment to ensuring building safety (Gonzáles-Retamal et al., 2022:30).

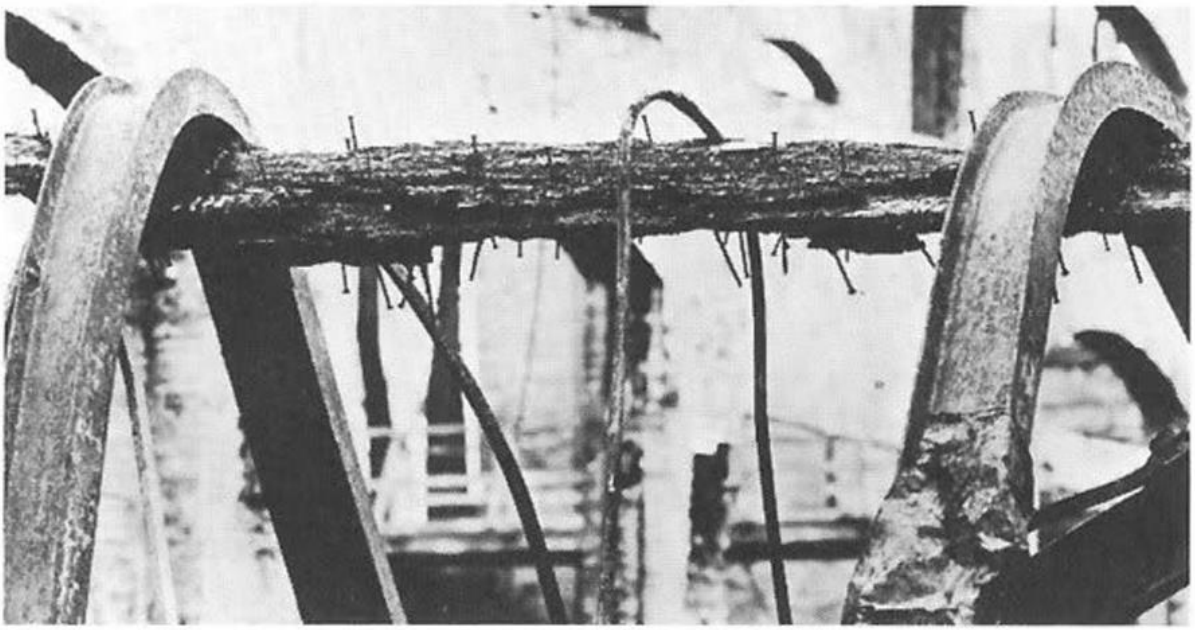


Figure 8: After the fire scene. Shows a wood beam supporting twisted steel I-beams (Forest Products Laboratory; v.d Merwe, 2024)

MT, unlike light timber frames, can provide fire resistance comparable to or greater than other materials. MT behaves similarly to heavy wood members, forming a char layer that insulates the core and preserves structural strength (Figure 9)(Baker & Schultz, 2014; Lyons, 2009). Unlike light-wood frame construction, MT panels minimise air voids, reducing the risk of fire spread and structural collapse (Abed et al., 2022). MT as a fire mitigation strategy is highlighted in designs using CLT cores over concrete walls as fire escapes (ARUP, 2019:72). Recent research in SA has even shown that locally manufactured CLT panels can achieve significant fire resistance ratings (van der Westhuyzen et al., 2020:40).

Figure 9: Charing Layer protecting the structure of the internal timber beam (van der Merwe, 2024).

2.4.10 Mass Timber Infill and Hybrid Construction

Timber integrated with concrete, steel, and even glass maximises structural efficiency (ARUP, 2019:74). These hybrid structures offer improved medium in construction time, reduced carbon footprint and lower construction costs compared to RC structures (Goubran, Masson & Walker, 2020). Comparative studies have shown that CLT infills possess superior shear strength compared to strengthened masonry panels, promoting CLT's effectiveness in reinforcing RC structures (Stazi et al., 2019).

Throughout history, steel has been combined with timber to enhance its strength and stiffness, leading to innovative research in this area. Studies with prestressed glulam beams have demonstrated load increases of up to 438% for beams with wider spans affected by point loads at the midpoint, and up to 346% for similar beams under uniformly

distributed loads (Al-Djaber & Veghar, 2018:19). One notable approach involves encasing thin-wall cold-formed steel sections within split glulam beams, allowing for optimum sizing where both materials reach their limiting bending stresses simultaneously under load (Figure 10)(ARUP, 2019:82).

Figure 10: encasing thin-wall cold-formed steel sections within split glulam beams (ARUP, 2019:82)

2.4.11 Perceptions of Timber in SA

Hassan & Grobbelaar (2023:56) found that over 47% of South African questionnaire respondents (N = 100) had no experience with timber. Timber was perceived as a weak and 'hollow' material, susceptible to insect and mould infestation and moisture damage, and lacked acoustic or thermal insulation abilities, mostly only fit for low-cost, short-term construction (Hassan & Grobbelaar, 2023:65). The paper specifically studied timber perceptions, mentioning that misconceptions about wood carry over to MT even though the technology is extraordinarily improved (Hassan & Grobbelaar, 2023:53).

Hassan & Grobbelaar (2023:67) found that when asking respondents about potential adoption strategies for timber, access and availability to knowledge were common, requesting statistics about properties and performance like resistance to fire, durability, and construction manuals and details through regularly updated documents (Hassan & Grobbelaar, 2023:67). This can be conducted by manufacturers (MTT and XLAM) through workshops, conferences, seminars, research journals and magazines that publish cost comparisons, carbon emission data and important information that can promote adoption (Hassan & Grobbelaar, 2023:67). It is vital to debunk the misconceptions about MT in relation to timber (Hassan & Grobbelaar, 2023:68). Finally, it was recommended that promotion might highlight timber construction as a solution to the housing crises in SA Hassan & Grobbelaar (2023:68).

2.4.12 Perceptions of Mass Timber

Hassan & Grobbelaar (2023:66) discovered that a barrier to MT implementation is due to practitioners' unwillingness to take risks and prefer solutions that are tried and tested. The premium cost of MT emerges as a common barrier, with construction companies charging additional fees due to risks incurred (Gosselin et al., 2017:558-559; Riala & Llola, 2014).

Laguarda Mallo & Espinoza (2015) highlight that the future adoption of MT (in the United States) relies on consumer awareness and the spread of positive attitudes through effective information dissemination. The lack of building codes and standards is also detrimental, as they protect professionals against potential liability (Laguarda Mallo & Espinoza, 2015:206).

Laguarda Mallo & Espinoza (2015:208) found a correlation between exposure and appreciation for MT abilities and potential as a structural material, improving consideration. South African practitioners are assumed to have negative or unfamiliar perceptions of MT due to limited exposure, though overall perceptions remain broadly unknown. It is vital to understand the barriers, experiences, and perceptions of South African construction industry practitioners for improved MT adoption.

2.5 Summary

The literature review provides comprehensive insights into using obsolete buildings in the Pretoria CBD for social housing through AR and the integration of MT. These buildings offer significant potential for addressing the housing crisis due to their central location, existing infrastructure, and suitability for vertical densification. Prioritising the repair and densification of AR projects is crucial for mitigating service strain and leveraging resources while maintaining historical urban fabrics.

The central location of the CBD offers residents proximity to essential services, employment opportunities, and transportation networks, enhancing their quality of life. Catalytic projects integrating mixed-income housing can prevent gentrification and ensure low-income residents benefit from urban renewal. The success of such projects depends on overcoming challenges like regulatory hurdles, strategic planning, and collaboration between the public and private sectors.

Converting obsolete offices into residential units addresses the urgent need for social housing and avoids demolition. Office-to-residential conversions offer unique benefits like vertical extensions due to robust load-bearing capacities and abundant circulation. Challenges include the lack of existing building and structural plans, heritage considerations, and the need for increased services and shafts. However, thorough inspections, strategic planning, and collaboration can enhance the feasibility and success of AR projects.

MT is a pivotal material in this context, offering eco-friendliness, strength, lightweight properties, speed of construction, sustainability, and improved fire ratings. MTs' prefabrication capabilities significantly reduce construction time and impact on the surrounding inner city. Despite these benefits, MT adoption in South Africa faces obstacles like limited awareness and negative perceptions. Educational initiatives and successful case studies are needed to demonstrate MTs' potential and address misconceptions.

In conclusion, the literature strongly supports the appropriateness of obsolete buildings in the Pretoria CBD for social housing. By integrating AR strategies with MT benefits, social housing solutions can be created. Effective implementation will require strategic collaboration, financial incentives, and efforts to shift industry perceptions toward embracing these innovative approaches.

Chapter 3 – Research Methodology

The following chapter delves into the research methodology employed, outlining the philosophical framework, data collection methods, and analysis techniques. It explores the rationale behind choosing industry professionals as the research group and discusses ethical considerations and limitations.

3.1 Paradigm and Research Design

The research adopted an interpretivist paradigm, which is a philosophical approach that emphasise understanding the meaning and context of human experiences and social phenomena. In using a mixed-method approach, the research uses quantitative data to complement qualitative insights (Table 2). This allows the qualitative findings to be grounded in broader quantitative contexts, enhancing the robustness of the interpretations (Proofed, 2024). The method of Interpretivist paradigms is often used in the combination of quantitative and qualitative research and is rooted in the belief that reality is constructed through social interactions and cultural norms (Table 1) (Schwandt, 2007).

Table 1: Key Aspects of the Interpretive Paradigm (Author, 2024)

Subjectivity	The interpretive paradigm recognises that researchers and participants bring their perspectives and biases to the research process. It values subjective experiences and interpretations (Creswell & Poth, 2018).
Contextual Understanding	This paradigm emphasises understanding phenomena within their specific contexts. It seeks to explore the deeper meaning behind actions and interactions (Geertz, 1973).
Holistic Approach	Instead of breaking down phenomena into isolated variables, the interpretive paradigm looks at the whole picture, considering various factors and their interconnections (Denzin & Lincoln, 2011).
Emergent Design	Research design in the interpretive paradigm is often flexible and adaptive, allowing for changes as new insights emerge during the study (Creswell & Poth, 2018).
Qualitative Methods	Methods such as interviews, observations, and document analysis are commonly used to gather rich, detailed data (Denzin & Lincoln, 2011).
Quantitative Methods	Methods such as surveys, interviews, and correlational research are often used to gather quantifiable, numerical values (Denzin & Lincoln, 2011).

Table 2 below gives an overview of the aspects related to the research design, with a basic summary of each.

Table 2: An overview of the aspects related to the research Methodology (Author, 2024)

Aspects	Summary
Research Paradigm	The data, containing the perceptions and experiences of industry professionals, required an interpretive philosophy for a holistic view of potentially convergent and divergent views.
Methodology	The mixed method approach facilitated the analysis of both quantitative and quantitative data.
Data Collection Methods	Data collection methods included questionnaires (quantitative data), interviews, and literature studies (qualitative data).
Ethics	Ethics approval was obtained by the research and ethics committee of the University of Pretoria. Questionnaire respondents were kept entirely anonymous, and interviewees signed consent forms.
Research Boundaries	The research focused on South African practitioners in the construction industry and not global practitioners, end-users, or clients.
Focus	The studies focus centred around the perceptions and experiences of construction industry practitioners around MT and AR, who recommended strategies and construction processes in design and development.

The study is characterised by the diversity of experiences and perceptions of industry professionals, further underscoring the need for an interpretivist paradigm. This philosophy guided the interpretation of divergent and convergent responses of the qualitative data. The inductive interpretations of the data were towards an unknown outcome, so informed theories could arise surrounding the perceived barriers and opportunities of AR and MT. This can lead to explorative strategies.

The literature review set out to answer sub-question one: the appropriateness of the Pretoria CBD for social housing by looking at coinciding literature that analysis the needs and opportunities of social housing. The literature review provided insights to MT and AR considerations. To answer sub-questions two and three, exploratory research looked to gain insight into an under-researched field in SA, namely the perceptions and challenges of industry professionals on AR projects and the use of MT (Table 3).

The research questions are answered in the following way:

Table 3: Methodology used to answer the research sub-questions (Author, 2024)

Research Methodology	Sub-Research Question
Literature Review	1) Are obsolete buildings in the Pretoria CBD appropriate locations for social housing?
Questionnaire, Interviews, and Literature	2) What are the perceptions of engineers, architects, quantity surveyors, contractors, and project managers regarding MT and AR projects?
Questionnaire Interviews And Literature	3) What are the challenges facing AR projects for transitioning inner-city buildings from office to residential, and what are the potential solutions provided by MT?

Descriptive research through interviews and questionnaire comments was used to gather primary data without changing or controlling variables. Obtaining open-source and seemingly broad information from respondents was vital as this was the first known round of questionnaires given to industry professionals concerning AR and MT. Further questionnaires can define variables that lead to more precise theories about these topics.

3.2 Data Collection Methods

This section gives an understanding of the data collection tools used in the study. It outlines the studies approach to collecting data and means of analysis. The study utilised a mixed method approach, as the data collection tools were varied. A mixed methods approach is instrumental in addressing complex research questions where both numerical data and contextual understanding are necessary. By integrating different types of data, researchers can validate their findings through triangulation, ensuring greater reliability and validity (Proofed, 2024). Figure 11 shows the complex relationships of the research questions, the methodology, the data analysis and then finally the results.

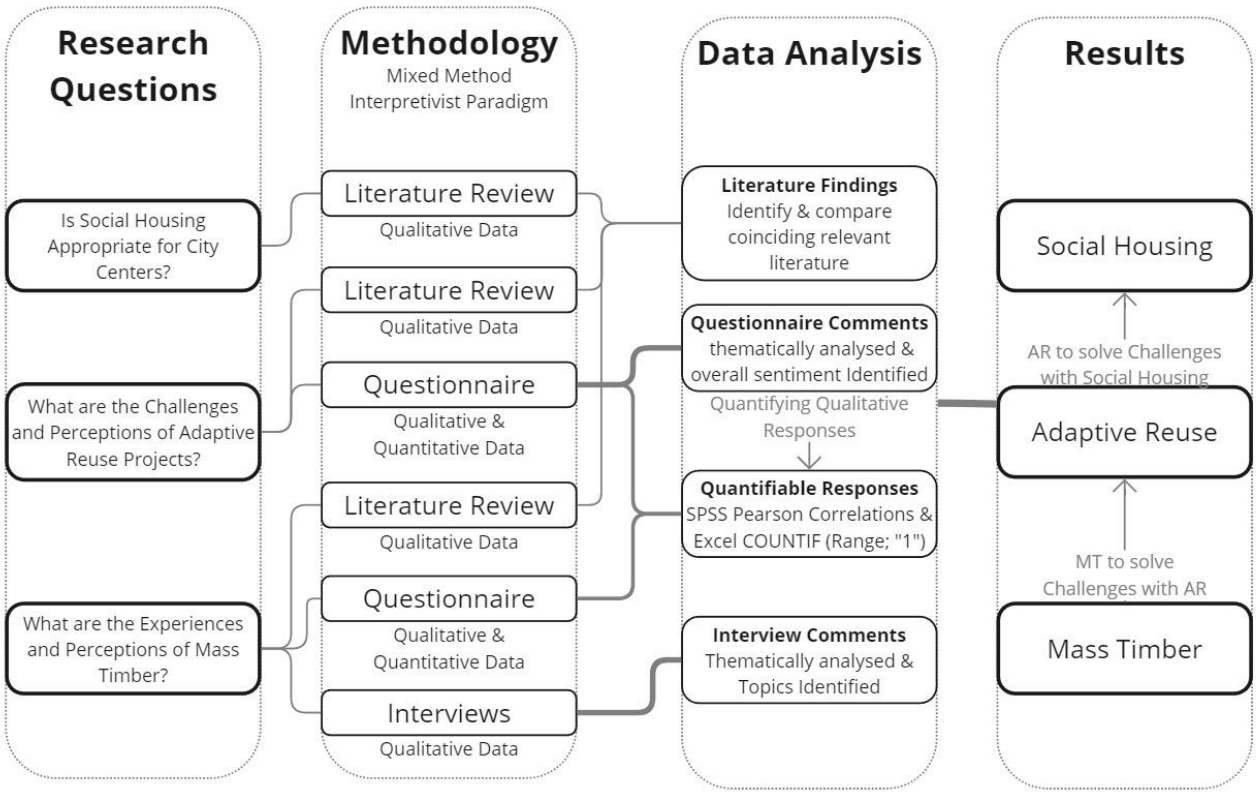


Figure 11: The research methodology outlined for the study (Author, 2024).

3.2.1 Literature Review

The literature review addresses the question: Are obsolete buildings in the Pretoria CBD appropriate locations for social housing? By identifying current knowledge gaps, the review positions the research to contribute original insights rather than replicating existing studies (Randolph, 2009). This process lays the groundwork for integrating qualitative and quantitative approaches regarding AR and MT.

In particular, the review analysed sources not previously considered together, revealing coinciding findings related to the needs of social housing residents and identifying how the inner-city meets the needs of low-income residents. This comprehensive analysis ensures a thorough understanding of the feasibility and practical aspects of utilising obsolete buildings for social housing.

To define the scope, the review considered local academic articles, government reports, policy documents, and case studies focused on social housing, urban regeneration, and adaptive reuse of obsolete projects. The geographic focus on the Pretoria CBD guided the search for relevant documentation and comparative studies from similar urban contexts within South Africa.

A strategic search was conducted using databases such as Google Scholar, JSTOR, Taylor & Francis, ResearchGate, and various government or NGO publications. Keywords included "obsolete buildings," "adaptive reuse," "social housing," "urban regeneration," "social housing needs," "Pretoria CBD," and "housing policy." The prioritisation of peer-reviewed and local journals ensured the inclusion of recent sources reflecting current trends and policies relevant to the South African context. Key arguments, themes, and topics were analysed for their relevance to social housing and the potential reuse of obsolete buildings.

3.2.2 Questionnaires

Questionnaires and surveys are indispensable tools in research due to their ability to gather comprehensive data from large populations efficiently and cost-effectively. Their standardised format ensures consistent data collection, enhancing the reliability and validity of the results (Brace, 2018). The flexibility in question design allows researchers to capture both qualitative and quantitative data, providing a holistic view of the research problem (De Vaus, 2013).

Primary data was collected using online questionnaires and semi-structured interviews, found in appendixes A, B, and C. Convenience sampling was the primary recruitment method, targeting participants based on their availability, willingness, or ease of access. This non-probability approach included industry professionals who market themselves through social networks (LinkedIn), local advertising, or online websites. Participants were initially recruited from existing professional networks of the author and supervisor. The pool was then broadened by searching for local construction professionals (engineers, construction managers, architects, and quantity surveyors) and emailing requests to their relevant admin departments, inviting participation in the questionnaire.

To further enhance the sample and capture a broader range of experiences, the questionnaires concluded with a request for participants to courteously forward the survey to relevant industry professionals within their network (snowball sampling). Additionally, the questionnaire offered the option of being contacted for an interview by the research team.

The questionnaires were distributed over a period of three weeks between April and May 2024. They included a mix of closed-ended questions (yes/no outcomes) like 'Have you ever taken part in an adaptive reuse project?' and open-ended questions that allowed for more descriptive responses, such as 'If applicable, please expand on your experience with MT.' Therefore, the responses collected included qualitative and quantitative data, aligning with an interpretivist research paradigm. “Interpretivism is based on the assumption that reality is subjective, multiple and socially constructed” (Nottingham University, 2023).

3.2.3 Interviews

In an interpretive paradigm, interviews are crucial for contextualising quantitative data. While surveys can indicate what is happening, interviews can explain why it is happening by uncovering the meanings and interpretations that individuals attach to their experiences (Creswell & Plano Clark, 2018). This approach ensures that the quantitative data is not interpreted in isolation but is enriched by qualitative insights, leading to more comprehensive and valid conclusions.

Interviews were arranged with participants who formally accepted the invitation. The first interview was conducted in May, and the last interview was conducted at the beginning of June 2024. The interview questions delved deeper into the industry professionals' experiences and perceptions concerning MT or AR projects. To facilitate the semi-structured format, open-ended questions were prepared beforehand, such as” Why do you think clients or practitioners are cautious in the adoption of MT?” These questions aimed to encourage participants to elaborate on their experiences with MT or AR projects. In addition, unprepared questions were included to withdraw further data concerning the topics. The interview data was qualitative in nature, further determining an interpretivist paradigm."

3.3 Motivations for Industry Professionals as a Research Group

This research focuses on understanding the perceptions of industry professionals in SA regarding MT and AR projects. Industry professionals hold a critical position within the construction sector. They act as trusted advisors, influencing stakeholders' decisions on adopting new technologies. However, stakeholders are influenced by fabricators and manufacturers; as Orozco et al. (2023:22) point out, "Timber-building knowledge seems to come from fabricators". This highlights the collaborative nature of the industry. Industry professionals are ultimately responsible for specifying and recommending materials and technologies. Their confidence in and understanding of these innovations is crucial for driving wider adoption.

By analysing the perceptions of industry professionals, this research aims to identify potential obstacles hindering the implementation of innovative building technologies, such as MT, and undertaking AR projects. This knowledge will be instrumental in informing collaborators, fabricators, researchers, and other stakeholders about the ground-level realities that influence adoption. With this understanding, the industry can develop more effective strategies to address these obstacles and promote the successful integration of these advancements.

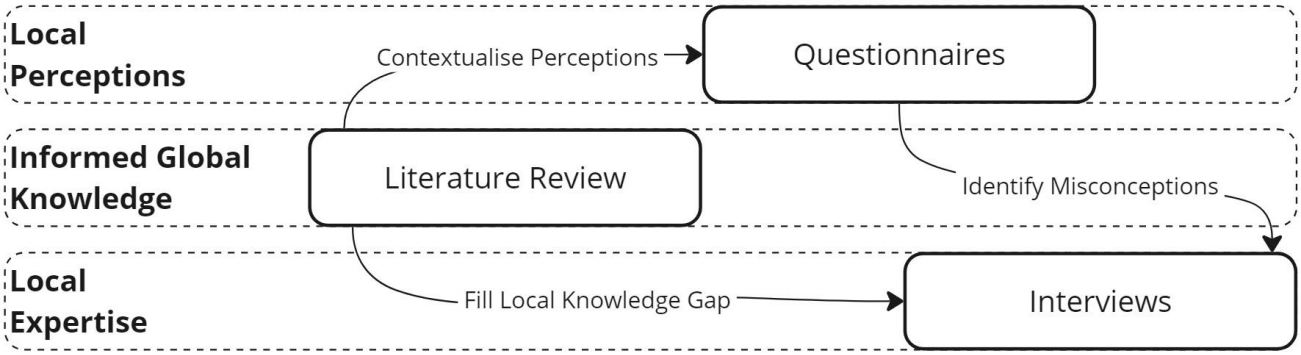


Figure 12: Understanding the relationship between local perceptions, established knowledge and local expertise (Author, 2024).

Additionally, the research conducted through the questionnaires aimed to understand practitioners' perceptions rather than the validity of those perceptions. Consequently, experience with MT or AR projects was not a prerequisite for the sample group. The primary objective was to understand the information gathered and shared among practitioners rather than solely focusing on their expertise. Four interviewees were selected to validate accurate assumptions and prevent biased responses based on their extensive experience.

The choice to focus on those with MT experiences rather than AR experience was due to better access to practitioners with experience in MT, as the research relied on non-probability sampling of accessible knowledge. Further research should aim to specifically investigate the challenges, opportunities, experiences, and perceptions of AR projects to provide a detailed understanding.

3.4 Data Analysis

The results were analysed in two sections: MT and AR. This categorisation was used to better understand the data in terms of the correlations, statistics, and interview answers. However, some questionnaire data encompass both categories and will be analysed first.

The results of the questionnaires were collected on Google Forms, and the data was exported to Microsoft Excel. Responses were coded (0 = no, 1 = yes, 2 = other, and 99 = no answer) to facilitate quantitative analysis. The cleaned data was then imported into IBM SPSS Statistics (version 28) for further analysis.

Pearson correlation coefficients were used to identify statistically significant correlations between key variables, such as industry professionals' perceptions and experience of MT. The author worked at a significance percentage of

1% ($p < 0.01$). Correlation strengths were interpreted as follows: moderate ($0.36 < r < 0.67$) and strong ($r \geq 0.67$). Qualitative data of comments given by respondents were analysed through thematic and sentiment analyses.

The interviews were audio-recorded with the participants' signed consent. The recordings were transcribed identically. The author identified common topics, ideas, themes, or patterns emerging from the data. Emerging themes were then studied for correlations with relevant topics discussed in the literature review and reviewed for any connections with the quantitative findings of the questionnaires. The quantitative data was transcribed into various graphs and pie charts using Excel's COUNTIF (range; "1") feature.

The quantitative and qualitative findings were surveyed and compared to provide a more comprehensive understanding of perceptions. This included comparing the quantitative results (correlations and statistics) with the themes identified in the qualitative data.

3.5 Research Ethics Applied

The research process was outlined and submitted to the Faculty Committee for Research Ethics and Integrity of the University of Pretoria. The Chair subsequently granted ethics approval under the conditions of the Code of Ethics for Scholarly Activities of the University of Pretoria, or the Policy and Procedures for Responsible Research of the University of Pretoria. The ethics approval is found in Appendix D.

The research utilised a 'snowball method' to identify industry professionals through company websites. To avoid any perception of coercion, only one request per company or individual was sent to relevant administrative personnel. All questionnaire respondents remained anonymous, as the questionnaire did not ask for names or contact details, ensuring complete protection of respondents' identities. For participants who agreed to be interviewed, an optional space was provided to include contact details.

Potential interviewees were contacted based on their willingness to be interviewed, indicated by their final questionnaire responses, and were asked to sign a consent form before the interview, giving explicit permission for their names and identities to be included in the research. Interviewees also consented to be named and quoted in the study. Consequently, the research paper was reviewed by all interviewees prior to submission for scrutiny to confirm the accuracy of the information provided.

Chapter 4 – Results

The following chapter delves into the results of the data analysis, offering insights into the perceptions and experiences of industry professionals regarding MT and AR in SA. The chapter is separated into three sections: first the success of the questionnaires and interviews are discussed with its effect on the data; second, it outlines the results of the questionnaire, and finally the relevant themes of the interviews are outlines.

4.1 Questionnaire and Interview Success

51 questionnaires were dispatched, and 15 questionnaires were completed (N = 15), yielding a response rate of 29%. The 15 respondents were made up of 11 architects, three engineers and one construction manager. Four industry professionals indicated their willingness to be interviewed (N = 4). Subsequently, the researchers reached out to an architect, quantity surveyor and construction manager and conducted interviews with each. Therefore, four interviews were held with an engineer, architect, quantity surveyor and construction manager. The diverse group of interviewees mitigated the overreliance on quantitative feedback from architects in the questionnaires.

The reliability of the small sample size of the questionnaires collected was scrutinised. The 'true' relationship in the population is that of r = 0. However, the sample correlation in the study will be between -0.35 and 0.35 at least 80% of the time (Figure 13). Which leaves 20% of correlations to be extreme values that occur by chance. Therefore, to mitigate the potential for extreme values, the data excluded Pearson correlations of 5% ($p < 0.05$) and didn't consider weaker correlation strengths ($r \leq 0.35$). Strong or moderate correlations and Pearson correlations of 1% will be confirmed by the interview results.

Sample size:	80% limits for *r*:
5	-.69 to +.69
15	-.35 to +.35
25	-.26 to +.26
50	-.18 to +.18
100	-.13 to +.13
200	-.09 to +.09

Figure 13: Limits within which 80% of sample r's will fall when the true (population) correlation is 0 (Graham Hole, Unknown date)

4.2 Questionnaire Data

The following section focuses on the responses of the questionnaire which are analysed with Pearson pairwise relationships and Excel's quantitative analysis tools. A Pearson pairwise correlation measures the strengths linear relationships between variables with a value between -1 to 1 (Berman, 2016).

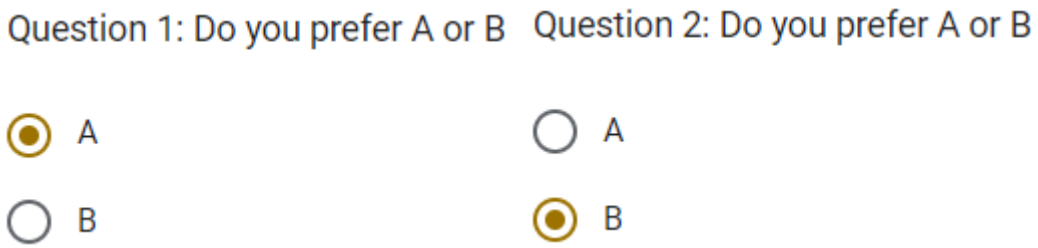


Figure 14: An of two questions in a survey used to explain a Pearson pairwise correlation (Author, 2024)

In the questionnaire analysis, a perfect positive correlation of 1 (1.000) occurs when all participants consistently choose the same response for two questions (e.g., all answer 'A' to question 1 and 'B' to question 2 (Figure 14)). This indicates a strong positive relationship between 1A and 2B, where a change in one variable predicts a corresponding change in the other. A weaker correlation (e.g., 0.686) still suggests a positive relationship but with less consistent responses.

A perfect negative correlation of -1 (-1.000) occurs when participant responses are opposed across two questions. For instance, all those who answer 'A' to question 1 did not answer 'A' to question 2 (Figure 14). This indicates a strong inverse relationship between 1A and 2A, where an increase in one variable predicts a corresponding decrease in the other. Weaker negative correlations (e.g., -0.686) still suggests a negative relationship but with variances among some respondents.

To iterate, 1A and 2B have perfect positive relationships, and 1A and 2A have perfect negative relationships.

4.2.1 Data Analysis

Table 4 looks to understand the weight of sustainability among respondents in all question categories. The results showed a statistically significant ($p < 0.01$), perfect positive correlation ($r = 1.000$) between sustainability of MT, circular economy of MT, material savings of AR, improved carbon footprint of AR, and sustainable densification of urban cities. No correlations were found between these concepts and the improved carbon footprint of IBTs.

Table 4: A Pearson pairwise correlation matrix results showing the relationships between questions related to sustainability.

Sustainability Considerations									
	Improved Carbon Footprint of IBT	Sustainable	Circular economy of MT	Material Savings of AR	Improved Carbon footprint of AR	Sustainable Densification with AR	Worked with IBT	Worked with MT	AR Projects
Improved Carbon Footprint of IBT	1								
Sustainable	-0,076	1							
Circular economy of MT	-0,076	1,000**							
Material Savings of AR	-0,078	1,000**	1,000**	1					
Improved Carbon footprint of AR	-0,078	1,000**	1,000**	1,000**	1				
Sustainable Densification with AR	-0,078	1,000**	1,000**	1,000**	1,000**	1			
Worked with IBT	0,101	0,107	0,115	0,103	0,101	0,109	1		
Worked with MT	0,258	-0,281	-0,276	-0,279	-0,287	-0,282	0,419	1	
AR Projects	0,287	-0,242	-0,247	-0,250	-0,247	-0,242	0,367	0,339	1
**. Correlation is significant at the 0.01 level (2-tailed).									

4.2.2 Mass Timber

43.7% of respondents worked with MT on about 19 MT projects, and 93% of respondents would consider MT if the client was open to it. Most professionals used MT in the roof structures (n = 6), while beams and walls closely followed (n = 5). Only two respondents used MT for a complete structural system (Figure 15).

The most common perceived benefit of MT was the reduction of the foundation sizes (n = 11), followed by the speed of construction and the availability of CNC technology (Figure 16). The lowest perceived benefits are the cost (n = 3), the abundance of availability (n = 3) and its effectiveness against water (n = 4) once it's been treated. The biggest perceived limitation of respondents was the lack of experience of construction industry professionals to use MT and the adoption of new ways of building in the construction industry (Figure 17). MT was mostly considered for beams, walls, and floors; however, there exists a small margin of difference among the other uses (Figure 18).

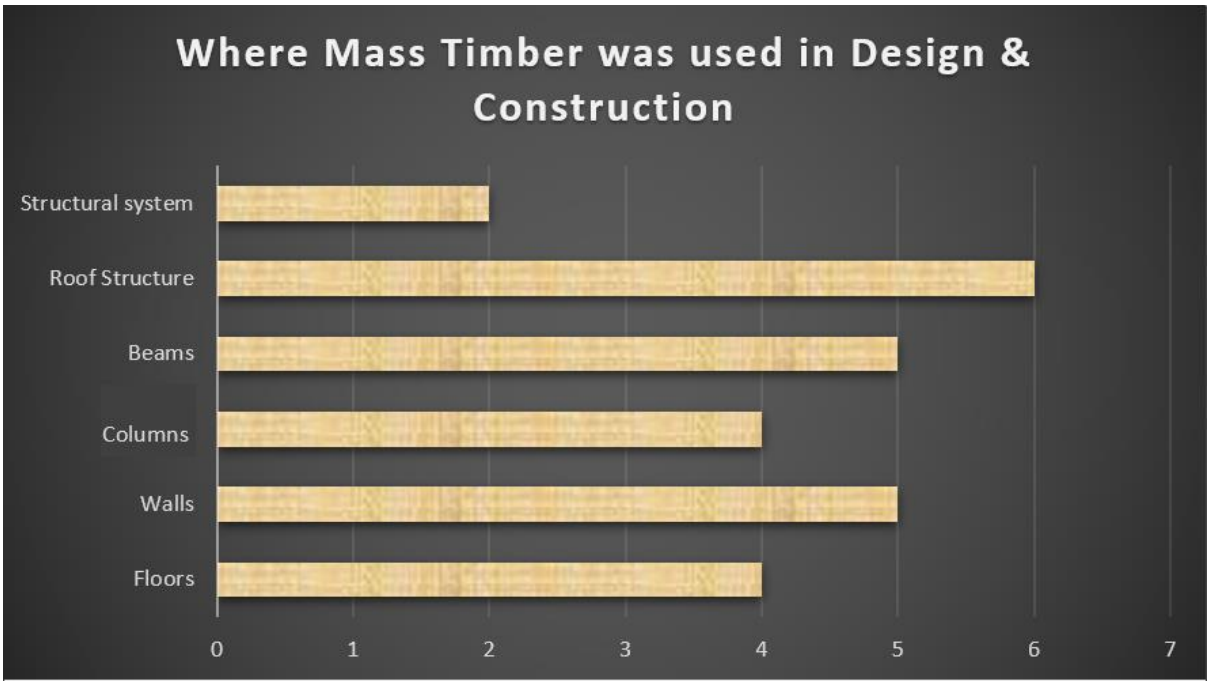


Figure 15: Results showing where MT was used in the building by questionnaire respondents.

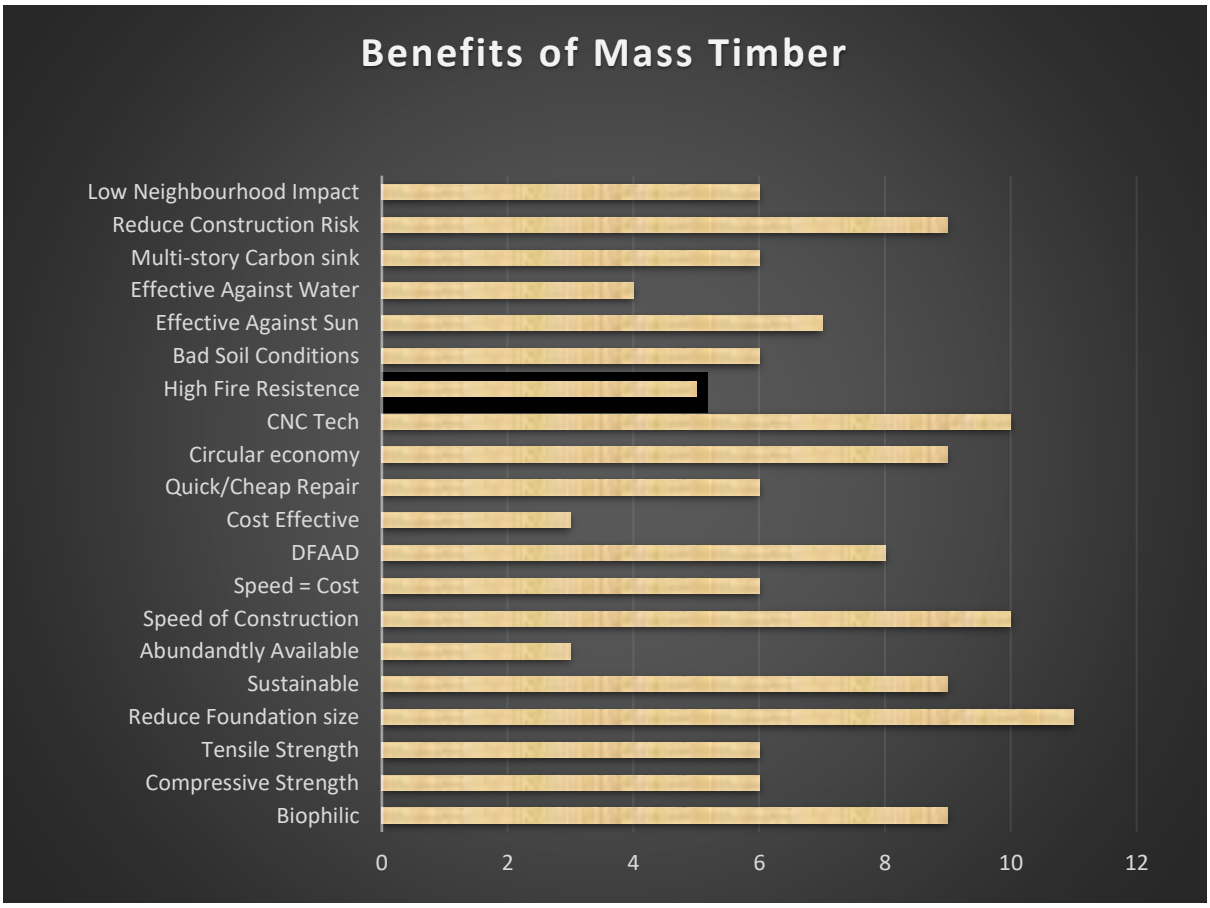


Figure 16: Results showing the perceived benefits of MT by questionnaire respondents.

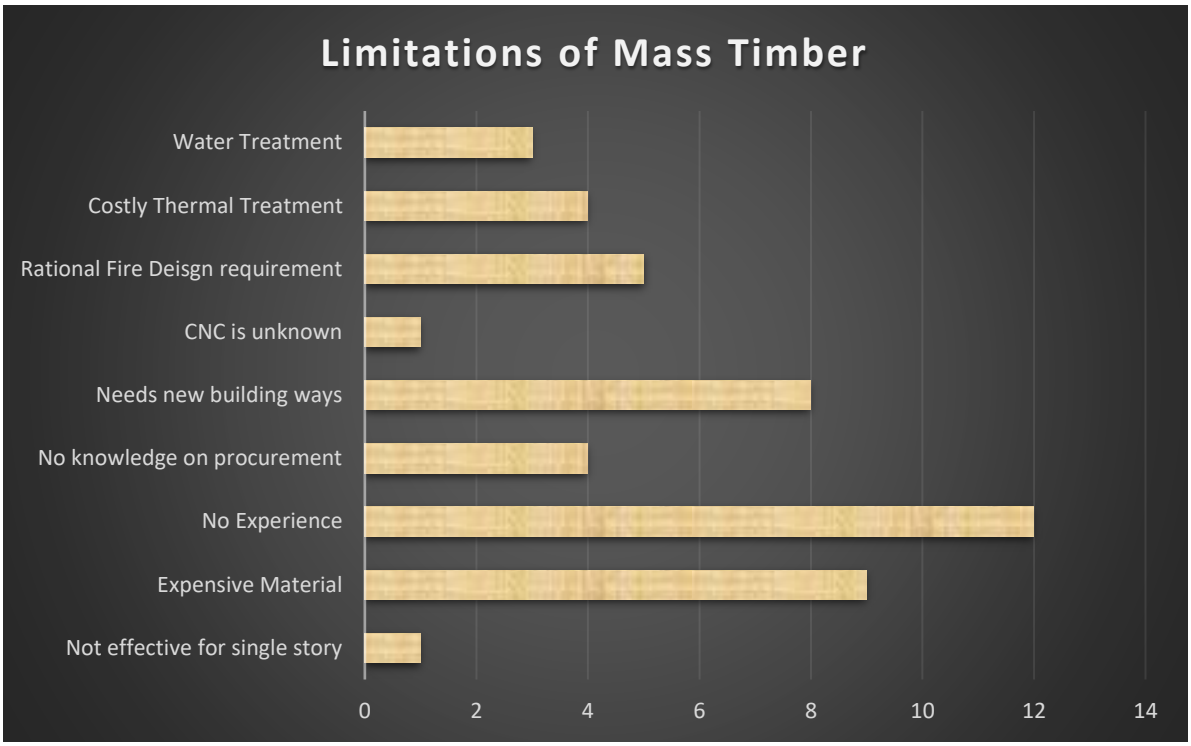


Figure 17: Results showing the perceived limitations of using MT by questionnaire respondents.

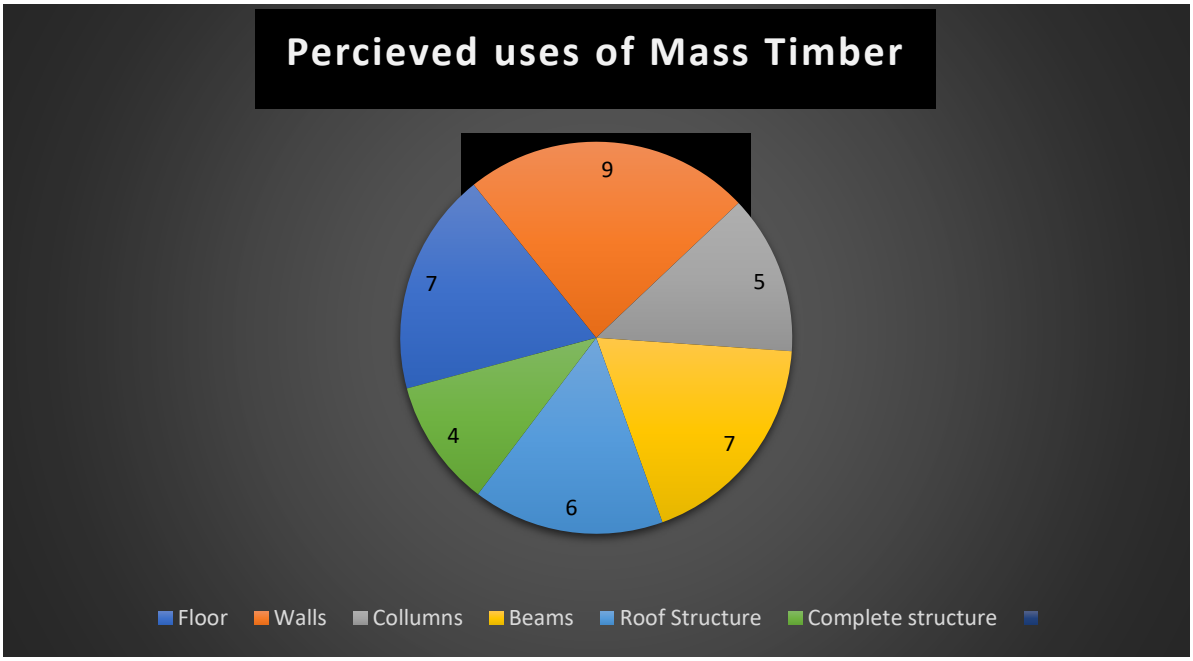


Figure 18: Results showing the perceived uses of MT by questionnaire respondents.

In understanding the respondents' perceptions of MTs' cost, questions relating to cost were analysed for relationships (

Table 5). Obviously, there is a high negative statistically significant correlation ($p < 0.01$; $r = -0.725$) between those who worked with MT and the number of MT projects done. Additionally, there is a perfect, positive, highly significant statistical correlation between the benefits of the speed and cost of construction and the cost-effectiveness of MT. A lower correlation ($r = 0.686$) is found between the benefits of speed and cost of construction and the cost-effectiveness of the repair of MT. The same correlation was found between the cost-effectiveness of the material and the cost-effectiveness of its repair.

Table 5: A Pearson pairwise correlation matrix results showing the relationships between questions related to price & cost.

Price Perceptions						
	Worked with MT	Number of MT Projects	Speed and Cost (Benefit of MT)	Cost Effective (Benefit of MT)	Quick Cheap Repair (Benefit of MT)	Expensive Material (limitation of MT)
Worked with MT	1					
Number of MT Projects	-0,725**	1				
Speed and Cost (Benefit of MT)	-0,027	0,422	1			
Cost Effective (Benefit)	-0,021	0,415	1,000**	1		
Quick Cheap Repair (Benefit of MT)	0,250	0,288	0,686**	0,686**	1	
Expensive Material (limitation of MT)	0,577*	0,600*	-0,319	-0,083	-0,075	0,221
*. Correlation is significant at the 0.05 level (2-tailed).						
**. Correlation is significant at the 0.01 level (2-tailed).						

There is a perfect, high, statistically significant positive correlation ($p < 0.01$; $r = 1.000$) between the difficulties of altering the layout and structure of an AR project and altering the horizontal circulation of an AR project (Table 6). There was only a low correlation between those who consider MT for infill walls and layout changes, structure changes, and horizontal circulation changes of AR projects, which will not be considered for this paper.

Table 6: A Pearson pairwise correlation matrix results showing the relationships between questions related to MT and installing or altering interior infill walls.

Timber as Infill Walls						
	Worked with MT	Consider MT for Walls	Changing the Layout of an AR project (difficulty)	Altering Structure of AR Project (difficulty)	Altering the Horizontal Circulation of an AR Project. (difficulty)	Timber as the Best Material to Alter the Structure of an AR Project
Worked with MT	1					
Consider MT for Walls	-0,193	1				
Changing the Layout of an AR project (difficulty)	-0,279	0,530*	1			
Altering Structure of AR Project (difficulty)	-0,286	0,534*	1,000**	1		
Altering the Horizontal Circulation of an AR Project. (difficulty)	-0,283	0,534*	1,000**	1,000**	1	
Timber as the Best Material to Alter the Structure of an AR Project	-0,365	0,527	1,000**	1,000**	1,000**	1
*. Correlation is significant at the 0.05 level (2-tailed).						
**. Correlation is significant at the 0.01 level (2-tailed).						

In considering the perceptions of the strengths of materials, a perfect positive, statistically significant correlation ($p < 0.01$; $r = 1.000$) is seen between the strengths of RC, steel, MT, and brick and mortar (Table 7).

Table 7: A Pearson pairwise correlation matrix results showing the relationships between questions related to the perceptions of different materials.

Material Strength Comparison				
	Timber Strength	RC Strength	Steel Strength	Brick and Mortar Strength
Timber Strength	1			
RC Strength	1,000**	1		
Steel Strength	1,000**	1,000**	1	
Brick and Mortar Strength	1,000**	1,000**	1,000**	1
**. Correlation is significant at the 0.01 level (2-tailed).				

In comparing the relationships between steel and MT in the questionnaire, a statistically significant, perfect positive correlation ($p < 0.01$; $r = 1.000$) can be seen in almost all questions relating to strength (Table 8).

Table 8: A Pearson pairwise correlation matrix results showing the relationships between questions related to steel and timber.

Timber and Steel Comparison											
	MT (IBT used)	Tensile Strength (Benefit MT)	Speed of Construction (Benefit MT)	Timber as Structural Material	Steel as Structural Material	Timber for North Facade	Steel for North Facade	Timber for West Facade	Steel for West Facade	Timber for DFMA	Steel for DFMA
MT (IBT used)	1										
Tensile Strength (Benefit of MT)	-0,190	1									
Speed of Construction (Benefit of MT)	-0,186	1,000**	1								
Timber as Structural Material	-0,228	1,000**	1,000**	1							
Steel as Structural Material	-0,189	1,000**	1,000**	1,000**	1						
Timber for North Facade	-0,186	1,000**	1,000**	1,000**	1,000**	1					
Steel for North Facade	-0,184	,999**	1,000**	1,000**	1,000**	1,000**	1				
Timber for West Facade	-0,188	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1			
Steel for West Facade	-0,186	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1		
Timber for DFMA	-0,187	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1	
Steel for DFMA	-0,186	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1
**. Correlation is significant at the 0.01 level (2-tailed).											

There is a negative moderate (r = -0.681) statistical significance (p < 0.01) between those who would consider MT if the client was open to it and those who perceive MTs' high fire resistance abilities (Table 9). Additionally, there is a positive moderate statistical significance (p < 0,01; 0.681) between the need for rational design being a limitation in MT projects and the benefits of MTs' high fire resistance.

Table 9: A Pearson pairwise correlation matrix results showing the relationships between questions related to fire.

Fire Considerations				
	Worked with MT	Those who would Consider MT	High Fire Resistance (benefit of MT)	Rational Fire Design (limitation of MT)
Worked with MT	1			
Those who would Consider MT	0,286	1		
High Fire Resistance (benefit of MT)	-0,021	-0,681**	1	
Rational Fire Design (Limitation of MT)	0,264	0,075	0,679**	1
**. Correlation is significant at the 0.01 level (2-tailed).				

There is a moderate negative relationship (r = -0.681) between those who would consider working with MT and those who think MT is abundantly available, which is statistically significant (Table 10).

Table 10: A Pearson pairwise correlation matrix results showing the relationships between questions related to the abundance of timber.

Abundance of MT				
	Worked with MT	Consider Working with MT	Consider MT an IBT	MT Abundantly Available (Benefit)
Worked with MT	1			
Consider MT	0,286	1		
Consider MT an IBT	0,535*	0,535*	1	
MT Abundantly Available (Benefit)	-0,021	-0,681**	-0,292	1
**. Correlation is significant at the 0.01 level (2-tailed).				
*. Correlation is significant at the 0.05 level (2-tailed).				

4.2.3 Adaptive Reuse

Notably, nearly half (47%) of the respondents have engaged in AR endeavours, contributing to a collective portfolio of around 69 AR projects, underscoring the prevalence of AR experience among the participants. However, one engineer took up 50 of those. The most respondents (n = 5) had each updated the building's façade and services (Figure 1). Interestingly, the least renovated part of the building was the structure, nor were roofs made accessible. 77% of respondents considered an AR project to involve simply changing the program.

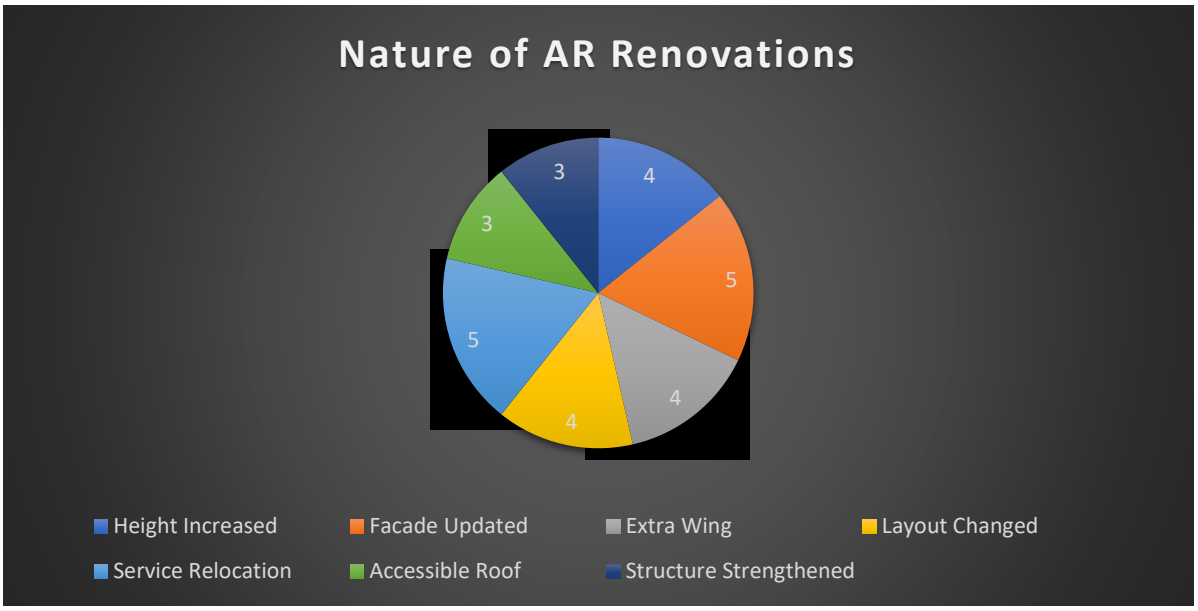


Figure 19: Results showing the nature of renovations in AR projects by questionnaire respondents.

Most benefits listed in the questionnaire were considered among respondents, except for time savings and avoiding wet works (Figure 20). The most common benefit perceived by almost all respondents was to prolong the building's life. The biggest difficulty perceived among industry professionals is understanding the quality and condition of the existing materiality (Figure 21). Consequently, the lack of as-built plans is another barrier to entry. The least limiting component of AR projects, perceived among respondents, was changing the layout. The most challenging aspect to alter in an AR project is the structure, agreed by all those who participated in the question. Despite the perceived limitations, 100% of respondents would consider an AR project, and all but one would recommend an AR project to clients– with the latter requiring the consideration of the context prior to making a recommendation. The highest perceived difficulty of an AR project was outstandingly altering the structure, with changing or repairing services being second (Figure 22).

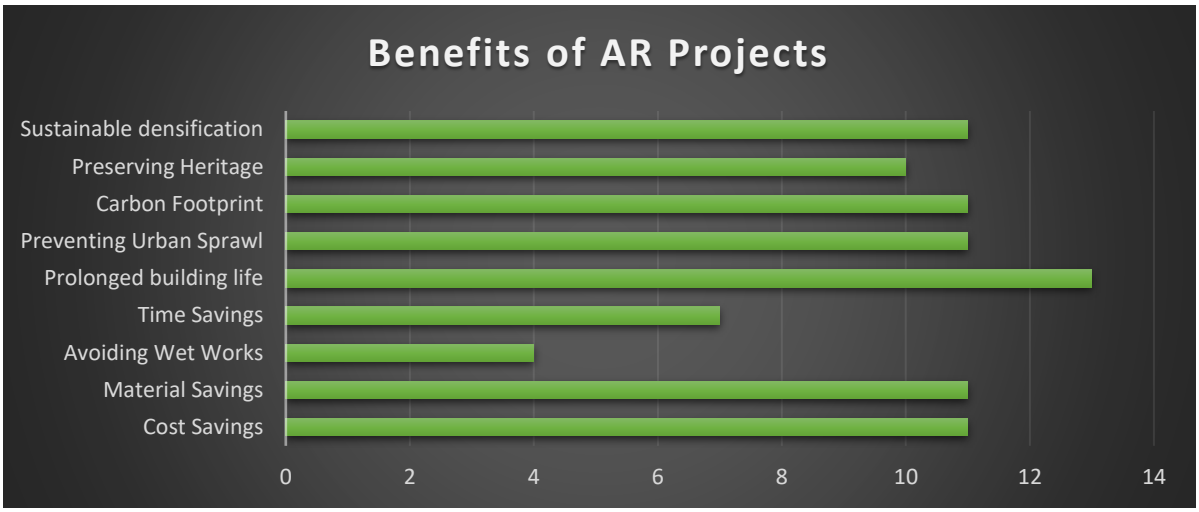


Figure 20: Results showing the perceived benefits of AR projects by questionnaire respondents.

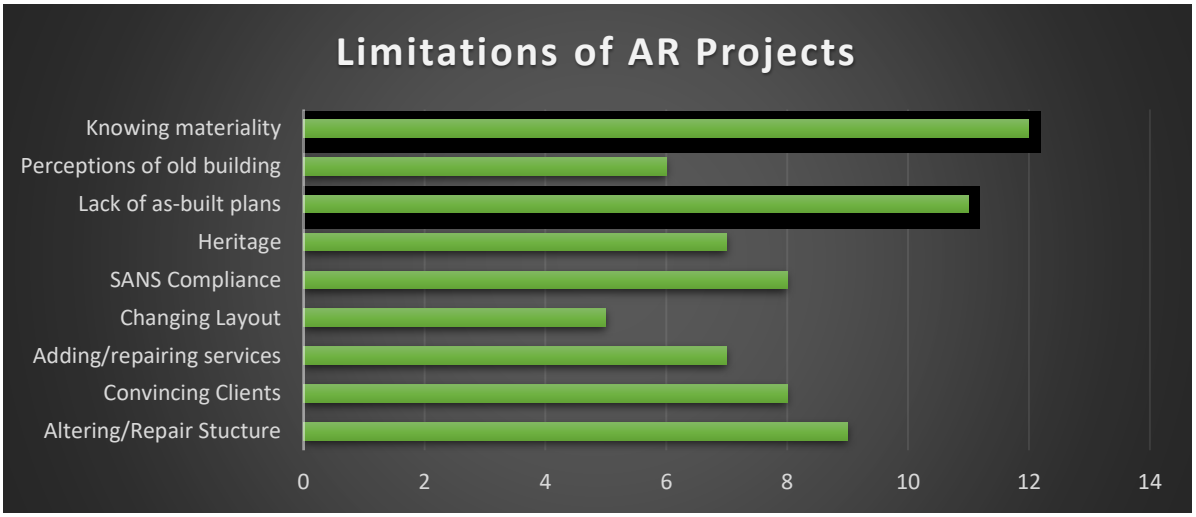


Figure 21: Results showing the perceived limitations of AR projects by questionnaire respondents.

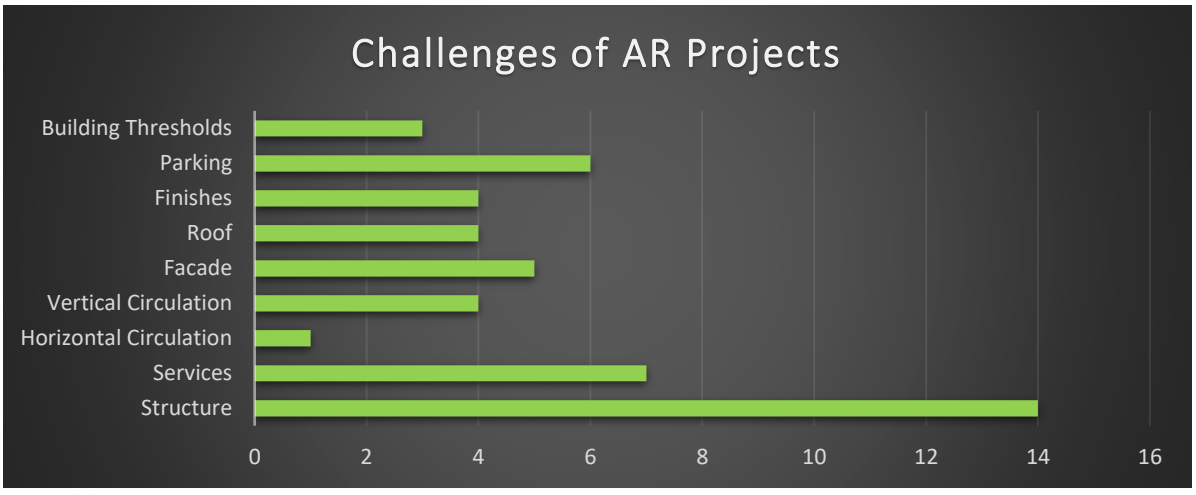


Figure 22: Results showing the perceived challenges of AR projects by questionnaire respondents.

Though the structure poses the biggest obstacle for AR projects, the material that provides the solution, as perceived by the questionnaire respondents, seems to be timber (n = 12) and steel (n = 11) (Figure 23). Additionally, there was a perfect positive statistical correlation ($p < 0.01$; $R = 1.000$) between those who consider timber to be a structural material and those who consider altering the structure to be a difficulty and challenge in AR projects (Table 11).

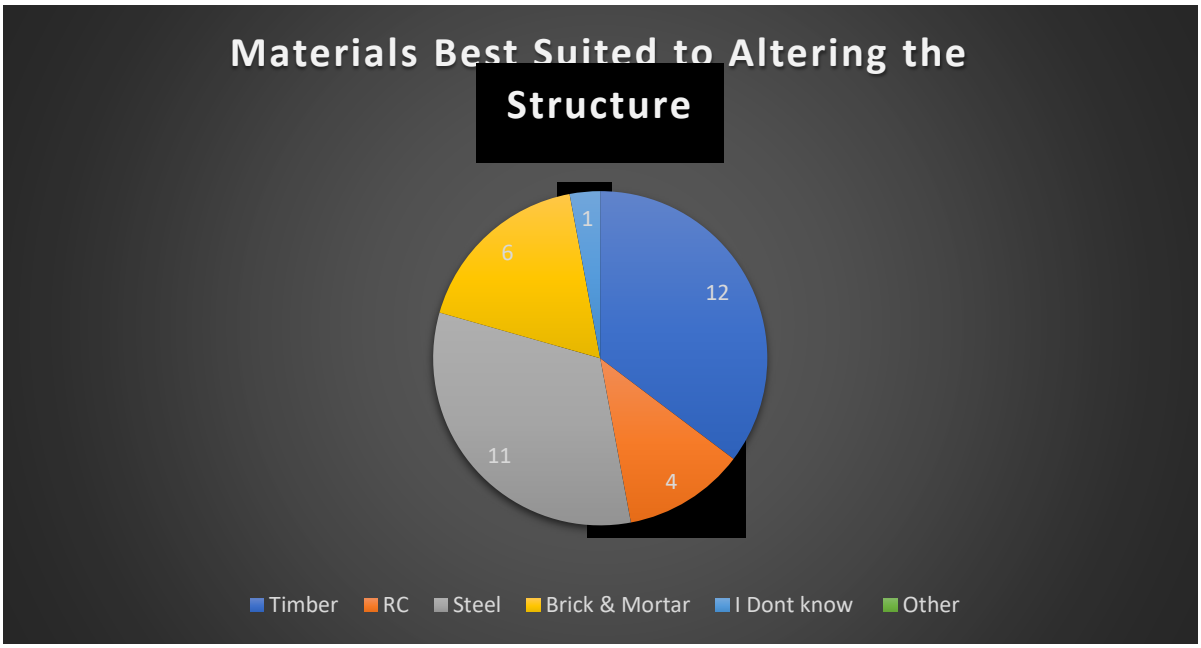


Figure 23: Results showing the materials perceived to be best suited for altering the structure of an AR project by questionnaire respondents.

The results of the questionnaire data analysis, shown in Table 11, showed a statistically significant ($p < 0.01$), moderate positive correlation ($r = 0.667$) between MTs' low impact on the neighbourhood during construction and reduced construction risk due to less construction time. There was also a statistically significant ($p < 0.01$), perfect positive correlation ($r = 1.000$) between respondents who considered undertaking AR projects and those who saw the benefits, like prolonging the building life and reducing urban sprawl, and difficulties/challenges, like altering/repairing the structure and changing the structure components. Additionally, there was a perfect positive correlation between these specific benefits and the challenges/difficulties of AR.

Table 11 A Pearson pairwise correlation matrix results showing the relationships between questions concerning urban densification.

Urban Densification									
	Reduce Foundation size (MT Benefit)	Reduce Construction Risk (MT Benefit)	Low Neighbourhood Impact (MT Benefit)	Consider AR Project	Structure Strengthened (nature of AR project)	Prolonged Building Life (Benefit AR)	Reduce Urban Sprawl (Benefit AR)	Altering Repair Structure (Difficult AR)	Structure Change (Challenger AR)
Reduce Foundation size (MT Benefit)	1								
Reduce Construction Risk (MT Benefit)	0,431	1							
Low Neighbourhood Impact (MT Benefit)	0,492	0,667**	1						
Consider AR Project	0,161	-0,327	-0,218	1					
Structure Strengthened (Nature of AR project)	-0,302	-0,068	-0,272	-0,535*	1				
Prolonged Building Life (Benefit AR)	0,166	-0,329	-0,216	1,000**	0,132	1			
Reduce Urban Sprawl (Benefit AR)	0,162	-0,328	-0,217	1,000**	0,129	1,000**	1		
Altering Repair Structure (Difficult AR)	0,165	-0,326	-0,217	1,000**	0,133	1,000**	1,000**	1	
Structure Change (Challenger AR)	0,161	-0,327	-0,218	1,000**	0,134	1,000**	1,000**	1,000**	1
Timber as A Structural Material	0,158	-0,365	-0,228	-0,312	0,158	1.000**	1.000**	1.000**	1.000**
**. Correlation is significant at the 0.01 level (2-tailed).									

The results, shown in Table 12, looks to understand the factors in the questionnaire that relate to vertical extensions of existing buildings. There was an important statistically significant ($P < 0.01$) perfect positive ($r=1.000$) relationship between understanding the material property of the existing building as a difficulty of an AR project and

altering the existing structure as a difficulty/challenge and changing the vertical circulation and altering the structure of the structure. Additionally, the exact correlation was found between all these factors and those that considered timber a structural material.

Table 12 A Pearson pairwise correlation matrix results showing the relationships between questions concerning vertical extensions of AR in general.

Vertical Densification									
	Reduce Foundation size (MT Benefit)	Height Increased (Nature of AR Project)	Cost Saving (AR Benefit)	Sustainable Densification (AR Benefit)	Altering Repair Structure (AR Difficulty)	Existing Material Prop (AR Difficulty)	Altering / Repairing the Structure (AR Challenge)	Changing the Vertical Circulation (AR Challenge)	Timber as a Structural Material
Reduce Foundation size (MT Benefit)	1								
Height Increased (Nature of AR Project)	-0,364	1							
Cost Saving (AR Benefit)	0,162	0,156	1						
Sustainable Densification (AR Benefit)	0,168	0,156	1,000**	1					
Altering Repair Structure (AR Difficulty)	0,165	0,159	1,000**	1,000**	1				
Existing Material Prop (AR Difficulty)	0,164	0,158	1,000**	1,000**	1,000**	1			
Altering / Repairing the Structure (AR Challenge)	0,161	0,161	1,000**	1,000**	1,000**	1,000**	1		
Changing the Vertical Circulation (AR Challenge)	0,162	0,162	1,000**	1,000**	1,000**	1,000**	1,000**	1	
Timber as a Structural Material	0,158	0,192	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1
**. Correlation is significant at the 0.01 level (2-tailed).									

Table 13 shows the relationship between the questions that had factors relating to heritage. A statistically significant ($P < 0.01$) perfect positive ($r=1.000$) correlation exists between the preservation of heritage and prolonged building life as a benefit, as well as considering heritage during renovations as a difficulty. Additionally, convincing clients has a perfect correlation between considering heritage as a benefit, having difficulty altering the finishes, and using timber for the north and west façade. Altering the façade is also a difficulty, yet there is a statistically significant ($p < 0.01$) perfect positive ($r = 1.000$) correlation between altering the façade and finishes being a difficulty and using timber on the north and west façade.

Table 13: A Pearson /pairwise correlation matrix results showing the relationships between questions related to heritage concerns.

Correlations Heritage Considerations								
	Experience with AR Projects	Prolonged Building Life (AR Benefit)	Preserving Heritage (AR Benefit)	Convincing Clients (AR Difficulty)	Considering Heritage (AR Difficulty)	Altering the Façade (AR Difficulty)	Altering Finishes (AR Difficulty)	Timber for North Facade
Experience with AR Projects	1							
Prolonged Building Life (AR Benefit)	-0,247	1						
Preserving Heritage (AR Benefit)	-0,239	1,000**	1					
Convincing Clients (AR Difficulty)	-0,250	1,000**	1,000**	1				
Considering Heritage (AR Difficulty	-0,247	1,000**	1,000**	1,000**	1			
Altering the Façade (AR Difficulty)	-0,242	1,000**	1,000**	1,000**	1,000**	1		
Altering Finishes (AR Difficulty)	-0,245	1,000**	1,000**	1,000**	1,000**	1,000**	1	
Timber for North Facade	-0,242	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1
Timber for West Facade	-0,247	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**	1,000**
**. Correlation is significant at the 0.01 level (2-tailed).								
a. Cannot be computed because at least one of the variables is constant.								

4.3 Interview Data

4.3.1 Interviewees

The interviewees, as previously stipulated, were contacted due to their extensive experience with or current involvement in MT research. Their level of expertise, achievements and experiences are outlined below:

Angus Fleming - Construction Manager.
Fleming is a construction manager working for a MT design company, BOXA, which has close affiliation with one of the largest MT suppliers in SA - MTT. BOXA develops prefabricated MT units for residential programs and offices. Fleming has overseen numerous developments, infill projects, residential extensions, new builds of offices and newly built residential. In his interview, he highlighted over five projects that made use of prefabricated units for rapid builds, one of which was an infill project in a dense area with two 10m high buildings on either side, on a 14m street front, with a half meter access into the building. This made for a challenging project that MT provided many solutions for.

Christo v.d. Hoven - Architect.
Van der Hoven is a second-generation architect specialising in biobased materials, like MT, computational design, digital fabrication, and the networked knowledge production of rapidly reformulating cross-disciplinary design teams. He holds a M.Arch(Prof) from the University of Cape Town (Cum Laude) and, most recently, an M.Sc from the acclaimed ITECH Master's Program (University of Stuttgart). Previously, he worked in Europe at the Renzo Piano Building Workshop, the ICD (Institute for Computational Design and Construction), and FibR GmbH, as well as in his native South Africa. In nearly a decade of practice, he has completed projects of various scales, ranging from

temporary research demonstrators to generous private residences and large-scale commercial schemes. A number of regional and international awards have recognised the success of many of these projects. Currently, he leads a team of specialists as Co-Founder and Technical Director of MTT in Johannesburg.

He believes that design can go beyond merely catering to an economic elite in increasingly exotic and fashionable ways and that emergent technologies and processes can be wrangled for more democratic use, allowing architecture to assume its social role and fulfil the egalitarian promises made by its Modernists.

Dr. J.H. Cruywagen - Quantity Surveyor.
Dr Cruywagen is a quantity surveyor and professor at the University of Pretoria, supervising multiple master's students and engaging in progressive research to develop tools for industry. He was involved in developing a program that assists developers (like the Development Bank) in pricing any number of student housing units through a plug-in system. He is also researching methods to accurately price the use of MT in design projects, which is not currently developed in SA. He is closely affiliated with Architects and Engineers developing research and construction of MT at the University of Pretoria.

Dr. Johann v.d. Merwe - Engineer.
Van der Merwe is a structural engineer, senior lecturer, and researcher at the University of Pretoria, with experience as a design engineer. He completed his master's degree in structural engineering (2009) at the University of Stellenbosch, and he obtained his doctorate at the Swiss Federal Institute of Technology in Zurich (ETH Zürich) in 2019. In New Zealand, he conducted seismic assessments of existing structures (often single and double-story light timber structures). He currently heads the Timber Structural Engineering working group in the York Timbers Chair, where his research and supervision focus on the structural use of MT in undergraduate and postgraduate programs at the University of Pretoria. He is also involved with several South African standards working groups that focus on the structural use of MT, which influences how we reshape robust MT design standards for engineers.

4.3.2 Industry Professional Opinions of Mass Timber

The interviewees' responses concerning MT and their topics and themes were outlined in Table 14, found in Appendix A. The relevant topics are extracted and highlighted in bold below. Each interviewee's responses regarding each topic are therefore analysed in conjunction with the other.

Figure 24: Summary of the results of the related themes (Author, 2024)

Perceptions: It is agreed amongst the interviewees that MT is appropriate to be used in SA due to its favourable climate, likened to Australia with similar climate and timber species. Australia, alongside its more advanced supply chains and practices, can be used as a model for SA (Cruywagen, 2024). Van der Hoven (2024) argues that understanding specific manufacturing processes when designing with MT allows for appropriate design changes during the manufacturing process, which is made possible through good BIM integration. Issues such as chasing services into masonry walls or the complications of making design changes to RC structures can be avoided through the lightweight nature and workability of MT. Despite a lack of examples of MT fire-compliant detailing in SA, van der Hoven (2024) explains that complex detailing is possible. It is important to note that MT for affordable housing is not advised due to the high cost of materials; however, demand will eventually reduce this cost. All the interviewees agree that not enough professionals are familiar with MT capabilities and limitations, leading to a hesitancy of adoption. For this reason, education targeted towards professionals is mandatory through the showcasing of successful MT projects (Cruywagen, 2024). Dr Johan van der Merwe (2024) discusses the importance of the end user perception: where in SA, the "knock test" shows that many South Africans doubt MT as it is not as dense as conventional and accepted masonry and concrete. For this reason, he argues that upper-income groups will need to drive change towards acceptance of MT.

Availability: All interviewees agree SA is more than capable of making MT sustainable and viable through its already vast timber plantations and faster-growing tree species, which result in accelerated carbon absorption and are still

being researched in comparison to European forests. There is a significant opportunity for excess timber capacity to be channelled into creating high-performance structural elements, as illustrated through York Timbers' current 60-70% quota use (Flemming, 2024; Cruywagen, 2024). In terms of manufacturing capability, research and collaboration are actively underway through The University of Pretoria, York Timbers and MTT, expanding on the existing developed timber supply chains in SA (Cruywagen, 2024; van der Hoven, 2024).

Price: All interviewees agree that due to low demand and limited competition, there is a limited supply of MT, resulting in high costs compared to conventional materials. However, as previously mentioned, upper/middle-class interest could drive demand. It is also agreed that although MT has a higher initial cost, it does prove to have long-term savings and environmental benefits through increased local production and economies of scale (Cruywagen, 2024). The formalisation of the carbon tax will also dramatically reduce the cost of MT through its environmental benefits (van der Merwe, 2024).

Building Practices: The current construction industry is focused on building cheaply, often resulting in the support of polluting practices and schedules that are fast-tracked, resulting in errors. Developers and contractors are reluctant to adopt alternative methods due to the time and effort involved in learning how to work with MT. Reform is possible, as expressed by all interviewees, through closer collaboration between architects and engineers (van der Merwe, 2024), the adoption of hybrid systems (Fleming, 2024), carbon tax formalisation (Cruywagen, 2024) and education on the use of MT as developed by MTT (van der Hoven, 2024). Van der Hoven (2024), however, emphasises that the adoption of IBTs without considering skills transfer can result in slower construction processes instead of optimised ones. Van der Hoven (2024) advocates that firms must change their ways of working to be better equipped to deal with change in the industry and activate the benefit of project time reduction and risk reduction through using MT. MT can be used for all building components (6 S's), which allows for various applications and scales of adoption within a project, in line with the client's willingness to embrace technology and risk (Fleming, 2024).

Technology: MT can be designed for assembly and disassembly, made possible through the prefabrication process, resulting in quicker erection times compared to conventional methods, where it is a timeline of days and weeks instead of months (Fleming, 2024; van der Merwe, 2024 & Cruywagen, 2024). There is also an opportunity for skills development and transfer in factory-based manufacturing and assembly processes, and the introduction of highly skilled carpenters on building sites can support the domestic industry (Cruywagen, 2024; van der Merwe, 2024). However, services must be carefully planned as alterations are difficult to do once the system has been designed (Fleming, 2024). There is also a need for an existing code of practice to be developed for engineers to fall back on (van der Merwe, 2024).

4.3.3 Industry Professional Opinions of Adaptive Reuse

The interviewees' responses concerning MT and their topics and themes were outlined in Table 15 found in Appendix A. The relevant topics are extracted and highlighted in bold below. Each interviewee's responses regarding each topic are therefore analysed in conjunction with the other.

Construction: Fleming, van der Merwe & van der Hoven agree that MT can be used for AR projects, especially in cases where internal structural elements are removed and then replaced with MT for the same use. However, understanding the existing structure and load considerations at the foundation level is imperative (van der Merwe, 2024), and Fleming (2024) expresses that this may be difficult to determine. Services are one of the biggest concerns of AR projects, as described by Cruwagen, Fleming & van der Hoven (2024), and developers often aim to maximise FAR to increase the number of units and potential profit, further exemplifying this issue (Cruywagen, 2024). MT has a distinct advantage in AR projects as it can reduce neighbourhood impact due to faster construction, assembly, and construction staging (van der Hoven, 2024). Smaller tools and dry construction minimise mess and disruption in both densely populated and limited access sites (Fleming, 2024).

Cost considerations: Upgrading services is one of the main costs in AR projects, as expressed by all interviewees. Demolition and rebuilding are deemed to be more expensive and unrealistic in cases where the building is not profoundly damaged (Cruywagen, 2024). One needs to consider where the value will be added and what the return on that investment will be (van der Hoven, 2024). Inner city (CBD) revitalisation through AR is appropriate and examples can be seen in Cape Town, Hong Kong and London, highlighting its use in cities with land scarcity and indicating a growing trend towards sustainable and efficient use of building stock (van der Merwe, 2024; Cruywagen, 2024).

Technology: Collectively, the interviewees emphasise the environmental benefits of reusing existing buildings and reducing waste compared to demolition and new construction, further advocating for the adoption of MT in AR projects for vertical expansion. Van der Hoven (2024) underscores the advantages of prefabrication, particularly for façades and bathroom units, which not only shorten construction times but also increase returns for building owners. MT has the potential to minimise structural modifications and disruptions while offering lightweight, easy-to-install solutions for internal modifications and extensions (Cruywagen, 2024). MT is cost-effective and versatile, applicable to various components of AR projects. Additionally, MTs' flexibility and capacity to optimise space allows for the addition of structures between wings and the enhancement of natural light and ventilation (van der Hoven, 2024).

Heritage: The need for industry professionals to prioritise impact and energy use over aesthetics, questioning where the inherent heritage value lies in AR projects, is emphasised among the interviewees. A heritage strategy might involve removing elements while preserving materiality to prevent buildings from becoming obsolete based solely on appearance. Christo van der Hoven challenges the notion of rebuilding heritage structures piece by piece, advocating for a critical approach that goes beyond mere replication. There is a challenge in navigating heritage regulations and building codes, particularly in historic city centres (Cruywagen, 2024). Furthermore, van der Hoven (2024) emphasises the importance of considering the street façade in discussions of heritage value and criticises approaches that only reuse façades while overshadowing them with new construction. He suggests that heritage practitioners should focus on identifying and making accessible the valuable aspects of heritage structures rather than merely protecting them. Additionally, Dr. Johann van der Merwe proposes using Building Information Modeling (BIM) to archive buildings and ensure their accessibility for future generations.

Residential: The interviewees highlight various aspects regarding residential AR projects. Dr JH Cruywagen emphasises the role of AR in addressing housing shortages by converting commercial buildings into residential spaces, especially for social housing. He notes the importance of balancing affordability with development costs and considers factors such as proximity to jobs, safety, and privacy in CBD social housing projects. He also points out preferences for individual bedrooms among residents. In the conversion from office to residential spaces, challenges arise in altering services due to differences in loading on ablutions and electrical systems. Van der Hoven (2024) notes that residential occupants prioritise control over natural light and airflow compared to mechanical systems common in commercial buildings. He underscores the importance of considering circulation, as commercial buildings often have different elevator and fire safety requirements. Densification can be achieved by breaking down existing structures or expanding vertically while ensuring the system isn't overloaded, especially if designing for a different use with potentially lower imposed loads on the floors (van der Merwe, 2024).

Chapter 5 - Discussion

This chapter delves into research findings, aiming to answer the three research questions posed in Chapter 1. Therefore, it begins by examining the literature reviewed in chapter 2 which determines the suitability of obsolete buildings in the Pretoria CBD for social housing, considering socio-economic, environmental, and infrastructural factors.

To answer the broader second sub-question, the next section then explores the perceptions and experiences of industry professionals regarding AR projects and MT. Each aspect (AR and MT) is split into a section. Each section thus uses the results of the interview data to contextualise and confirm the results from the questionnaire data. The literature review confirms some topics and themes. New information provided in the interviews were also confirmed with additional relevant literature.

The AR section focuses on challenges and opportunities related to serviceability, structure, economy, and heritage preservation. Additionally, the MT section discusses the perceptions and experiences of using mass timber (MT) in construction, addressing aspects such as speed of construction, cost, availability, building components, and fire ratings.

Finally, the chapter explores the solutions provided by MT to overcome the difficulties in office-to-residential AR projects to answer the final sub question. This final section discusses the integration of MT in AR projects, particularly in the context of future adaptability and vertical extensions.

5.1 Social Housing in the Pretoria CBD

The suitability of the Pretoria CBD for social housing is a multifaceted issue that requires consideration of various socio-economic, environmental, and infrastructural factors. The literature review provides a comprehensive framework for evaluating these factors through the focus on sustainable human settlements and then centralised human settlements specifically, which will be synthesised with some interview data to answer the research question.

As mentioned in the literature review, the critical shortage of housing in SA, with a backlog of 2.4 million houses and many living in informal settlements, underscores the urgency of finding viable social housing solutions. Mahlatsi (2022) explained that existing social housing solutions are criticised for the quality and distance from the city, as decentralised social housing perpetuates historical segregation which limited access to essential services and economic opportunities. Wilhelm-Solomon (2022) highlights the existing demand for inner-city living, as low-income residents and illegal immigrants have taken up residents in similarly abandoned buildings in Johannesburg due to proximity to jobs, transport, services, and amenities. This takes advantage of the compact, walkable, and social aspects of a compact CBD (Red Book) (Department of Human settlements, 2019). These aspects highlight the demand of low-income residence to take advantage of the benefits of inner-city living.

The literature revealed the significant inventory of obsolete buildings in the CBD due to the lack of office space demand. This leaves a considerable void in the growth and development of the city. Considering South Africa's economic challenges, prioritising the reuse of existing infrastructure in the CBD is critical. This practice not only lowers development costs and reduces loading the municipality with additional services, but also prevents further service and infrastructure decay stemming from neglect. By preventing urban sprawl and focusing efforts on densifying existing cities, the city can promote cost-effective development and ensure efficient resource allocation. Russel (2018), mentioned in the literature review that global and local strategies for urban renewal have included rezoning offices to residential to catalyst redensification. Therefore, it is vital to rezone the CBD offices to mixed-use residential blocks to exploit the demand for inner-city living - promoting cost-effective development, reusing existing infrastructure and services, and promoting inner-city renewal through a shift in the target market.

The literature promoted catalytic projects as a strategy for mixed-use, racially, and class-integrated developments, promoting shared economic prosperity support and socio-economic integration. These projects aim to create feasible

investments for private developers to include 30 – 70% of social housing in residential blocks, providing capital grants of up to 77% of construction projects, or renovations. Additionally, the current buyers' market (determined by supply exceeding demand) gives purchasers an advantage in an improving market. Figure 25 shows the current property market in the Pretoria CBD, revealing an increasing number of sales and average selling price in only four months since the beginning of 2024. Therefore, an opportune investment strategy exists, with catalytic projects, to renew the city's existing office buildings for socially inclusive economic prosperity that relieves the demand for housing.

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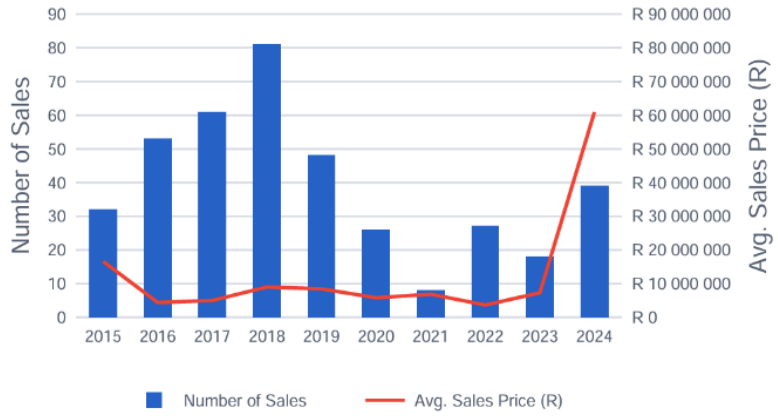

Year	Number of Sales	Avg. Sales Price (R)
2015	32	R 16 600 000
2016	53	R 4 400 000
2017	61	R 5 000 000
2018	81	R 9 000 000
2019	48	R 8 450 000
2020	26	R 5 800 000
2021	8	R 6 850 000
2022	27	R 3 650 000
2023	18	R 7 275 000
2024	39	R 60 950 000

Figure 25: A Comparative Market Analysis (CMA) report (May 2024) showing the average selling price and number of sales from 2015 - 2024.

The literature exposes the feasibility of AR over demolition and new builds. Ellison et al. (2007) argue that upgrading and maintaining services, fabrics, and quality fully realises the lengthy lifecycle expectancy of existing buildings. Over a third of questionnaire respondents increased the height of buildings during AR projects, further improving the feasibility of AR projects as strategic investment opportunities over demolition and new builds. Additionally, the literature showed that improving the footprint of the building by adding additional floors, possible with the office-to-residential live load reductions, creates the potential for increased income through sales and rentals, potentially mitigating the cost of overall renovations.

In conclusion, the AR of existing building stock in the Pretoria CBD for social housing presents a feasible and strategic investment opportunity. This approach not only addresses the pressing housing shortage but also fosters inner-city renewal, social integration, and economic growth. By repurposing obsolete office buildings into vibrant mixed-use residential complexes, the city can leverage existing infrastructure, reduce the burden on municipal services, and promote sustainable urban development. The potential for vertical expansion further enhances the economic viability of these projects. Moreover, the integration of social housing within these developments can foster inclusivity and contribute to a more equitable urban fabric. The property market in the Pretoria CBD shows promising signs of growth, revealing a prime opportunity to drive positive change in the city's landscape.

5.2 Perceptions and Experiences in Adaptive Reuse Projects

5.2.1 Adaptive Reuse in the Pretoria CBD

Half of the questionnaire respondents reported involvement in AR projects, which underscores the existing demand for building reuse in the development market. However, successful implementation requires overcoming overarching challenges, such as the lack of coordinated efforts between government and private sectors (Turok, Seeliger, & Visagie, 2021:22), Zoning laws that demand a redundant amount of parking spaces (Russel 2018:50), and increased

construction times negatively impacting inner-city logistics and causing unnecessary congestion (Russel, 2018:50-51). Questionnaire respondents sympathise with parking as a barrier to AR or renovation projects. When asked about the challenge of AR projects, almost half of respondents perceived including parking to be a difficulty – making it the third biggest 'challenge' of AR projects. If up to 70% of the residential units are dedicated to low-income groups, providing parking might be unnecessary, as they are less likely to own cars.

Most questionnaire respondents viewed AR projects favourably, with a majority indicating more perceived benefits (n = +10) than difficulties (n = -10). The most significant benefit identified was the extension of the existing building's lifespan. This was followed by consideration towards preventing urban sprawl and improving carbon footprint through material savings. Notably, a perfect positive correlation was observed between preventing urban sprawl and improving the carbon footprint of developments, suggesting that respondents value sustainable urban development and prioritise the lifecycle of buildings and materials.

Cruywagen (2024) further highlights the environmental benefits of AR, as demolition contributes significantly to landfill waste. He advocates for office-to-residential AR projects to address housing shortages while utilising empty office buildings. Cruywagen (2024) emphasises the importance of balancing renovation costs with affordability, particularly for low-income end-users. He illustrates this with an example from student housing, where individual rooms and proximity to work are critical considerations for tenants. This cost-savings of utilising an existing structure, combined with government subsidies for social housing, emphasises AR's appeal as an investment strategy.

5.2.2 Existing Structures

When comparing the costs of demolition and new construction versus AR projects, Cruywagen (2024) estimates that AR projects are often more cost-effective if the existing structure is maintained. Most 20th-century buildings were not designed with considerations for AR and are primarily constructed with RC, making understanding the location and quality of the structure a challenge. Due to construction practices involving masonry and RC, elements are often concealed, leading to hidden beams or load-bearing walls that might be mistaken for infill. Van der Merwe (2024) advocates for an intimate construction process that carefully considers the building's existing structure, even potentially exposing it.

The data analysis revealed that few practitioners altered the existing structure. The greatest difficulty of AR projects, perceived by almost 90% of respondents, was determining the properties and location of the building materials, exacerbated by the difficulty of obtaining as-built plans - Russel (2018:37) confirms that plans are not always correct or the case of SA, sometimes missing entirely. Consequently, altering or repairing the structure is ranked as the third most significant limitation for clients and practitioners in undertaking AR projects. Van der Merwe (2024) confirms that structural drawings are often unavailable, necessitating exploratory investigations to determine the structure's configuration. This requires close collaboration among industry professionals and a step-by-step approach to construction.

Therefore, van der Merwe (2024) provides two options for determining the structural material's strength: testing the concrete quality and analysing the rebar content through rebar scanning. He continues that understanding the age of the rebar can also provide insight into its yield strength. Once the structure is thoroughly understood and analysed, the construction team, in collaboration with heritage practitioners, can develop appropriate value propositions.

5.2.3 Heritage

A perfect positive correlation was observed between respondents who valued prolonging building life and preserving heritage as benefits of AR, highlighting the respondent's consideration for maintaining and enhancing the existing historical urban fabric of current building stock. However, convincing clients to undertake AR projects and adhering to heritage standards were identified as significant limitations. This suggests that developers, as decision-makers, may

be a barrier to AR implementation. This may be due to heritage practitioners having the authority to halt construction, as seen with City Properties Marchie Mansions, creating a significant obstacle for developers. Clarke & Corten (2011:890) advocate for the creation of a heritage registry, as required by the NHRA (National Heritage Resources Act, 1999).

Similarly, van der Hoven (2024) questions the efforts of heritage practitioners in effectively communicating the heritage value of buildings to both the public and potential investors. This resonates with Andersen et al. (2021:7), noting that “public building registers can provide easily accessible and cheap data for indicators to support assessments of the optimisation potential of existing buildings”.

Van der Merwe (2024) emphasises the importance of understanding what constitutes heritage and how to approach its treatment. He cautions against preventing building reuse due to overly restrictive heritage laws and advocates for a nuanced approach that considers the building's inherent value. For example, he suggests that removing an element while preserving its materiality could be a viable solution. "In that case," he states, "I want to treat every new build as heritage because I want to maintain the materiality" (van der Merwe, 2024).

The most renovated component of an AR project included altering the façade and relocating services. This aligns with an AR challenge identified in the literature review: altering façades (Russel, 2018:46). While the street-facing façade is often considered a primary focus of heritage value, reducing the building's heritage solely to the façade leads to problematic outcomes. Van der Hoven (2024) illustrates that preserving a two-story heritage façade while constructing a disproportionately large tower behind it overshadows the building's historic character. He criticises this approach as a superficial "checkbox" exercise that neglects a critical evaluation of a building's true heritage value.

Van der Hoven (2024) emphasises that overlooked elements, such as room interiors, framing systems, or unique historical fixtures like doorknobs, could hold significant heritage value. He advocates for a thoughtful dialogue between the development team and heritage components during the design process to ensure the appropriate preservation of heritage value for future generations (van der Hoven, 2024). He cautions against postmodern ideals that prioritise façade treatment as mere skin while disregarding or demolishing the interior structure.

5.2.4 South African Regulations and Services

Alterations of AR projects must modernise buildings to comply with current South African National Standards (SANS 10400) building codes, a significant limitation to AR projects for about 50% of questionnaire respondents. While office-to-residential conversion typically reduces occupancy loading, it usually involves reorganising layouts, leading to potential relocations of elevators, walkways, and fire safety requirements (Van der Hoven, 2024). However, changing the building layout is perceived as the least limiting aspect of AR projects, and horizontal circulation is the least concerning challenge among questionnaire respondents.

A significant challenge in office-to-residential conversions is the increased density of services (Remøy & Van der Voordt, 2007:6). The number of water points rises with the addition of toilets, showers, baths, basins, and washing machines (Cruywagen, 2024). As the QS expert notes, "You're going to need voids and ducts for water and sewage, though electrical is easier to hide away." This is echoed by most respondents, who identify altering services as the second biggest challenge in AR projects.

Van der Hoven (2024) also highlights the reliance on mechanised ventilation systems in commercial office buildings. These systems are costly to operate and maintain in residential projects, as they typically require a separate HVAC unit for each apartment. He emphasises the importance of considering natural ventilation systems, which are feasible in buildings with a footprint narrower than 15 meters, allowing for better airflow.

In addition to airflow, natural lighting is a crucial consideration, as it reduces electricity costs for occupants (van der Hoven, 2024). However, optimising natural light and ventilation in a closed building typology often necessitates rethinking the façade's surface area and design (van der Hoven, 2024).

One common approach to adding services like air conditioning and plumbing is to simply attach them to the building's exterior (van der Hoven, 2024). Alternatively, Cruywagen (2024), Fleming (2024), & van der Hoven (2024) propose coring through the existing structure, creating additional service shafts. Each option has pros and cons that practitioners must carefully consider based on project-specific parameters (van der Hoven, 2024). If existing services are in poor condition, Fleming (2024) suggests removing or disconnecting them and implementing a new system.

Ultimately, practitioners must approach each AR project with meticulous consideration, considering the unique challenges and opportunities presented by the existing structure and its intended new use (Cruywagen, 2024; Fleming, 2024; van der Hoven, 2024; van der Merwe, 2024).

5.3 Perceptions and Experiences of Mass Timber

5.3.1 Speed of Construction

Industry practitioners exhibit reluctance towards adopting MT due to practitioners' unwillingness to take risks (Hassan & Grobbelaar, 2023). Quantity surveyors struggle to price MT, while engineering consultants may hesitate due to limited experience and familiarity (Cruywagen, 2024). IBTs often present an initial learning curve for experienced contractors, potentially leading to slightly extended construction timelines and costs (van der Hoven, 2024). It stands to reason that as IBTs become more mainstream, this cost will disappear. However, currently, some contractors charge construction premiums due to risks incurred (Gosselin et al., 2017:558-559). However, MT projects consistently demonstrate significantly faster completion times compared to conventional methods, even with inexperienced contractors, with timelines often measured in weeks rather than months (van der Hoven, 2024). Van der Hoven (2024) reflects on a project in Cape Town, where they placed hundreds of square meters of CLT slabs in a day.

Shorter construction times cannot be understated, as they mitigate problems synonymous with lengthy construction schedules (van der Hoven, 2024). These include minimising disruptions to surrounding neighbourhoods and reducing the likelihood of errors and risks (van der Hoven, 2024). Notably, 60% of respondents identified reduced construction risk as a specific advantage of MT.

Respondents' additional comments highlight MTs' ability to mitigate errors through early involvement of specialists and practitioners in the design phase. Fleming (2024) emphasises that design elements such as fire safety, moisture control, durability, and building services integration must be meticulously planned before construction commences, as the manufacturing process solidifies design decisions. He advocates for a shift away from ad hoc on-site construction decisions towards a collaborative, team-based approach that involves close coordination between professionals from the outset of the project. The literature confirms that a strategic shift is needed from traditional methods for the local implementation of MT (Goubran et al., 2020:106). Van der Hoven (2024) agrees by calling for a different way of working - "from a design point of view, you will reduce errors, you will reduce mistakes, and you will be able to build faster".

The questionnaire data revealed a strong statistical correlation between the cost-effective repairability of MT and both its overall cost-effectiveness and speed of construction. This indicates that when errors or changes occur in MT construction, they are relatively inexpensive to rectify. Areas of uncertainty around a project can be ring-fenced in the design stage (van der Hoven, 2024). Van der Hoven (2024) confirms that modifications can occur during construction, such as drilling holes or filling gaps, as MT is a remarkably forgiving material. This contrasts with changes in RC construction, which typically involves time-consuming and costly procedures with cascading effects on time and budget (van der Hover, 2024; Greyling, 2020). Additionally, van der Hoven (2024), a director at MTT, explains that

MTT's manufacturing process is broken into stages to allow for changes. However, relying on changes is risky as it can lead to material waste when unnecessary cuts are made into manufactured billets.

5.3.2 Cost

Questionnaire respondents widely perceive the speed of construction as a significant benefit of MT, while cost-effectiveness is viewed as a lesser advantage. Interestingly, despite recognising the cost of MT as a significant limitation, a perfect positive correlation exists between perceived cost-effectiveness and speed of construction. This suggests that practitioners attribute MTs' cost-effectiveness to the significantly shorter construction periods and therefore reduced costs. This aligns with the findings of Westhuyzen & Wium (2021:44) in the literature review, who concluded that the primary cost savings of MT arise from accelerated construction schedules. Reduced timeframes translate to lower costs of labour, machinery, transport, and other costs generated by lengthy construction schedules, as well as shortened interest accrual periods and a quicker return on investment from rentals (Westhuyzen & Wium, 2021:42).

The comparatively high cost of MT is attributed to limited supply (Cruywagen, 2024; van der Hoven, 2024; van der Merwe, 2024). Westhuyzen & Wium (2021:43) calculated that the price of S7 SA pine would need to decrease by at least 33% to surpass the IRR of a RC structure, a scenario deemed unlikely. However, Cruywagen (2024) is positive that improved research and development in forestry, manufacturing, local production, and economies of scale will have tremendous reduction on cost. Van der Merwe (2024) agrees, expanding that when carbon tax "gets more formalised, you will see the comparative cost of timber beating the other materials".

5.3.3 Availability

There is a strong negative correlation between practitioners' experience with MT and their perception of its availability. This suggests that practitioners who have experience with MT don't believe it is abundantly available, potentially revealing it to be challenging to procure. However, the literature review, and all interviewees agree that there are sufficient timber plantations to support a MT market (IOECadmin, 2022).

Van der Merwe (2024) highlights SA's favourable climate, which accelerates tree growth and allows for cultivated plantations rather than reliance on natural forests, ensuring a renewable supply. However, limited demand currently constrains companies like York Timbers, one of SA's largest lumber and plywood processors, who utilise only 60-70% of their allocated quota (Cruywagen, 2024). Of their 88 600 hectares of forests, 58 700 hectares are dedicated to cultivating FSC-certified pine and eucalyptus plantations, making up 66% of land dedicated to trees grown for construction (York Timbers, n.d). This provides ample room for growth within the current quota, with potential to repurpose an additional 24% of forest land for construction purposes. Furthermore, Cruywagen (2024) reveals ongoing research to enhance tree genetics, aiming to improve wood quality and accelerate growth and harvesting cycles, potentially addressing future demand surges. Notably, this research has already demonstrated success in reducing tree growth cycles by three years.

Van der Merwe (2024) notes a supply challenge arising from the discrepancy in availability between timber grades: S5 SA Pine is readily accessible due to demand, while S7 and S10 are not, primarily due to a lack of demand. This lack of demand forces timber suppliers to market S7 or S10-tested timber as S5 due to market preferences and sellability. Currently, the predominant use of MT in roof trusses, which typically require only S5 grade, has not incentivised the market for higher grades. However, incorporating MT into a broader range of building components could shift this dynamic, creating a greater demand for stronger timber grades and fostering a more comprehensive and transparent market.

To address this issue, van der Merwe (2024) refers to an ongoing study, at the University of Pretoria's engineering department, that aims to comprehensively assess lumber properties to reveal actual market supply of S7 and S10 timber for MT manufacturing of structural components. By determining the potential prevalence of higher-grade timber,

this study could empower engineers to confidently spec S7 and S10 for diverse applications, thereby stimulating demand.

Van der Merwe (2024) confirms that with only three MT manufacturers in South Africa (MTT, XLAM SA (Pty), and HWZ International), production is slow. This aligns with the findings of Westhuyzen & Wium (2021:44), who reported that local suppliers, like XLAM SA (Pty), advised large projects may require extended lead times due to limited manufacturing capacity. This suggests a need for either additional factories per supplier or a greater number of suppliers overall to boost availability and potential for higher adoption.

5.3.4 Mass Timber Building Components

The overwhelming willingness of 93% of respondents to advocate for MT demonstrates a positive perception among industry professionals. However, most practitioners continue to primarily associate MT with roof structures, adhering to traditional construction methods. Respondents have utilised MT for a variety of other applications, including beams, walls, columns, and floor slabs, underscoring its potential for use in all structural components. However, additional comments suggest a potential knowledge gap regarding MTs' full capabilities among practitioners' colleagues, primarily associating it with roof trusses and beams.

Van der Merwe (2024) advocates for MTs' use in all structural components. Though, he suggests that a pragmatic approach is needed, as the material properties might not be best suited for all uses or all regions in the country. Van der Hoven (2024) shares the sentiment, promoting the use of MT as a holistic building material with potential for use on all façades if practitioners maintain design considerations like solar heat gain, internal comfort, and water penetration.

Fleming (2024) and van der Hoven (2024) suggest that floor slabs present a strategic entry point for MT into the market due to their relative simplicity within a project. They continue to suggest the potential for composite arrangements, where concrete and CLT work together synergistically, providing practitioners with a sense of familiarity, easing the transition to MT. In this case, a concrete topping is layered on a structural timber floor slab, which serves as both a permanent formwork and a ceiling, providing improved acoustic insulation compared to CLT-exclusive floors (Fleming, 2024).

Fleming (2024) further highlights the substantial weight reduction potential of MT floor slabs, noting that floor slabs typically account for 60-70% of the total weight of a traditional multi-story building. A study by Bahrami et al. (2021:1407) supports this claim, revealing a staggering difference of over 615 tons between 300mm thick MT and 250mm thick RC floors over just three stories, representing an almost 20% load reduction. While this figure may vary slightly between projects, even a conservative 20% reduction of 60-70% of the building load translates to 14% of total building weight lifted off the foundations. As building heights increased, so do the weight ratios, potentially leading to substantial cost savings in groundworks of mid- and high-rise buildings. This benefit resonated with most questionnaire respondents, with 73% identifying reduced foundation size as the most appealing advantage of MT.

5.3.5 Fire Ratings and Performance

GLT frame structures, comprising of columns and beams, present increased complexity due to the intricate nature of their connections (van der Hoven, 2024). These connections necessitate rigorous fire design considerations, as columns and beams are particularly vulnerable in fire scenarios, posing unique challenges compared to other building elements (van der Hoven, 2024). The survey results revealed a mixed response regarding MTs' fire performance: 30% of respondents acknowledged its fire resistance as a benefit, while another 30% considered the need for rational fire design a limitation. The positive statistically significant correlation between these two factors suggests participants recognise the importance of fire design strategies in ensuring MTs' fire safety.

However, the biggest obstacle to MT adoption, according to Fleming (2024), pertains to the perceptions of clients and professionals that are completely unfounded. He gives reference to perceptions of fire, which he extinguishes by discussing the definite burn rate and char rate.

Interestingly, a negative statistically significant correlation was observed between respondents considering MT and those perceiving high fire resistance. This suggests that practitioners who have used MT don't consider it to be effective in a fire. This may indicate a persistent caution surrounding MTs' fire performance and the inherent responsibility of practitioners to protect construction teams and end-users. Local literature clearly outlines that MTs' performance in fires is comparable to RC and superior to steel (van der Westhuyzen et al., 2020:40).

Negative perceptions regarding MTs' performance in fires might be exacerbated by those who haven't yet explored MT, contributing to a general reluctance towards adoption. Studies have shown MT to be sufficiently fire-resistance, promoting use in 10-storey buildings with a 90min fire rating, as it maintains structural integrity even under extreme heat due to protective charring layers (Gonzáles-Retamal et al., 2022:16; van der Westhuyzen et al., 2020:40). Promotional campaigns, incentives, and demonstration projects can enhance the exposure and acceptance of timber construction in areas where it faces unfounded scepticism (Goubran, Masson, & Walker, 2020:104). Van der Hoven's (2024) and van der Merwe's (2024) involvement in establishing design codes hopes to assure practitioner confidence, provide standards that ensure users' safety, and guard against potential liabilities for practitioners. This is confirmed by V. Salvadori (2024:260), where "the cooperation between stakeholders often determines how MSTBs will evolve".

5.3.6 Mass Timber as a Structural Material

A perfect statistically significant correlation exists between respondents' consideration of MT, RC, steel, and masonry as structural materials, indicating that practitioners view MT as a viable structural option. Additionally, perfect positive correlations were found between MT and steel for use on east, west, and north facades, as well as for speed of construction, suggesting a perceived similarity between steel and MT. Interestingly, van der Merwe (2024) suggests that warehouses, typically constructed with steel frames, are ideal building typologies for MT. MTs' comparable lightweight nature and strength to steel highlights its potential to replace steel structures in various applications. Additionally, the literature reveals the combination of steel improves the strength of MT, and MT protects steel against the effects of fire, utilising the benefits of both materials (Al-Djaber & Veghar, 2018).

5.3.7 Improving Perceptions

Fleming (2024) explains that extensive experience among practitioners with steel, RC, and masonry creates reliance on such processes. All interviewees agree that clients and practitioners lack knowledge about MT capabilities and limitations. Therefore, MTT often advises practitioners on the use of MT, and they have also provided a design guide, downloadable on their website, for industry professionals to use in the construction process (MTT, 2024). Fleming (2024) describes that allowing practitioners to touch MT and expose them to the possibilities of supplying a 1,8m wide, 6m long beam creates a 'light bulb moment'.

Similarly, Cruywagen (2024) promotes the use of case studies to convince practitioners of the potential of MT, as practitioners are worried about cost, their buildings burning down, and the longevity of the building. Cruywagen (2024) encourages practitioners to investigate the historical longevity of timber structures, citing examples of buildings in Japan lasting over 1400 years and in England lasting over 1000 years (Oldest.org, n.d.). As mentioned in the literature review, research indicates no correlation between building materials and useful lifespan (ARUP 2019:70).

Fleming (2024) advises close collaboration between contractors and professionals to create a smooth transition for understanding small intricacies that don't normally need to be explained to contractors. Van der Hoven (2024) agrees, prioritising the manner of entry into the market. Beyond prescribing relatively simple CLT floor slabs to improve exposure, he argues the need to de-risk construction processes for project partners.

The comments from questionnaire respondents suggest the value of showcasing successful MT projects to inspire and educate others in the industry. There is disappointment among questionnaire respondents about the perceptions of MT as an inferior material. There is a call for practitioners to get involved in promoting MT throughout the industry (Cruywagen, 2024). Practitioners experienced with MT must expose their colleagues to the potentials of MT (Orozco et al. 2023:21). Additionally, it is important to consider the perceptions of MT among end users of different economic groups (González-Retamal et al., 2022) especially when considering it for use in social housing.

5.4 Mass Timber in Adaptive Reuse Projects

5.4.1 Future Adaptability

It is important to promote future adaptability when renovating or undergoing AR projects. Cruywagen (2024) cites hotels in Japan as an example, where intense competition necessitates building upgrades every five years to keep pace with contemporary design and construction trends. These buildings are temporarily closed or "mothballed," and elements are removed and replaced. Cruywagen (2024) suggests that if residential buildings were to undergo similar upgrades and renovations every decade or so, prefabricated units, rather than in-situ construction, would simplify the process.

With CNC technology, prefabricated MT elements are particularly well-suited for inner-city buildings, promoting adaptability and facilitating system changes (Cruywagen, 2024; Fleming, 2024; van der Hoven, 2024; van der Merwe, 2024). Additionally, van der Merwe (2024) advocates for the digital documentation of both new builds and AR projects in the city, providing design plans, structural plans, service plans, and material properties to facilitate seamless future renovations or AR. “A potential way of handling the data challenge in buildings is to use automatisation and Building Information Modelling (BIM)” (Andersen et al., 2021:2). This would allow future professionals to access crucial information about the structure, services, and other hidden building components, aiding in future adaptations. Moreover, subcontractors who repair services post-construction, such as electricians and plumbers, could also benefit from this information for improved service provision.

5.4.1 Vertical Extensions

Changing a building's program can provide designers with flexibility when considering the live loads associated with each program (van der Merwe, 2024). Transitioning from a higher imposed load to a lower one (office-to-residential) allows for vertical expansion without overloading the existing structural system. Structural calculations and studies are recommended to evaluate the permissible height increase, taking up the live load reduction with structural loads.

When asked about materials best suited for altering existing building structures, participants most frequently chose steel (n = 11) and MT (n = 12). Additionally, van der Merwe (2024) notes that vertical extensions are “where timber might have the upper hand, as that kind of vertical expansion is not heavy." He suggests that MT has the potential to replace heavier building components like infill walls, beams, or floors. Due to its higher strength-to-weight ratio, MT can reduce the load on vertical elements and the foundations.

Van der Hoven (2024) concurs with the potential for vertical extensions and suggests further exploration of innovative solutions, such as suspension systems between existing building wings.

Finally, when considering the conjunction of the 14% reduced load achieved by replacing floor slabs with CLT floor slabs, the reduced live load achieved from office-to-residential conversion, and the potential to add two to three stories of MT on existing structures – the potential exists to completely reconfigure mid-rise office buildings to high-rise residential units with MT-RC-steel hybrid material technology (Figure 26).

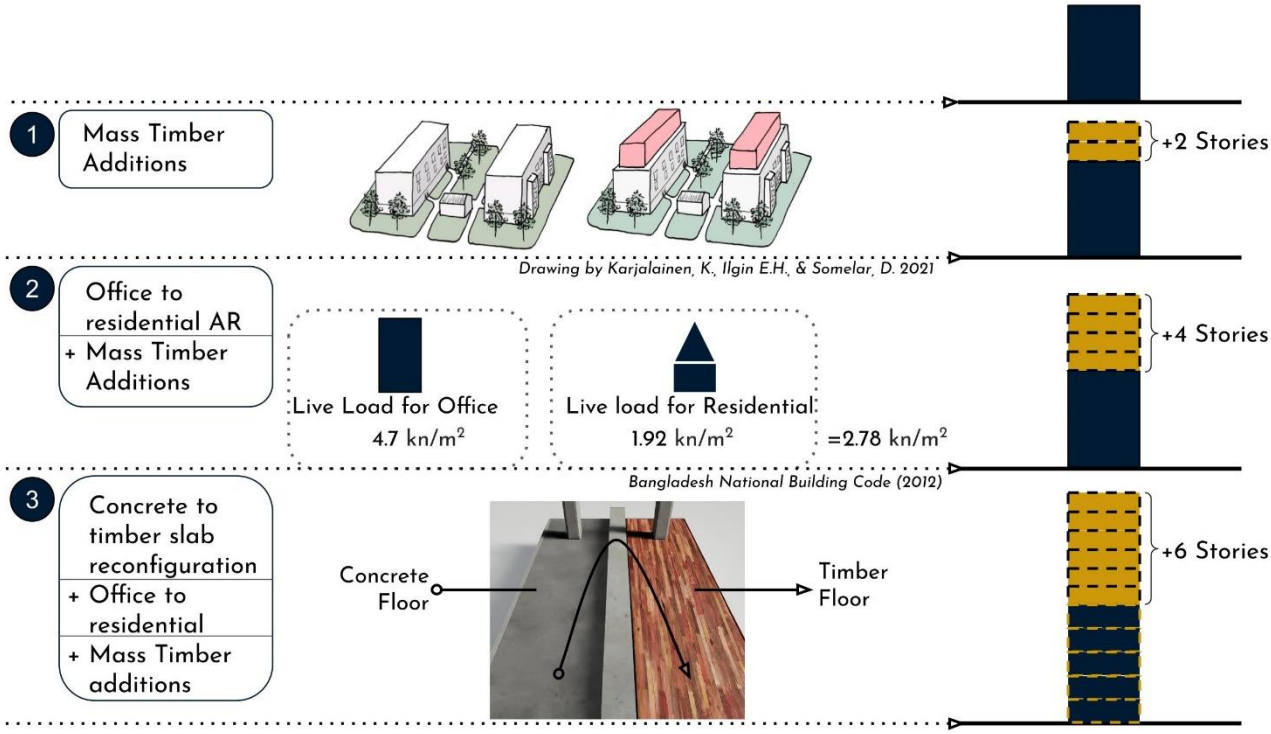

Figure 26: MT additions (1), Vertical extensions possible with AR office-to-residential (2), and reconfiguration of floor slabs from concrete to MT (3) (Author, 2024).

Chapter 6 – Conclusion

The final chapter concludes the research by summarising the key findings and implications of the study. It addresses the research questions posed in Chapter 1, focusing on how MT can assist in overcoming the challenges of AR projects for sustainable human settlements. The chapter outlines the benefits and challenges of inner-city construction from the discussion, emphasizing the positive impact of MT on reducing neighbourhood disruption and construction timelines. It also explores the potential of the Pretoria CBD for social housing, highlighting the role of catalytic projects to achieve responsible urban renewal and social integration. Additionally, the chapter delves into considerations for AR projects, including structural assessments, heritage preservation, and service upgrades. It also concludes the findings of MT, addressing perceptions, costs, availability, and building components. Finally, the chapter concludes by discussing the possibilities of MT in AR projects, particularly in the context of vertical extensions and future adaptability.

6.1 Inner City Construction

AR projects in CBDs can negatively impact neighbourhoods by obstructing streets necessary for vehicular and pedestrian movement (van der Hoven, 2024). The construction or deconstruction of multi-story buildings often involves large delivery trucks transporting materials or removing debris, potentially occupying significant street space (van der Hoven, 2024). If a building mass occupies most of its designated ERF, the entire street might be affected, causing cascading traffic disruptions.

While constructing or adapting multi-story buildings with MT in the CBD requires similar space, potentially on the street, the duration of impact is considerably shorter compared to traditional construction methods (van der Hoven, 2024). If minimising neighbourhood disruption is a priority, van der Hoven (2024) suggests prefabricating MT room modules off-site, significantly reducing construction time on-site. Therefore, MT, in combination with prefabrication, rises as a strategic solution to inner-city construction, with quieter and faster construction, coupled with improved safety and minimal disruption to the local neighbourhood (Abed et al., 2022:18; ARUP, 2019:42; Leskovar & Premrov, 2021).

This approach benefits not only the city but also the building owners. It allows occupants to remain in the building longer while portions are being constructed or 'prepped' for prefabricated unit installation, and it enables earlier reoccupation after construction (van der Hoven, 2024). Westhuyzen & Wium (2021:40,42) confirmed this, finding that a 50% reduction in MT construction time allowed for earlier occupancy and an additional R4.6 million in revenue for the owner during construction, assuming 100% occupancy in Johannesburg's Sandton CBD. Additionally, as mentioned earlier, a shorter construction timeline leads to faster repayment of borrowed capital and reduced interest costs (van der Hoven, 2024).

Overall, interviewed practitioners and questionnaire respondents expressed positive sentiments, emphasising the advantages of MT in AR projects and the importance of collaboration and education for successful implementation. There is optimism about MTs' potential to transform the construction industry, along with an acknowledgement of the need to address existing biases and misconceptions.

6.2 Social Housing in the Pretoria CBD

In conclusion, the revitalisation of the Pretoria CBD through adaptive reuse (AR) projects offers a multifaceted solution to the pressing needs of low-income residents while addressing economic and infrastructural challenges. The proximity of city centres, as observed in South African CBDs, meets the demands of low-income residents by providing better access to jobs, services, and amenities. Recent trends show that low-income residents and even illegal immigrants have moved into abandoned buildings in SA, for example, Johannesburg. This highlights an existing need for housing in CBDs among poverty-stricken citizens, emphasising the necessity of such developments.

The substantial inventory of empty or obsolete buildings in the Pretoria CBD presents a significant opportunity to utilise existing infrastructure and enhance service provision. Prioritising the reuse of these buildings not only lowers development costs but also reduces the burden on municipal services, preventing further service and infrastructure decay. By focusing efforts on densifying existing urban areas and avoiding urban sprawl, the city can promote cost-effective development and ensure efficient resource allocation.

Catalytic projects promoting shared economic prosperity can cement low-income residents into the city, counteracting gentrification trends common in urban renewal. These projects aim to create feasible investment opportunities for private developers to include a significant portion of social housing in residential blocks, supported by substantial capital grants. Additionally, for cost-effective residential renovations with capital grants, the current buyers' market presents an advantageous scenario for investment in such catalytic projects, further supported by improving market conditions.

Renovating existing buildings is potentially more cost-effective than demolition and offers potential increased profits through vertical extensions when converting from office to residential. This approach maximises the lifecycle expectancy of buildings, promotes sustainable development, and can mitigate renovation costs by increasing rentable or sellable floor areas.

Overcoming challenges such as public-private coordination, zoning laws, and parking requirements is crucial for the successful implementation of AR projects. Modifying zoning laws to reduce redundant parking requirements, especially for social housing or student accommodation, can alleviate one of the significant barriers to AR projects. Additionally, addressing the impact of construction times in inner cities is essential to minimise congestion and ensure smooth project execution.

Ultimately, AR projects present a sustainable and cost-effective development strategy, but developers must prioritise affordability and the needs of end-users. By balancing renovation costs with affordability, particularly for low-income groups, AR projects can address housing shortages while utilising existing structures. Therefore, the revitalisation of the Pretoria CBD through AR projects represents a strategic investment in socially inclusive economic prosperity and sustainable urban growth.

6.3 Adaptive Reuse Considerations

Adaptive Reuse (AR) is viewed favourably by both questionnaire respondents and interviewees for its potential to address housing shortages, revitalise urban areas, and promote sustainable development through the extension of a building's lifespan.

However, AR projects face challenges in understanding and adapting existing building structures, especially those constructed with reinforced concrete and masonry. Determining the properties and location of building materials is often difficult due to inaccurate or missing as-built plans. Thorough analyses of the building's structural and material properties, including testing concrete quality and analysing rebar content, are essential.

Several recommendations emerge from the research to facilitate the implementation of AR projects. Early involvement and collaboration of professionals, including architects, engineers, and other specialists, can help identify and address potential challenges upfront, ensuring a smoother and more efficient project timeline. Conducting a comprehensive assessment of the existing building's structure, materials, and services is crucial for understanding its potential for adaptive reuse and identifying any necessary modifications or upgrades. Strategies must, therefore, be established to overcome the challenges facing AR projects through close collaboration between academia and practice.

Heritage preservation is crucial but can sometimes hinder AR projects, potentially leading to demolitions. Developing a heritage registry of existing buildings and effectively communicating their value to the public and investors can facilitate AR projects. A nuanced approach that considers the building's inherent value, including interiors and unique historical fixtures, is necessary. Close collaboration with heritage practitioners is essential to ensure that the

adaptive reuse project respects and preserves the building's historical value while meeting modern building codes and regulations.

Updating buildings to comply with current SANS standards involves reorganising layouts, relocating services, and optimising natural light and ventilation. Adding services like air conditioning and plumbing requires careful consideration, with solutions including attaching these services to the building's exterior or creating additional service shafts. Exploring innovative solutions for integrating new service systems, such as prefabricated modules or external service runs, can help overcome the challenges associated with upgrading services in existing buildings. Practitioners must balance renovation costs with affordability, particularly for low-income groups, to address housing shortages sustainably.

Ensuring future adaptability is crucial in AR design and construction. Proper documentation of the design, structure, and services, with Building Information Modelling (BIM), is vital for maintaining building serviceability and facilitating future adaptations without incurring additional documentation costs. Prefabricated MT elements, supported by CNC technology, provide cost-effective adaptability and seasonal building changes due to MTs' lightweight properties and workability. Finally, methodologies need to be established by academia and practice to analyse the existing structures and implement effective strategies for common challenges. This paper serves as an example, revealing the potential for investment when considering building height extensions and phases of construction.

Ultimately, AR projects in the Pretoria CBD represent a strategic investment in socially inclusive economic prosperity and sustainable urban growth. By prioritising affordability and effective coordination, these projects can revitalise the inner city, utilising existing structures to create resilient and inclusive urban environments.

6.4 Mass Timber Considerations

The perceptions of mass timber (MT) among South African construction industry professionals and interviewees are generally positive, with many recognising its potential benefits like speed of construction, sustainability, and lightweight properties reducing foundation costs. Interviewees echoed the positive perceptions, emphasising MTs' suitability for the South African climate, design flexibility, and risk reductions. However, the premium cost of MT, and the lack of experience and knowledge among professionals, were identified as barriers to adoption.

The rapid construction timeline associated with MT projects significantly reduces costs, risks, and neighbourhood impact. Despite initial inexperience from industry practitioners due to unfamiliarity, MT projects maintain their improved construction schedules. Faster construction schedules reduce disruptions, errors, and risks, as identified by 60% of respondents who highlighted MTs' ability to mitigate construction errors through early involvement of specialists.

While the cost of MT is higher, the overall savings from reduced construction schedules, lower interest costs, and quicker returns on investment make MT a feasible material with an IRR of 5% above the benchmark 15%. The high cost is due to limited manufacturing processes rather than forestry supply, which has capacity for growth. As carbon taxes become more formalised, MT could become cheaper than other materials. Continued investment from MTT, York Timbers, and the University of Pretoria in research and development to optimise manufacturing processes and reduce costs can further incentivise the adoption of MT in SA.

Literature and industry feedback advocate for using MT in all building components. However, CLT floor slabs are targeted as a strategic entry due to their relative simplicity. Additionally, hybrid floor slabs combining concrete and MT can provide familiarity for practitioners while improving construction speeds and weight reduction. Hybrid technology includes the combination of MT and steel, which improves structural capacity and addresses the limitations associated with each material, enhancing overall benefits.

MTs' improved fire rating, while supported by literature, still faces scepticism among some practitioners. Exposure to MT through case studies, demonstrations, and established building codes can change perceptions and increase

confidence among engineers and architects. Its potential to transform the construction industry underscores the importance of continued research, development, and industry engagement.

6.5 Possibilities of Mass Timber in Adaptive Reuse Projects

Adaptive reuse (AR) projects in city centres can significantly impact the local urban environment, especially with traditional construction methods. However, incorporating mass timber (MT) can accelerate project timelines and mitigate these impacts. MT reduces the duration of street congestion with fewer loading and unloading times, minimises waste, and reduces construction errors, ensuring a smoother and faster process. This is crucial for developers eager to see a return on investment.

Prefabrication technology further enhances MTs' advantages by shortening on-site construction time. Off-site manufacturing and assembly minimise disruptions, noise, congestion, and waste, which benefits building owners with existing tenants. Similarly, owners can phase construction, allowing one side or wing of the building to undergo preparation and construction while tenants on the other side remain minimally disrupted. This approach maintains a reduced income during construction and allows for a quicker return to full income.

Vertical extensions present building owners with a significant opportunity to increase gross rentable area (GRA) and subsequently boost overall income. MT and office-to-residential AR offer owners three distinct scenarios for achieving this (Figure 26 found in the discussion):

1) MT construction allows for the addition of one or two floors to existing buildings with minimal disruption to tenants.
2) When MT is combined with office-to-residential AR conversions, which reduce structural loads, the potential for adding additional floors increases to four or five.
3) Finally, during the reconfiguration of a building to accommodate additional services, change layouts, and alter façades, the heavier RC floor slabs can be replaced with lightweight CLT floor slabs, further reducing the overall load by approximately 14% (for three stories). The combination of the two previous scenarios creates the potential for a mid-rise building (6 stories) to add half a dozen additional floors, nearly doubling the gross rentable floor area and the number of units. Although this process may require temporary tenant relocation, it promises substantial investment returns in accelerated periods.

Despite MTs' premium cost, its benefits in accelerated construction make it suitable for social housing. Owners can take advantage of capital grants by dedicating 30% of new floors to social housing, making the project financially viable. Upgrading current tenants to premium units and renovating units closer to ground floors for social housing can maximise rental income by providing premium rental prices on the additional MT timber floors.

Economic and logistical research is required to outline the potential challenges and possibilities of phasing construction of inner-city mid-rise buildings with MT, concentrating efforts on maintaining rentable income during construction. Additionally, cost comparisons of renovations and MT extensions are required alongside projected income from increased floor area to understand if vertical extensions can help mitigate renovations, or perhaps make it profitable. Further collaborative research and experimentation in engineering and architecture are recommended to validate the strategy of doubling building height, which could revolutionise AR projects and the construction industry. Additionally, careful consideration of policies is required to understand the limitations of extensions in the city, such as fire escapes, increased services, and occupancy limitations.

Further research is recommended to assist industry practitioners in overcoming the barriers common in AR projects. This includes addressing the challenges and possibilities of phasing construction in mid-rise buildings with MT. Economic and logistical studies, cost comparisons, and income projections from increased floor areas are essential to determine the feasibility and profitability of vertical extensions. Though this paper argues that increased floor rental areas are expected to offset or even generate profits from renovations, it is recommended that future papers corroborate these suggestions. Collaborative research in engineering and architecture is recommended to validate

the strategy of doubling building heights, potentially revolutionising AR projects and the construction industry. Additionally, policy must be considered to locate and address limitations related to fire escapes, increased services, and increased occupancy in terms of regulations.

As cities densify and office spaces convert to residential units, suddenly adding rentable floor areas to existing structures becomes increasingly valuable. MT, with its lightweight nature and strength comparable to traditional materials, is ideal for rapid vertical expansion. This approach supports the global trend towards densification and sustainable construction practices, making MT a valuable tool for future urban development and social housing provision. As Cruywagen suggests, "MT can play a role in AR, reducing the need for extensive structural modifications and minimising the disruption caused by wet trades." This strategy aligns with the growing demand for efficient and socially conscious urban development.

6.6 Summary and Recommendations

In conclusion, this research set out to understand how MT can assist in overcoming the challenges facing AR projects for sustainable human settlements. Through feedback from questionnaires filled out by various construction industry professionals, the study was able to ascertain the perceptions and experiences of MT, and the difficulties and opportunities of AR projects. The literature review and interviews highlighted the capabilities of MT and its potential for use in MSTB, which helped suggest how they can assist in overcoming challenges facing AR projects. The study uncovered a substantial demand for inner-city living among low-income groups in Johannesburg, underscoring the various advantages inner-city social housing offers. Given this demand and the benefits identified, Pretoria's CBD, with its large stock of unused buildings, emerges as a prime area for social housing development.

The abundance of underutilised buildings in Pretoria's CBD is a prime opportunity for social housing developments. Repurposing these buildings can address the housing shortage, utilise existing infrastructure, and promote cost-effective densification. For effective AR projects, the study emphasises the importance of early involvement of professionals, thorough building assessments, and a balanced approach to heritage preservation. These measures can help overcome challenges related to structural modifications, service upgrades, and regulatory compliance. The research highlights the potential of vertical extensions using MT to increase rentable floor area and create more housing units. This approach is particularly promising for office-to-residential AR conversions, where reduced structural loads allow for additional floors. Replacing concrete floor slabs with lighter MT slabs can further optimise the building's weight and cost-effectiveness – providing the potential for increased vertical extension and, therefore, increased gross rentable area. To promote the wider adoption of MT, the study recommends continued research and development, education, and collaboration among stakeholders. Addressing concerns about cost and perceptions of MT is crucial for its successful integration into the construction industry.

The findings of this study suggest that MT, as a sustainable and innovative building technology, has the potential to revolutionise the construction industry and address the pressing need for social housing in urban areas. However, strategic collaboration, financial incentives, educational initiatives, and industry guidelines are essential to overcoming barriers and promoting the widespread adoption of MT in AR projects.

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Appendices

Appendix A: Interview Responses

Table 14: Topics and themes outlined in the interviews of 4 industry professionals concerning Mass Timber.

		Interview responses on Mass Timber
Themes	**Topics**	**Interviewee's Responses**
Perceptions	Climate	**DR JOHANN VAN DER MERWE** -SA has good climate to build with MT **CHRISTO VAN DER HOVEN** -Change in moisture results in cracking in MT / Moisture considerations direct the need for local MT manufacturing plants / MT works in countries with similar climate (New Zealand, Australia, Japan) **DR. JH CRUYWAGEN** -Australia can be used as a model for SA, due to similar climate and similar timber species. They have advanced practices and supply chains.
	Design Changes	**CHRISTO VAN DER HOVEN** -MTT breaks manufacturing into design changes to allow for design changes / Changes occur while machining billets, though the process can be admin intensive and requires good digital systems (BIM) / Drilling panels to provide services on site is possible as the material is easy to work with compared to problems that occur by chasing. / Areas of uncertainty can be ring-fenced and addressed later due to workability of MT. / Make more difficult to make changes with RC (Produces dust, heavy, rebar calculations and locations).
	Improving Negative Perceptions	**CHRISTO VAN DER HOVEN** -Complexity of details must be considered for fire design / Columns & beams are incredibly complex for fire designs / MT is restricted because people haven't been exposed to such builds / MT for affordable housing is not possible, as it is too expensive. Desire will influence price. **ANGUS FLEMING** -Professionals are not familiar with the product, capabilities, and limitations (creating hesitancy and uncertainty in recommending it to clients) / Perceptions must be improved by educating clients and changing perceptions of professionals / Proper education and demonstration can overcome misconceptions / Address details like service integration and cladding, which is daunting when implementing new materials / MTT provides a design guide for construction industry professionals. **DR. JH CRUYWAGEN** -Clients and practitioners lack knowledge about MTs' performance, cost, and durability, leading to hesitation in adoption / Widespread misconception about MTs' longevity and fire resistance must be addressed through demonstration and education / Absence of visible, successful MT projects makes it difficult for clients to envision potential / Showcasing successful projects is important for awareness / Research and collaboration between universities, industry experts, and practitioners will further refine knowledge and application of MT. **DR JOHANN VAN DER MERWE** - "knock test" as a cultural South African habit will prevent adoption of MT as it's not as dense as concrete or brick & mortar / Upper income groups needs to drive change, before the lower income groups accept it as a appropriate material.
Availability	Forests	**ANGUS FLEMING** -Abundant and well-managed forestry resources makes timber sustainable and viable **DR. JH CRUYWAGEN** -York Timbers has vast timber plantations (half a million hectares) and only using 60 – 70% of quota. Excess capacity can be channeled toward MT. / Ongoing research in tree genetics is leading to faster-growing (18yrs – 15yrs) and higher-quality trees. **CHRISTO VAN DER HOVEN** -Investment of forestry sectors are seen in countries with underdeveloped supply chains (unlike SA) highlights drive towards the use of MT as a building product. **DR JOHANN VAN DER MERWE**

		-European forests are natural (and lessening), South African forests are farmed / Faster growing trees results in more carbon absorption.
	Wood	**ANGUS FLEMING** -Transformation of Pine into high-performance structural element represents a significant opportunity for industry **DR JOHANN VAN DER MERWE** -Timber is a readily available material & Renewable. / Trees in SA grow faster which results in lower density / S10 timber pieces are sold @ S7 prices due to lack of market / Studies are being done on marketed wood to test grading.
	Manufacturing	**DR. JH CRUYWAGEN** -York Timbers is actively investing in research at the University of Pretoria to optimize manufacturing processes. **CHRISTO VAN DER HOVEN** -increased supply chain can enable the use of MT / MTT & York Chairs consulting with forestry consortiums and green funds. / SA has developed supply chains /
Price	High Prices	**DR JOHANN VAN DER MERWE** -Limited market supply of manufactured timber increases prices. / Market must grow with increased production and demand is important / **CHRISTO VAN DER HOVEN** -Very expensive to build in SA compared to the GDP / Wealthy upper-middle class bring opportunity for new products & Technology and develop supply. **DR. JH CRUYWAGEN** -Lack of comprehensive data on the cost-effectiveness of MT compared to traditional materials. / Current pricing for MT construction can be higher due to novelty and limited competition.
	Reduced cost	**DR. JH CRUYWAGEN** -While initial costs are higher compared to traditional construction, increased local production and economics of scale can drive prices down over time. / MT reduces construction transportation costs / Additional factories within proximity of projects reduces transportation costs. **DR JOHANN VAN DER MERWE** -Formalization of carbon tax in developments bottom line will dramatically drop the price of MT. **ANGUS FLEMING** -Cost can be a barrier, but long-term savings and environmental benefits need to be highlighted.
Building Practice	Current Construction Industry	**DR JOHANN VAN DER MERWE** -Solution to increased development projects and polluting construction industry / Decarbonize the built environment / Developers build on cheapest construction model / Carbon doesn't currently influence the bottom line / Price of steel is skyrocketing due to carbon tax, and erosion in some areas. **DR. JH CRUYWAGEN** -Limited information is provided by developers of current carbon emissions from developments. **CHRISTO VAN DER HOVEN** -SA's fast-track schedules, propagated by the economic climate – forces foundations to be dug before designs are finalised. Resulting in frequent errors / Construction companies are closing (Murray & Roberts) due to economic trouble / Slow adoption is due to high risk of fire, structural failure – which translate to human death or danger, and financial investment / Multiple subcontractors adopting differing methods makes collaboration difficult / Existing methods take very long, where MT is 1000sqm a day. **ANGUS FLEMING** -Construction Industry is resistant to change with professionals accustomed to materials and methods / Learning new systems require times and effort, which developers are reluctant to invest. / Construction industry is slow to adopt new technologies due to established practices and reliance on readily available skilled labour.
	Reforms in the Industry	**DR JOHANN VAN DER MERWE** -Small/medium warehouses are most suited to using MT / Most relevant work in Zurich ETH is done by architects and engineers that design vaulted structures –

		challenging how we design shape or form and how forces actually want to flow / Design away from the flow of force adds unnecessary materiality / Focus between professionals should be on circularity / Engineers and architects should work closely together in the rise of use of MT **ANGUS FLEMING** -Construction sites remain relatively clean and undisturbed due to lack of wet trades and heavy machinery. / There is less room for on-site changes compared to tradition construction / Initial focus on MT for floor slabs as it provides (60-70%) reduce load on foundation and faster construction / Hybrid floors as a steppingstone (combining structural timber with tinner concrete topping) for acceptance. Address concerns about aesthetics, finishes, service integration, improved acoustic insulation, and faster construction, light weight (40-50%) / **DR. JH CRUYWAGE** -MT to give potential to offset carbon tax and reduce developing cost. **CHRISTO VAN DER HOVEN** -Stalemate in the industry suggests scenario for innovation to happen and disrupt market / Change ways of working, firm by firm must be better equipped to adopt design and construction process / Adopting IBTs without considering transfer of skill can slow down construction processes instead of speed them up (autoclave aerated concrete blocks in the Michelangelo building.) / IBT can be more costly as contractor hires less workers due to marketing of quicker construction times / Transitional plan is detrimental to entry into the market. / Ring fence the risk for project partners – building with something not too complex and novel (MT Slabs) / Best place for MT in current industry is floor slabs as least complexity (CLT & RC can work together) / MTT provides a booklet to educate and assists with process /
	Rapid Build and Design of MT	**ANGUS FLEMING** -Design takes up-front planning time to consider services, fire, water, and thermal heating so the building can breathe. / MT can be used for all building components (structure, skin, space plan and services) depending on client's willingness to embrace technology. **CHRISTO VAN DER HOVEN** -Shift to MT necessitates construction practitioners to adopt design-first approach rather than traditional simultaneous design and construction model. / New design model is efficient and reduces risk of errors / Presents need for high quality, fully resolved, innovative designs / Important to provide flexibility for end-users (longevity) / Timber can be used as façade material, with similar considerations of materials on any facades (sun, shade, water, internal comfort) / New contractor erected first floor of MT house in Irene in a week. / Experienced contractors' erect buildings in two days – construction times are spoken about in weeks, not months. **DR JOHANN VAN DER MERWE** -Stuff (6 s's) must be responsibly manufactured / Design considerations must be made between very large open space (space plan) or pragmatic grid of 6x4m (structure) / Timber is biodegradable and can disappear as apposed to ending in landfills / MT building Skin is more complex / Complexity is situated in design details and connections.
Technology	Disassembly	**ANGUS FLEMING** -Almost every BOXA components can be taken down and reused (Disassembly and relocation) / Flexibility in commercial settings where needs change over time. **DR JOHANN VAN DER MERWE** -Mt is easily disassembled, structure is not demolished when site-plan is changed /
	Prefabrication	**ANGUS FLEMING** Avoid wet works / Minimize environmental impact / Prefabrication and dry assembly allows for rapid construction, completing projects in days instead of weeks / services need to be carefully planned / alterations are difficult to plan / Put together by paint-by-numbers set of instructions, screws, screwdrivers, and impact drivers. **DR JH CRUYWAGEN** -Quick erection time compared to traditional methods. / Prefabrication can reduce cost of labour with fewer on-site workers.
	Structural Capability	**DR. JH CRUYWAGEN** -York Timbers is actively investing in research at the University of Pretoria to explore structural capabilities of local timber

		DR JOHANN VAN DER MERWE -Structure is where MT thrives / Glulam columns is a more desirable material finish than concrete or column / Less density requires more timber and thicker structural components.
	Skills	**DR. JH CRUYWAGEN** -New opportunity for upskilling workforce in factory-based manufacturing and assembly process / Transferring traditional trades to factory work with sophisticated machinery. **DR JOHANN VAN DER MERWE** -Adoption of MT is lagging the rest of Europe / Need for highly skilled carpenters on buildings sites to support the domestic industry. **ANGUS FLEMING** -MT is easy to work with, forgiving of mistakes, and makes construction faster and simpler.
	SANS Standards	**DR JOHANN VAN DER MERWE** -There must be an existing code of practice for Engineers to fall back on

Table 15: Topics and themes outlined in the interviews of 4 industry professionals concerning Adaptive Reuse

Interview responses on Adaptive Reuse		
Themes	**Topics**	**Interviewee's**
Construction	Structure	**ANGUS FLEMING** -If basic structure is concrete, intact, and good to use, it can't be cheaper to demolish than reuse / Knowing location or material properties of existing structure is difficult. **DR JOHANN VAN DER MERWE** -Exposing the structure of a used building is beautiful / Fee partial for structure is based on percentage of material that's sued, and some engineers can oversize to get more money / As embodied carbon comes into the bottom line, it could offset cost risks associate with AR / Structure forensics must be tested with scans for reinforcing content, and rebar strength through age analysis / potential to remove internal structure and replace it with MT for the same use / Timber has higher strength to weight ratio / Load considerations at foundation level is very important. **DR. JH CRUYWAGEN** **CHIRSTO VAN DER HOVEN** -Possible to remove interior parts and replace it with MT to give more budget to the load.
	Services	**DR. JH CRUYWAGEN** -Main cost can stem from upgrading services like plumbing, electrical, elevators, especially when converting to residential use. **ANGUS FLEMING** -Rerouting services requires voids, ducts for water and sewage. Electrical is easier to hide / Services can be rebuilt instead of repairing old to reduce costs / Services can be difficult to locate / **CHRISTO VAN DER HOVEN** - Residential buildings require more water points, toilets, showers, and baths per square meter than commercial buildings. Solutions like external service runs or horizontal systems can be explored.
	Space Plan	**DR. JH CRUYWAGEN** -Developers often aim to maximize FAR to increase number of units and potential profit, which can influence design decisions.
	Neighbourhood Impact	**CHRISTO VAN DER HOVEN** -Multi-storey buildings take up a lot of space on the street, Trucks, delivering bricks, concrete trucks turn the street into site extension / MT can reduce impact due to faster construction and quicker unloading and construction staging's. **ANGUS FLEMING**

		-Using smaller tools and dry construction minimizes mess and disruption, making MT suitable for AR projects in densely populated areas or with limited access / Transporting bricks is difficult, dangerous, messy and takes a lot of time.
Cost Considerations	Demolition and New Build	**ANGUS FLEMING** -Starting again can't be cost effective or realistic, unless its profoundly damaged
	Building Stock Reuse	**DR. JH CRUYWAGEN** -AR can be more cost-effective than new construction, especially in city centers where land is limited and expensive. / If the structure is in good condition, repurposing it can save on demolition and reconstruction costs. / Renovating older buildings can significantly increase building value and attract tenants or buyers willing to pay a premium for a modern, well-located space / Hong Kong & London offer valuable lessons on AR strategies in dense urban environments / Potential in CBD as vertical construction is possible with MT. **CHIRSTO VAN DER HOVEN** -Consider where value is added (extension, reconfiguration etc.) **DR JOHANN VAN DER MERWE** -Challenges of cost can inflate risks that could create a cost premium / Cape Town has done very well in revitalizing the inner city with AR / Very few older buildings have been constructed with deconstruction in mind / AR projects should be considered as case-by-case bases.
	Commercial Adaptability	**DR. JH CRUYWAGEN** -AR is common in cities like London & Hong Kong due to land scarcity, indicating growing trend towards sustainable and efficient use of building stock.
Technology	Prefabrication	**CHRISTO VAN DER HOVEN** -Consider prefabrication (kit-of-parts) for the façade / Whole prefabricated bathrooms units installed into student housing / Shrink construction time due to pre-fabrication / Building owner has higher RR due to quicker construction and faster rentals collected. / Shorter construction also negates significant interest incurred by traditional construction.
	MT	**DR. JH CRUYWAGEN** -MT can play a role in AR, reducing need for extensive structural modifications and minimizing the disruption caused by wet trades / MT offers lightweight, easy-to-install solutions for internal modifications and extensions / MT can be cost effective option for AR projects, as it's lightweight and easy to transport and assemble / MT is useful for various components in AR project, including structural elements, interior finishes, or building additional floors. **CHIRSTO VAN DER HOVEN** -MT is useful as its light and flexible / MT provides the potential to add on-top, suspend or hang structures between wings / one can span further from edges or side due to strength-weight ratio / MT allows to decrease surface area of façade to allow light and air into the building. **ANGUS FLEMING** -MT is light weight and allows for easy transportation and assembly into tight spaces using small cranes (spider crane). Ideal for infill projects or additions to existing buildings / MT can be used in AR projects for vertical expansion (adding 3 or 4 floors to existing building without overloading foundations) internal partitioning (creating flexible and easily reconfigurable spaces), and interior finishes (using MT for walls, ceilings, or feature walls for a unique aesthetic appeal). **DR JOHANN VAN DER MERWE** -MTT is expanding vertically on residential projects
	Sustainability	**DR. JH CRUYWAGEN** -Reusing existing buildings reduces waste and environmental impact compared to demolition and new construction.
Heritage	Heritage as a consideration	**DR JOHANN VAN DER MERWE** -Industry professionals must not impose forcefully onto the world / Consider impact and energy use rather than considering beauty / Where does inherent heritage value lie in an AR project / Perhaps heritage strategy is to remove something but maintain the materiality / Buildings can become obsolete when considering how it looks rather than what happens to it.

		CHIRSTO VAN DER HOVEN -Questions if rebuilding piece for piece is valuable. Don't just rebuild the old heritage structure / **DR. JH CRUYWAGEN** -Navigating heritage regulations and building codes can pose challenges for AR projects, especially in historic city centers /
	Heritage as Value	**CHIRSTO VAN DER HOVEN** Street Façade is the first place practitioners speak about heritage value / Only reusing the façade of a heritage building, and then building a tower to overshadow it is not a critical approach (as seen in Cape Town) / It's a postmodern ideal to maintain 100% of façade / Arbitrary things have heritage value that can be brought into the design (proportions, framing etc.) / David Chipperfield's work in Germany finds a way to contrast and complement conventional ways of working with old heritage structures / Heritage practitioners must consider what is of value and how to make it accessible to the public, as apposed to merely protecting heritage structures. **DR JOHANN VAN DER MERWE** -BIM models can help archive buildings and make them accessible for the next 50 years.
Residential	Social Housing	**DR. JH CRUYWAGEN** -AR can help address housing shortages by converting underutilized commercial buildings into much-needed residential spaces. / Balancing affordability with development costs is crucial in south housing projects where tenants have limited budgets / Proximity to jobs, safety, affordability, privacy are all considerations for profitable CBD social housing / People don't like to share bedrooms.
	Conversion from office-to-residential	**DR. JH CRUYWAGEN** -Services are difficult to alter due to loading differences on ablutions and electrical / **CHIRSTO VAN DER HOVEN** Residential occupants typically desire more control over natural light and airflow compared to the mechanical systems often used in commercial buildings / Circulation must be considered as commercial buildings often have more elevators and different fire safety requirements due to higher occupancy / **DR JOHANN VAN DER MERWE** - If you want to densify, you must break down or expand on what's there / if you design for a different use, with a potential lower imposed load on the floors, it can assist with expanding vertically without overloading the system.

Appendix B: Questionnaire Comments

Table 16: Additional Comments given by Questionnaire Respondents on IBTs

Comments about IBTS from Questionnaire Respondents	
What are the Limitations of Using IBTs	
Thematic Analysis	
Lack of Expertise and Acceptance:	• Engineers are often not trained in designing with IBTs, requiring the involvement of experts, and increasing project costs. • There is a general reluctance to embrace IBTs due to uncertainty, lack of precedents, and tight project timelines and budgets.
Information and Costing Challenges:	• Information on IBT details and construction techniques is difficult to obtain. • Quantity surveyors struggle to cost projects involving IBTs due to limited precedents.
Socioeconomic Impact:	• IBTs may reduce the need for a large workforce in the construction industry, which is a significant concern in SA.
Overall Sentiment:	The sentiment across all three comments is predominantly **negative**. There is a clear sense of frustration and concern regarding the barriers to adopting IBTs in the South African context.
What are the Benefits of Using IBTs	
Thematic Analysis	
Environmental and Community Advantages:	• Engineers are often not trained in designing with IBTs, requiring the involvement of experts, and increasing project costs. • There is a general reluctance to embrace IBTs due to uncertainty, lack of precedents, and tight project timelines and budgets.
Aesthetic and Design Flexibility:	• Information on IBT details and construction techniques is difficult to obtain. • Quantity surveyors struggle to cost projects involving IBTs due to limited precedents.
Labor Considerations:	• IBTs may reduce the need for a large workforce in the construction industry, which is a significant concern in SA.
Overall Sentiment:	The sentiment across all three comments is predominantly positive. There is a clear sense of optimism and potential regarding the advantages of adopting IBTs.
Experiences of IBT's expanded upon	
Challenges in Implementation	• **Resistance to Change:** The construction industry is often "stuck" in traditional ways of thinking and working, leading to scepticism and reluctance to embrace IBTs due to a lack of precedents. • **Regulatory and Approval Hurdles:** Government projects and building approvals can pose difficulties in implementing IBTs. Clients need to be aware of the associated risks.

	• **Limited Expertise:** Engineers and other professionals may lack the necessary training and experience to work with IBTs effectively. • **Labor Concerns:** While some IBTs may require less skilled labour, others may necessitate specialized skills, potentially leading to workforce challenges.
Positive Experiences and Opportunities	• **Successful Projects:** Several respondents shared positive experiences with IBTs in various projects, including pre-cast concrete buildings, tiny homes with SIP panels, and MT structures. • **Efficiency and Speed:** IBTs can significantly reduce construction time and streamline the building process, leading to improved team morale. • **Innovation and Design:** IBTs offer opportunities for unique and versatile facades, pushing the boundaries of architectural possibilities. • **Environmental Benefits:** Reduced noise pollution and rubble removal are highlighted as positive environmental impacts of IBTs. **The Role of Architects and the Need for Change:** • **Advocacy and Leadership:** Architects are encouraged to take on a more active role in promoting and implementing IBTs, moving beyond a "consultant" role towards a "Master Builder" approach. • **Value and Compensation:** Fair compensation for architects is seen as crucial for fostering innovation and wider adoption of IBTs. • **Collaboration and Education:** The need for collaboration and knowledge sharing among architects, engineers, and other stakeholders is emphasized to overcome barriers and drive the adoption of IBTs.

Table 17: Additional Comments given by Questionnaire Respondents on Mass Timber

Comments about Mass Timber from Questionnaire Respondents	
Challenges in Implementation	• **Resistance from Consultants:** Engineering consultants are often hesitant to embrace MT due to a lack of experience and familiarity with the material. This can lead to delays, increased costs, and even the abandonment of MT designs in favor of conventional construction methods. • **Costing and Procurement Challenges:** Quantity surveyors may struggle to accurately estimate the cost of MT projects, leading to budget uncertainties and potential overruns. • **Limited Scope of Use**: Some respondents noted that their experience with MT was limited to specific applications like exposed roof trusses and beams, indicating a potential lack of broader understanding and utilization of the material's full capabilities.
Positive Experiences and Opportunities	• **Successful Projects with Early Involvement:** When timber specialists are involved early in the design phase, projects can proceed more smoothly and efficiently. • **Aesthetic Appeal:** MT is recognized for its aesthetic qualities, particularly in exposed structural elements. • **Potential for Large-Scale Projects:** The responses indicate a willingness to consider MT for large-scale projects, highlighting its potential beyond smaller applications.
Recommendations and Lessons Learned	• **Early Involvement of Specialists:** The importance of involving timber specialists early in the design process is emphasized to ensure successful implementation and avoid costly changes later. • **Collaboration and Education:** The need for greater collaboration and knowledge sharing among architects, engineers, and other stakeholders is highlighted to overcome resistance and promote the wider adoption of MT. • **Showcasing Precedents:** The reference to the prefabricated pavilion in Gothenburg suggests the value of showcasing successful MT projects to inspire and educate others in the industry

Appendix C: Questionnaire

Utilizing Mass Timber, as an IBT, for Adaptive Reuse Projects

The following survey forms part of a Master's degree research study conducted by Mishau Azar from the University of Pretoria Department of Architecture.

The title of the study is "Utilizing Mass Timber to Unlock the Potential in Adaptive Reuse Projects for Human Settlements" and considers the use and usefulness of alternative / innovative building technologies (ABTs / IBTs), especially mass timber (Cross laminated timber (CLT) & glue laminated timber (GLT), in adaptive reuse projects of relevant practices.

The purpose of this survey is to gather information from AEC practitioners to establish how widely IBTs are used, establish use cases and determine the suitability of IBTs for specific types of buildings.

Your participation in this survey is voluntary and you can withdraw from participation at any time without consequence. Your personal information will not be gathered or used, except by your own consent for the purpose of being contacted directly by the researcher for an in person interview.

If you agree to participate, please complete the following online survey, which should not take more than ten minutes to complete.

By completing the survey, you indicate that you voluntarily participate in this research. If you have any concerns, please contact the Research Supervisor, Dr Coralie van Reenen, at cvreenen@csir.co.za.

1) Please state your Profession

_____

Perceptions and Experience using Innovative Building Technologies (IBT)

Considering the definition of alternative or innovative building technologies (IBTs) to be the use of materials other than conventional brick and mortar for the construction of the building envelope, structure and finishes.

1.1.1) Have you ever worked with innovative building technologies (IBTs)?

Mark only one oval.

Yes ⬭

No ⬭

1.1.2) If yes to the above, was your experience working with IBTs positive?

Mark only one oval.

Yes ⬭

No ⬭

⬭ Other:

1.1.3) If yes to the above, in how many projects have you used IBTs?

_____

1.1.4) What types of IBTs have you worked with before?

Tick all that apply.

- Light steel frame
- Mass timber (GLT/CLT)
- In-situ alternative concrete (example: hempcrete)
- Polystyrene composite wall technologies
- Prefabricated block technology
- Concrete additives
- Lightweight tilt up panels Structural insulated panels
- Other:

1.2) What are the limitations using IBTs?

Tick all that apply.

- Unskilled workers aren't trained to use IBTs
- Requiring certificate holders to sign off is extra administration
- Certificate holders are unavailable to assist with the design/construction
- IBTs are often more costly
- Information of details and construction techniques are difficult to obtain
- Clients are not interested in IBTs
- Other:

1.3) What are the benefits of using IBTs?

Tick all that apply.

- Quicker construction times reduces cost
- Lower the buildings carbon footprint
- Improve construction techniques in practice
- Improved building performance
- A novel technology is attractive to clients
- Less material needed is cost effective
- Other:

1.4) Would you consider working with IBTs for certain projects if the client is open to it?

Mark only one oval.

Yes ⬭

No ⬭

Other: ⬭

1.5) If applicable, please expand on your experience with IBTs

_____

_____

Perceptions of Mass Timber, as an IBT, compared to Conventional Building Materials

Considering mass timber (Cross laminated timber (CLT) & glue laminated timer (GLT)) as an innovative building technology (IBT) compared to conventional materials, like brick & mortar, reinforced concrete and steel, for the construction of the building envelope, structure and finishes.

2.1.1) Have you ever worked with mass timber (CLC & GLT)?

Mark only one oval.

Yes
No

2.1.2) If yes to the above, in how many projects have you used mass timber?

_____

2.2) Would you consider working with mass timber for certain projects if the client is open to it?

Mark only one oval.

Yes
No

2.3) Do you consider mass timber as an IBT?

Mark only one oval.

Yes
No
Other:

2.4) What do you think are the beneficial qualities of mass timber (CLT & GLT) over conventional construction materials (brick & mortar, reinforced concrete and steel?

Tick all that apply.

- Biophilic features are pleaSouth Africant to look at
- It has a comparatively high compressive strength
- It has a comparatively high tensile strength
- Lightweight timber structures reduce foundation size and cost
- It is sustainable to source and manufacture
- It is an abundantly available
- It speeds up the construction process
- It's cost effective due to faster construction times
- It's appropriate to design for assembly and disassembly
- It is cost effective and quick to repair/replace
- It's circular resource (recyclable and reusable)
- It makes computer numerical control (CNC) cutting accessible for precise design
- It has high fire resistance due to the char layer protecting the internal structure
- It allows for movement without cracking in unstable soils
- After thermal treatment it can withstand extreme sun exposure
- After H3-6 water treatment it is effective against water damage
- Hybrid multi-story construction as carbon sinks
- Reduced construction risk due to low construction time
- Low Impact of construction to the surrounding context
- Other:

2.5) What do you think are the limitations of mass timber (CLT & GLT) over conventional construction materials (Brick and mortar, reinforced concrete and steel)?

Tick all that apply.

- It isn't effective in single-story development
- It is an expensive material to procure
- Construction industry service providers aren't experienced with mass timber
- I don't know how or where to procure the material
- It requires learning new ways of building
- Computer numerical control (CNC) cutting is unknown to me
- It requires a rational fire design to validate a buildings fire rating
- It needs costly thermal treatment to be effective against sun damage
- It needs costly H2-6 water treatment to be effective against water
- damage Other:

2.6) If applicable, please expand on your experience with Mass Timber.

Perceptions of Adaptive Reuse

Considering adaptive reuse as the process of altering an existing building for a purpose other than which it was originally built or designed for.

3.1.1) Have you ever worked in an adaptive reuse project?

Mark only one oval.

Yes

No

3.1.2) If yes to the above, how many projects were considered adaptive reuse?

3.1.3) If yes to the above, what was the nature of the renovations?

Tick all that apply.

- The height of the building was increased
- The façade was updated
- An extra wing was added to the building
- The entire layout of the building was changed
- The services needed to be relocated
- The roof was made accessible
- The structure needed strengthening/relocating
- Other:

3.2) In your opinion, what are the main drivers for an Adaptive Reuse project?

Mark only one oval.

Renovating/improving the building's characteristics for the same/similar program

Renovating the building for a new program

3.3) Would you consider working in an adaptive reuse project if the client is open to it?

Mark only one oval.

Yes ⬭

No ⬭

Other: ⬭

3.4) Would you recommend an adaptive reuse project to your clients in the future?

Mark only one oval.

Yes ⬭

No ⬭

Other: ⬭

3.5) In your opinion, what are the advantageous of an adaptive reuse project?

Tick all that apply.

- Cost savings
- Material savings
- Avoiding wet works
- Time savings
- Prolonging the life of an existing building
- Preventing unnecessary production attributing to urban sprawl
- Lowers the carbon footprint of developments
- Preserving Architecture heritage
- Sustainable densification
- Other:

3.6) In your opinion, what are the difficulties of an adaptive reuse project?

Tick all that apply.

- Altering/repairing the structure
- Convincing a client into an adaptive reuse project
- Adding/repairing services
- Changing the layout
- Making the building compliant to current SANS regulations
- Considering the Heritage Impact
- Lack of as-built plans
- Client perceptions of old buildings
- Knowing the existing material specification (strength, reinforcing design, foundational walls, Foundation strengths)
- Other:

3.7) In your opinion, what are the most challenging components to alter/repair in an existing building/structure

Tick all that apply.

- Structure
- Services
- Horizontal Circulation
- Vertical Circulation

- Façade
- Roof
- Finishes
- Parking allocation
- Altering the buildings thresholds
- Other:

3.8.1) In your opinion, which materials are best suited for altering the structure of an existing building?

Tick all that apply.

- Timber
- Reinforced Concrete
- Steel
- Brick and Mortar
- I don't know
- Other:

3.8.2) In your opinion, which materials are best suited for the adaption of the North façade in an existing building?

Tick all that apply.

- Timber
- Reinforced Concrete

Steel

- Brick and Mortar
- don't know
- There is no difference in materials for façade
- Other:

3.8.3) In your opinion, which materials are best suited for the adaption of the East & West façade in an existing building?

Tick all that apply.

- Timber
- Reinforced Concrete
- Steel
- Brick and Mortar
- don't know
- Different materials on the façade don't make a difference
- Other:

3.8.4) In your opinion, which materials are best suited for assembly & disassembly?

Tick all that apply.

- Timber
- Reinforced Concrete
- Steel
- Brick and Mortar
- Composite Blocks,
- Unitized Aluminum

- I don't know
- Other:

3.9) In your opinion, Is an adaptive reuse project cheaper compared to a new structure of a comparable scope?

Mark only one oval.

Yes
No
I don't know Other:

26. 3.10) In your opinion, Is an adaptive reuse project cheaper compared to the demolition of an existing structure, and a newly built structure in its place?

Mark only one oval.

Yes
No
I don't know
Other:

4) Do you have any other comments about Timber, or other IBTs, in Adaptive Reuse projects?

5) Your feedback is greatly appreciated and highly valued. Would you kindly offer the opportunity to be interviewed?

Mark only one oval.

Yes, please contact me regarding an interview
No, please do not contact me

5.5) If you would like to be interviewed, please provide your contact information

Thank you! You are done.

Thank you for being part of this questionnaire. Enjoy your day further!

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Appendix D: Ethics Clearance

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

11 April 2024

Reference number: EBIT/68/2024

Mr M Azar
Department: Architecture
University of Pretoria
Pretoria
0083

Dear Mr M Azar,

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Research Ethics Committee refers.

Conditional approval is granted.

This means that the research project entitled "Utilizing Mass Timber, as an IBT, for Adaptive Reuse Projects" is approved under the strict conditions indicated below. If these conditions are not met, approval is withdrawn automatically.

Conditions for approval:

Where applicable, no data is to be collected without first obtaining permission letter(s). The permission letter(s) from the organisation(s) must be signed by an authorized person and the name of the organisation (s) cannot be disclosed without consent.

Contacts of the participants are to be sourced with compliance to POPIA.

This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Code of Ethics for Scholarly Activities of the University of Pretoria, or the Policy and Procedures for Responsible Research of the University of Pretoria. These documents are available on the website of the EBIT Ethics Committee.

If action is taken beyond the approved application, approval is withdrawn automatically.

According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of the EBIT Research Ethics Office.

The Committee must be notified on completion of the project.

The Committee wishes you every success with the research project.

Prof K.-Y. Chan
Chair: Faculty Committee for Research Ethics and Integrity
FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY