HOW LOW CAN WE GO?

REDUCING EMBODIED CARBON IN AUSTRALIAN OFFICE BUILDINGS

UNSW SYDNEY

TERROIR

EXECUTIVE SUMMARY

Decarbonisation efforts in the built environment are now largely centred around reducing the embodied carbon emissions of buildings. Many governments and industry bodies have therefore set ambitious embodied carbon reduction targets for various building types between now and 2050. This study conducts a life cycle assessment of three office building scenarios to understand if these embodied carbon targets are feasible in the current Australian office building context. It asks 'how low can we go' regarding the embodied carbon emissions of office buildings in Australia and investigates the key factors that influence this. Key findings from this study include:

» There are simple design and material changes to reduce the embodied carbon emissions of office buildings. However, more significant savings (i.e. >40% in upfront embodied carbon [A1-A5]) are far more challenging and potentially require more radical material and design shifts.

» A 45% reduction in upfront embodied carbon emissions [A1-A5] is possible compared to a typical Australian office building scenario, and a 67% reduction is possible for whole of life embodied carbon emissions [A-C]. However, the magnitude of embodied carbon savings possible is highly dependent on the data sources and methodology used.

» Upfront embodied carbon emissions are significantly harder to reduce using the hybrid-based EPiC database compared to process-based EPDs due to its high embodied carbon figures for timber. This may lead to divergent embodied carbon reduction strategies across residential and commercial buildings as the new BASIX embodied carbon tool mainly uses EPiC whereas NABERS uses EPDs.

» Biogenic carbon (carbon stored in bio-based materials like timber and straw) can contribute to significant embodied carbon reductions, but the impact is only temporary. What happens at the end of the building's life is crucial but essentially uncertain. This study has shown that we can achieve a nearly net-zero upfront embodied carbon office building temporarily without any offsets right now, which is when embodied carbon reductions are most needed.

» The use of recycled and reused materials can lead to significant embodied carbon savings but could require a rapid scale up of the reuse market and the adoption of 'slow' architecture, where buildings are designed and constructed in alignment the availability of reused materials and components.

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1. INTRODUCTION

1.1. PURPOSE OF THIS REPORT

Recent studies have shown that embodied carbon can account for up to 50-75% of a building's life cycle carbon emissions (RICS, 2017; Robati et al., 2021; Schmidt et al., 2020). As a result, concerted efforts are underway to reduce embodied carbon emissions in buildings, with several reduction targets against defined benchmarks already in effect. Common embodied carbon reduction targets are a 40-60% reduction by 2030 and net-zero embodied carbon by 2040-2050 (Prasad et al., 2023). A recent study by the World Business Council for Sustainable Development and Arup argues that we can and should reduce embodied carbon by 50% in new buildings immediately and that we already have the technologies and strategies to do so (WBCSD & Arup, 2023). However, little research has sought to interrogate this 50% figure, to understand if this is feasible in the Australian office building context. And, more importantly, to understand if even more ambitious savings are possible, given current market constraints and technological developments such as material availability and methodological frameworks.

This research directly responds to this by investigating what is the lowest embodied carbon office building possible in the Australian context, and what factors influence this? The purpose of doing so is to elicit significant and urgent action in Australia's building sector to drastically reduce the embodied carbon of new office buildings, and to communicate the key opportunities and limitations of doing so under current market, regulatory and technological conditions.

1.2. METHODOLOGY

This project uses a life cycle assessment (LCA) methodology. LCAs are increasingly used in the built environment industry to systematically quantify a building's environmental impact throughout its entire life from the raw material supply to its final disposal. The typical procedure for conducting a LCA is governed by the International Organisation for Standardisation's (ISO) ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b). This involves four key phases: (1) goal and scope definition; (2) inventory analysis; (3) impact assessment; and (4) interpretation (Figure 1). For this study, these phases are outlined below.

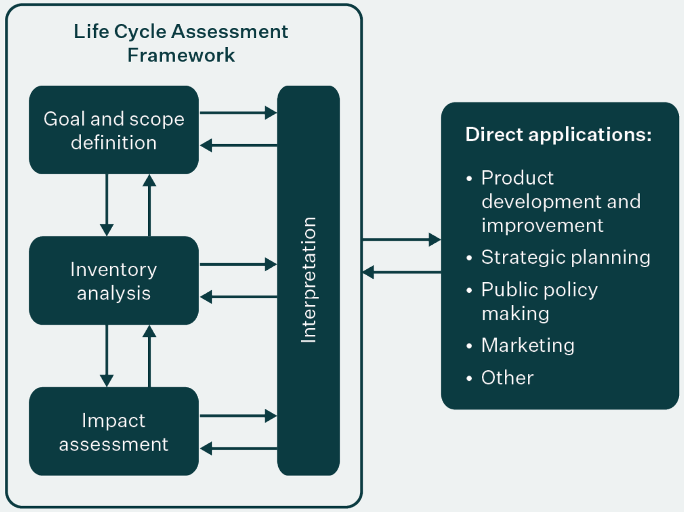

Figure 1. Phases of the LCA methodology according to ISO 14040.

1.2.1. GOAL AND SCOPE DEFINITION

The goal of this LCA is to investigate to what extent can we reduce embodied carbon in an office building in Australia. To conduct this investigation, an as-built office building designed by Terroir is used to establish three embodied carbon scenarios: '***typical***', '***best practice***' and '***stretch***' (see Section 2 for detailed descriptions of each scenario). This LCA considers only the embodied carbon impact of each office building scenario, which is determined by its global warming potential (GWP) and measured in kilograms of carbon dioxide equivalent (kgCO2e).

The life cycle of a building is commonly divided into five key stages and 17 modules in accordance with the European Standard EN 15978 (European Standards Organisation, 2011). The scope of this LCA is cradle-to-cradle [A-D] but does not include the carbon emissions associated with refurbishing the building [B5] and its operational energy [B6] and water [B7] use (Figure 2).

The building life span for all scenarios is 60 years to align with the Royal Institute of Chartered Surveyors (RICS) principles and guidance for whole life carbon assessments in the built environment (RICS, 2017).

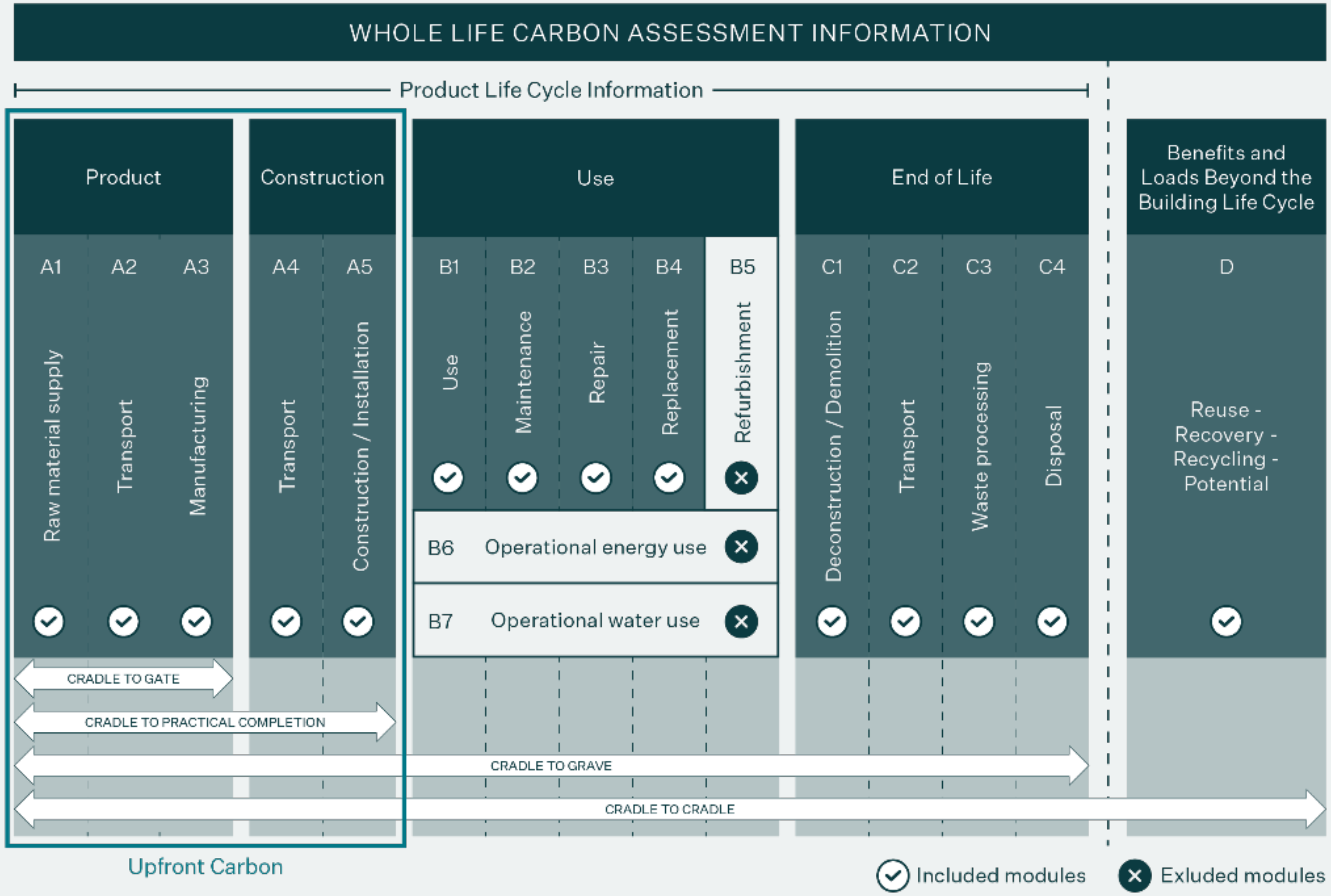

Figure 2. EN 15978 whole life carbon assessment modules included in this study.

The functional unit of an LCA is the quantified performance of a product system for use as a reference unit (ISO, 2006b), and as such becomes the basis for comparing the carbon performance of the three office building scenarios. The functional unit defined in this LCA is $1m^2$ of gross floor area (GFA) of an Australian office building.

1.2.2. LIFE CYCLE INVENTORY ANALYSIS

A detailed building information modelling (BIM) model for the best practice office building scenario was used to determine specific material types and quantities for this LCA (Appendix 1). This BIM model was adjusted based on specifications and design decisions from the project architects and structural and building services engineers to determine specific material types and quantities for the typical and stretch office building scenarios (Appendix 2 and 3). For all scenarios where specific material types and quantities were unknown, the Green Building Council of Australia's (GBCA) upfront carbon emissions calculation guide reference building was used (GBCA, 2022).

Two key sources of life cycle inventory data were used to determine the carbon impact of the materials in the office building scenarios. Firstly, type III environmental product declarations (EPD) were compiled for each system's materials and components (primarily from the EPD Australasia[1] and EPD International[2] systems). Data from these EPDs is independently verified to ISO 14025 and EN 15804, which allows for a more reliable comparative analysis of different EPDs within the same product category. Aligned with the RICS LCA principles and guidance, carbon emissions data from these EPDs was used for modules [A1-A3], [B1-B4], [C1], [C3-C4], and [D], whereas [A4-A5] and [C2] data was calculated on a project specific basis (see Section 3) (RICS, 2017). Where some materials and components for all scenarios were not available or limited from the sources above, additional type III environmental declarations were used, which included EPDs from other systems as well as product environmental profiles (PEP). Data from

[1] See https://epd-australasia.com/

[2] See https://www.environdec.com/home

the Chartered Institution of Building Services Engineers (CIBSE) TM65 embodied carbon tool for building services was also used for some of the building services and equipment in this LCA[3].

The best practice office building scenario is based on the as-built Terroir design. For this scenario, the specific product manufacturer's EPDs were used and where this was not possible, the closest equivalent product EPDs were used. For the typical and stretch office building scenarios, product specific EPDs were identified for more conventional office building practices and products (e.g. suspended ceilings) and low carbon building products and practices respectively. As there is uncertainty in the selection of the specific EPDs for all scenarios, a future academic publication will conduct a sensitivity analysis of EPDs to provide a range of embodied carbon analysis outcomes based on this LCA.

Secondly, the Environmental Performance in Construction (EPiC) database (Crawford et al., 2019) was also used to calculate the embodied carbon of the office building scenarios. The purpose of including this second key source of carbon data was to examine the variability in the calculation methods used in LCAs. Process-based LCAs, which EPDs use, itemise each specific input and output for a given step in producing a product, whereas economic input-output (EIO) LCAs are based on far broader economic transactions between industry sectors. The EPiC database uses a hybrid-LCA approach which combines the benefits of both approaches to provide a more comprehensive calculation of carbon impacts compared to an EPD (Crawford et al., 2022). However, the EPiC database only considers the product stage [A1-A3] and excludes the use [B] and end-of-life [C] data. As such, this LCA reports only the upfront embodied carbon [A1-A5] emissions for all office building scenarios using EPiC.

The EPiC database primarily reports the product stage [A1-A3] carbon impact of individual materials and not building components. Therefore, the material breakdown percentages from EPDs were used to calculate the product stage impact for these missing building components where possible. Due to this, the EPiC figures may be less complete in terms of material quantities than the EPD data. It is worth noting that both life cycle inventory data sources (EPDs and EPiC) are considered acceptable by RICS to conduct LCAs (RICS, 2017).

1.2.3. LIFE CYCLE IMPACT ASSESSMENT

The embodied carbon emissions of the office building scenarios are calculated from the sum of environmental impacts of their components. Where necessary from the life cycle inventory data sources outlined above, the impacts of these components are then calculated from the sum of environmental impacts of their materials. This is mathematically expressed by equations (1) and (2) respectively:

$$I_{Building} = \sum_{y=1}^{n_1} I_{component,y} = I_{component,1} + I_{component,2} + I_{component,3} + \ldots + I_{component,n_1} \quad (1)$$

$$I_{component} = \sum_{z=1}^{n_2} I_{material,z} = I_{material,1} + I_{material,2} + I_{material,3} + \ldots + I_{material,n_2} \quad (2)$$

where n_1 is the number of components within the office building, n_2 is the number of materials within a single component and I is the environmental impact reported in GWP ($kgCO_2e$).

The embodied carbon emissions for the product stage [A1-A3] of the office building scenarios were calculated by multiplying the material quantities taken from the detailed BIM model (Appendix 1, 2 and 3) with their associated embodied carbon values for production impacts ($kgCO_2e$/unit) from the life cycle inventory. As mentioned previously, the product stage embodied carbon emissions for each office building scenario were calculated using both EPDs and EPiC.

The transport emissions associated with the construction of each office building scenario [A4] were calculated by multiplying the material or component mass (t) with the distance from the manufacturing facility to construction site (km), and with the transport mode coefficient ($kgCO_2e$/tkm). Process-based transport coefficients were used for the EPD embodied carbon calculations, and hybrid-based transport coefficients were used for the EPiC embodied carbon calculations.

The embodied carbon emissions of construction [A5] for each office building scenario were calculated from the sum of the on-site building construction emissions and the impact of material wastage, which includes modules [A1-A4 + C1-C4]. This LCA used an estimation for the on-site building construction emissions from the recently updated RICS LCA principles and guidance (RICS, 2023), and calculated the impact of material wastage from wastage rates specified in the GBCA's upfront carbon emissions calculation guide (GBCA, 2022). Section 3.4 provides more detail on the data sources used for the [A4-A5] calculations.

Like the product stage calculations, the use stage [B1-B4] emissions were calculated by multiplying the material quantities with their associated carbon values for use stage impacts from the EPDs ($kgCO_2e$/unit). The replacement [B4] emissions were calculated by determining the number of replacements required for each building element across the building's 60-year lifespan and multiplying this by its whole-of-life carbon emissions [A-C]. The detailed list of indicative building

[3] See https://www.cibse.org/knowledge-research/knowledge-portal/embodied-carbon-in-building-services-a-calculation-methodology-tm65

component lifespans used for the [B4] calculations is given in Section 3.5.

The end-of-life modules [C1] and [C3-C4], and the potential benefits and loads beyond the system boundary (e.g. recycling, energy recovery) [D], were also calculated by multiplying the material quantities with their associated carbon values for end-of-life impacts from the EPDs (kgCO_2e/unit). As many EPDs did not include modules [C1] and [C3-C4], data from equivalent product EPDs with whole-of-life [A-C] carbon emissions data were used for these modules. The transport emissions associated with each component or materials end-of-life [C2] was calculated using the same method for [A4]. Estimated end-of-life transport distances were used from the RICS LCA principles and guidance (RICS, 2017) for these calculations, which is presented in more detail in Section 3.6.

1.2.4. INTERPRETATION OF LIFE CYCLE RESULTS

The final phase of conducting a LCA is interpreting the life cycle results. This firstly involved the identification of key limitations impacting the reliability and completeness of the LCA results, which is discussed in Section 3.8. The embodied carbon results and a comparative analysis of the three office building scenarios are presented throughout Section 3, and are broken down into each life cycle stage. Section 4 then provides a conclusion to this LCA, which involves a discussion of the key findings of the project and their significance for the Australian buildings sector.

2. TYPICAL, BEST PRACTICE & STRETCH OFFICE BUILDING SCENARIOS

An office building designed by Terroir and currently under construction is used as the basis for this research. From this base building, three office building scenarios are established to conduct this LCA: 'best practice', 'typical' and 'stretch'. This report presents the embodied carbon results of these three scenarios. The differences between the three scenarios are described below.

2.1. BEST PRACTICE SCENARIO

The office building used for this LCA is eight storeys with a GFA of 8,064m^2. The best practice scenario represents the as-built Terroir designed office building, which is constructed using a timber hybrid structure (Figure 3). The building's core and ground and first floors have a concrete structure, and the remaining floors above are built using cross-laminated timber (CLT) floors and glue-laminated timber (GLT) columns and beams. There is a basement escape pathway as well as adaptive reuse of a low-rise existing building's roof, floor and walls within the lower floors.

The best practice scenario has a total estimated mass of 646kg/m^2 and an approximate window-to-wall ratio of 60%. The detailed BIM model also included the electrical, fire, mechanical and hydraulic systems of the base build, which were included in the embodied carbon calculations. These services are exposed as the best practice scenario does not have suspended ceilings outside the bathrooms. The material schedule in Appendix 1, extracted from the detailed BIM model, outlines the building elements included in the embodied carbon calculations for the best practice scenario. This scenario, particularly due to its low carbon timber structure and adaptive reuse, is consistent with what we would expect from best practice performance in embodied carbon.

Figure 3. 3D visualisation of the best practice scenario.

2.2. TYPICAL SCENARIO

The typical office building scenario takes the best practice scenario and establishes a more conventional design based on typical office building practices (Figure 4). As mentioned above, this scenario was established based on specifications from the project architects and structural and building services engineers, as well as the reference building of the GBCA's upfront carbon emissions calculation guide (GBCA, 2022). The purpose of including this typical scenario is to determine 'how low' the best practice scenario already is regarding its embodied carbon emissions compared to a more conventional office building.

The most significant change for the typical office building scenario is that is has a concrete structure. The column grid (6m x 9m) and size did not change from the best practice scenario, but the typical scenario excludes beams and includes post-tensioned concrete slabs. It includes suspended ceilings and additional floor finishes and assumes the adaptive reuse component of the building is instead new-build, with new building materials. The substructure was increased proportionately to the added weight of the typical scenario building, whose total estimated mass is 1,068kg/m^2. Cement replacement (fly ash or slag) for any concrete elements was also removed for the typical scenario. The building services, window-to-wall ratio, envelope and interior partitions all remained the same as the best practice scenario. Importantly, the typical scenario also maintains the same GFA to ensure a fair comparison with the best practice scenario. The detailed material schedule in Appendix 2, extracted from the amended BIM model, outlines the building elements included in the embodied carbon calculations for the typical scenario.

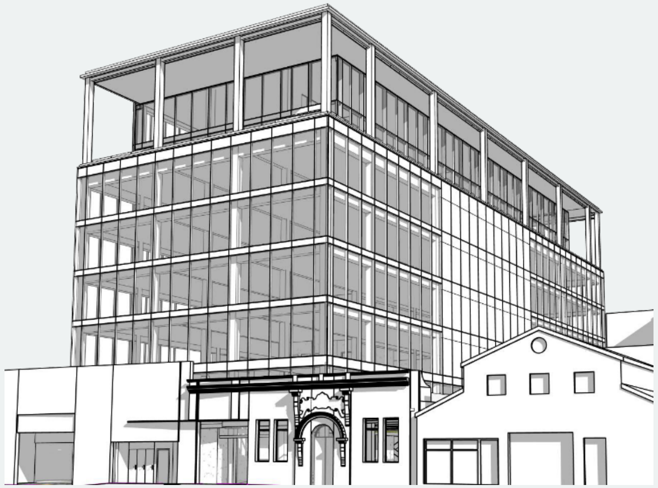

Figure 4. 3D visualisation of the best practice scenario.

2.3. STRETCH SCENARIO

The stretch office building scenario takes the best practice scenario and adjusts its structure and design for low embodied carbon emissions (Figure 5). The stretch scenario was developed from a series of design workshops with the multidisciplinary project team, which were informed by the interim embodied carbon results of the best practice and typical scenarios. The purpose of establishing a stretch scenario was to investigate how far an office building's design could be pushed to reduce embodied carbon emissions within the current Australian market, technological and material context.

Figure 5. 3D visualisation of the stretch scenario.

The most significant change for the stretch office building scenario is a timber structure. The stretch scenario has a column grid of 3.6m x 6m. This enabled the stretch scenario to integrate GLT columns and CLT floors without the need for any beams. Additionally, the top three stories integrate a lightweight timber stick frame in place of the GLT columns. Another design change for the stretch scenario was the integration of straw in the façade as a low embodied carbon insulation material. The substructure, building services, window-to-wall ratio and interior partitions all remained the same as the best practice scenario. The stretch scenario also has a comparable GFA to ensure a fair comparison with the other two scenarios. The estimated mass for the stretch scenario is 379kg/m^2. The detailed material schedule in Appendix 3, extracted from the amended BIM model, outlines the building elements included in the embodied carbon calculations for the stretch scenario.

This LCA also calculated the embodied carbon emissions of three stretch sub-scenarios. The first is a reduced window-to-wall ratio of 40% to limit the curtain wall quantities without significantly impacting indoor amenity or building performance (Figure 6). The second stretch sub-scenario is maximising reused and recycled materials. This involves reusing structural steel and hardwood finishes from other projects and recycled aluminium profiles and steel reinforcement. The third stretch sub-scenario is a combination of these two sub-scenarios.

Figure 6. 3D visualisation of the stretch scenario with a window-to-wall ratio of 40%.

3. EMBODIED CARBON ANALYSIS RESULTS: HOW LOW CAN WE GO?

This section presents the embodied carbon performance of the typical, best practice and stretch office building scenarios. It provides a comparative embodied carbon analysis of the LCA results for all scenarios across each life cycle stage and their whole life cycle. As mentioned previously, the scope of this analysis is an eight-storey office building with lifespan of 60 years and a GFA of 8,064m^2. The results are normalised to 1m^2 of GFA as per the functional unit of this LCA. The following sub-sections present the embodied carbon results for the three office building scenarios and outline the key assumptions and limitations of this LCA.

3.1. UPFRONT EMBODIED CARBON (A1-A5)

Upfront embodied carbon emissions include life cycle modules A1-A5, which consist of the product stage [A1-A3], the transportation of materials to site [A4] and the building's construction [A5]. Therefore, upfront embodied carbon emissions are those that are immediately *locked-in* once a building is constructed. Upfront embodied carbon emission reductions are therefore essential to meeting international and national decarbonisation targets. The World Business Council for Sustainable Development and Arup have set a target of 50% reduction in embodied carbon by 2030, most of which will be the upfront carbon emissions of new buildings (WBCSD & Arup, 2023).

In alignment with this target, Figure 7 shows that using EPDs, the combined stretch scenario represents a 45% reduction in upfront embodied carbon emissions compared to typical office building construction in Australia. However, embodied carbon reductions of this magnitude require significant design and supply chain re-evaluations to maximise the use of bio-based and reused building materials.

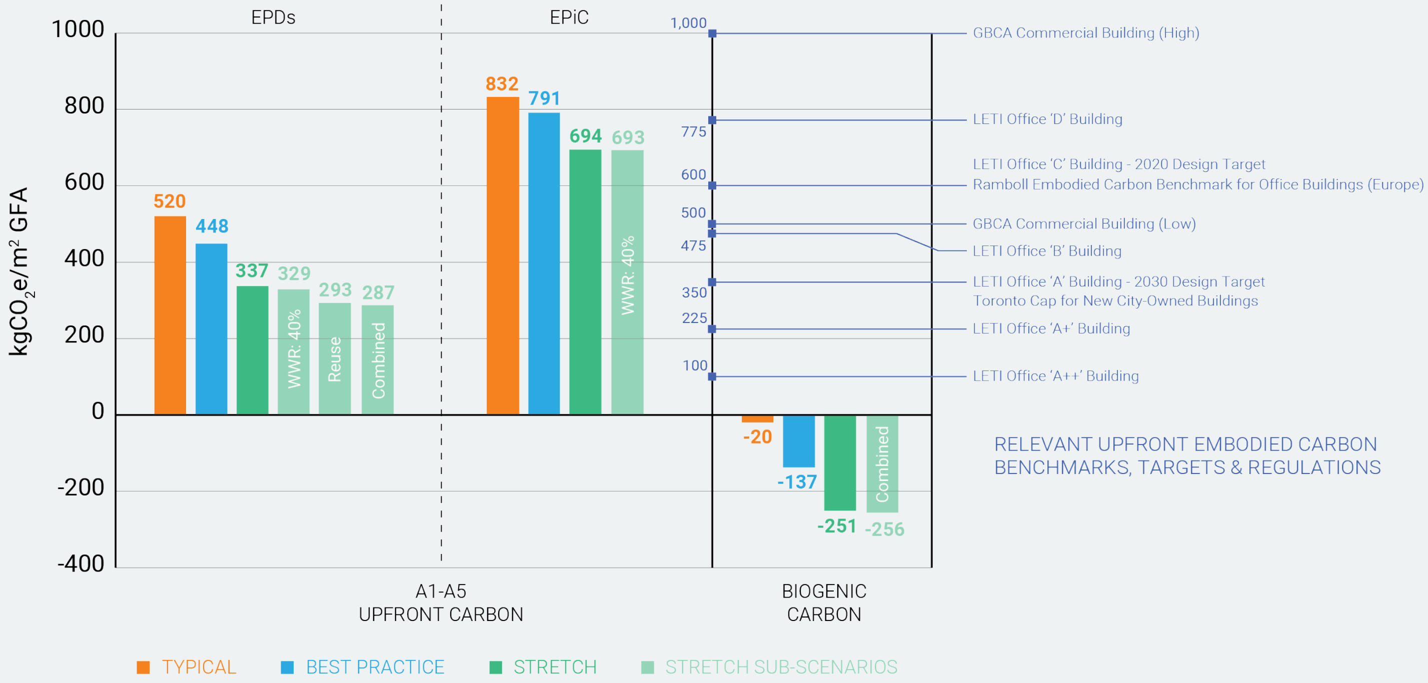

Figure 7. Upfront embodied carbon emissions for the typical, best practice and stretch scenarios (including stretch sub-scenarios).

Importantly, the potential reduction in upfront carbon emissions using the EPiC database is only 17% (Figure 7). This is primarily a result of the higher hybrid-based embodied carbon coefficients for timber used in EPiC, which emphasises how important the choice of LCA methodology is for the Australian building industry. Both EPDs and EPiC have their benefits and limitations, but these results demonstrate that it is considerably more difficult to reduce upfront embodied carbon using EPiC, especially for timber office buildings. It is worth noting that even though the typical office building scenario uses a concrete frame, it can already be considered a low embodied carbon building due to its highly efficient form and small core area. Therefore, higher percentage reductions in upfront embodied carbon emissions are likely possible if compared to structurally and materially inefficient office buildings.

The upfront embodied carbon emissions for all office building scenarios using the EPiC database are 60-110% higher than when using EPDs (Figure 7). Interestingly, the upfront embodied carbon of the best practice scenario using EPiC is only 5% less than the typical scenario. This can be largely attributed to the best practice scenario's significant quantities of engineered timber columns and beams, which have higher product stage [A1-A3] carbon coefficients in the EPiC database. The stretch scenario's 17% reduction compared to best practice using EPiC reinforces the argument that a more efficient timber structural system can reduce embodied carbon emissions more substantively (Figure 7). However, the timber components of the stretch scenario using EPiC represent a 15% greater portion of upfront carbon compared to the stretch scenario using EPDs. These results are particularly relevant to building practices in NSW with the implementation of the BASIX and NABERS embodied carbon tools which use EPiC and EPDs respectively. This could result in divergent approaches to reduce upfront embodied carbon, where timber construction is prioritised in commercial buildings and not in residential buildings.

Figure 7 also shows that it is possible, using EPDs, to get very close to net-zero upfront embodied carbon without the use of offsets when including the high biogenic carbon stored within the bio-based materials of the stretch scenario (i.e. timber and straw). Although the benefit of this biogenic carbon is temporary (discussed in Section 3.6), it demonstrates the potential to design and construct 'temporally' net-zero embodied carbon office buildings right now, which is when the largest embodied carbon savings are needed most.

To provide context on the magnitude of these values for an office building, Figure 7 provides examples of current upfront embodied carbon benchmarks, targets and regulations for office buildings[4]. Using EPDs, the best practice and stretch scenarios, including the stretch sub-scenarios, are below the GBCA's benchmark of 500kgCO_2e/m^2 GFA for low embodied carbon commercial buildings. The stretch scenario and sub-scenarios using EPDs are also considered an 'A' office building from the UK's Low Energy Transformation Initiative (LETI), which is their 2030 design target (Figure 7).

3.2. WHOLE LIFE CYCLE (A-C)

Figure 8 presents the embodied carbon impacts of the typical, best practice and stretch scenarios across its whole life cycle. As outlined in 1.2.2, the whole-of-life embodied carbon impacts were only calculated using process data from EPDs, PEPs and CIBSE's TM65 tool. Over its 60-year lifespan and excluding biogenic carbon, the typical scenario office building's whole life cycle embodied carbon impact is 917kgCO_2e/m^2 GFA. For the best practice scenario, it is 819kgCO_2e/m^2 GFA, which represents an 11% reduction from the typical scenario. For the stretch scenario, it is 620kgCO_2e/m^2 GFA, which represents a 32% reduction from the typical scenario (Figure 8). The stretch combined sub-scenario, which includes reducing the window-to-wall ratio and maximising reused and recycled materials, represents a 40% reduction in whole of life embodied carbon emissions from the typical scenario. If biogenic carbon is included in the whole of life embodied carbon calculations[5], reductions of 19%, 59% and 67% are possible for the best practice, stretch and stretch combined sub-scenario respectively compared to the typical scenario (Figure 8). This is due to the benefit of the carbon stored in the bio-based materials such as timber and straw included in these scenarios.

The product stage [A1-A3] and the replacement stage [B4] are the largest contributors to the whole life cycle embodied carbon impact of both scenarios. The product stage [A1-A3] accounts for 41-48% of the whole life cycle carbon impact for all three scenarios, and the replacement stage [B4] accounts for 33-36% (Figure 8). This is to be expected given the vast material quantities required to construct an office building, and the material replacements of various building components over its 60-year lifespan. Both stages are presented in more detail in Sections 3.3 and 3.5 respectively.

The carbon emissions associated with transporting the materials to site [A4] and construction [A5] represent 9-13% of the whole life cycle embodied carbon impact for all three scenarios (Figure 8). The transportation emissions [A4] for the best practice and stretch scenarios are slightly higher than the typical scenario, even despite the latter's extra mass, primarily due to the engineered timber manufacturer's European location for the GLT beams and columns. These life cycle stages are presented in more detail in Section 3.4.

The end-of-life impacts [C1-C4] are relatively low for all office building scenarios, accounting for 3-6% of the whole life cycle embodied carbon emissions (Figure 8). Despite its minimal contribution, there can be considerable variation in end-of-life impacts, especially for timber, depending on the end-of-life scenario (e.g. burning vs landfilling timber). As there are significant quantities of timber in the best practice and stretch scenarios, sensitivities for variations in timber end-of-life

[4] Variability of data is likely due to differences in data sources, calculation methodologies and local renewable energy mixes.

[5] Most embodied carbon calculation methodologies and guides report biogenic carbon separately.

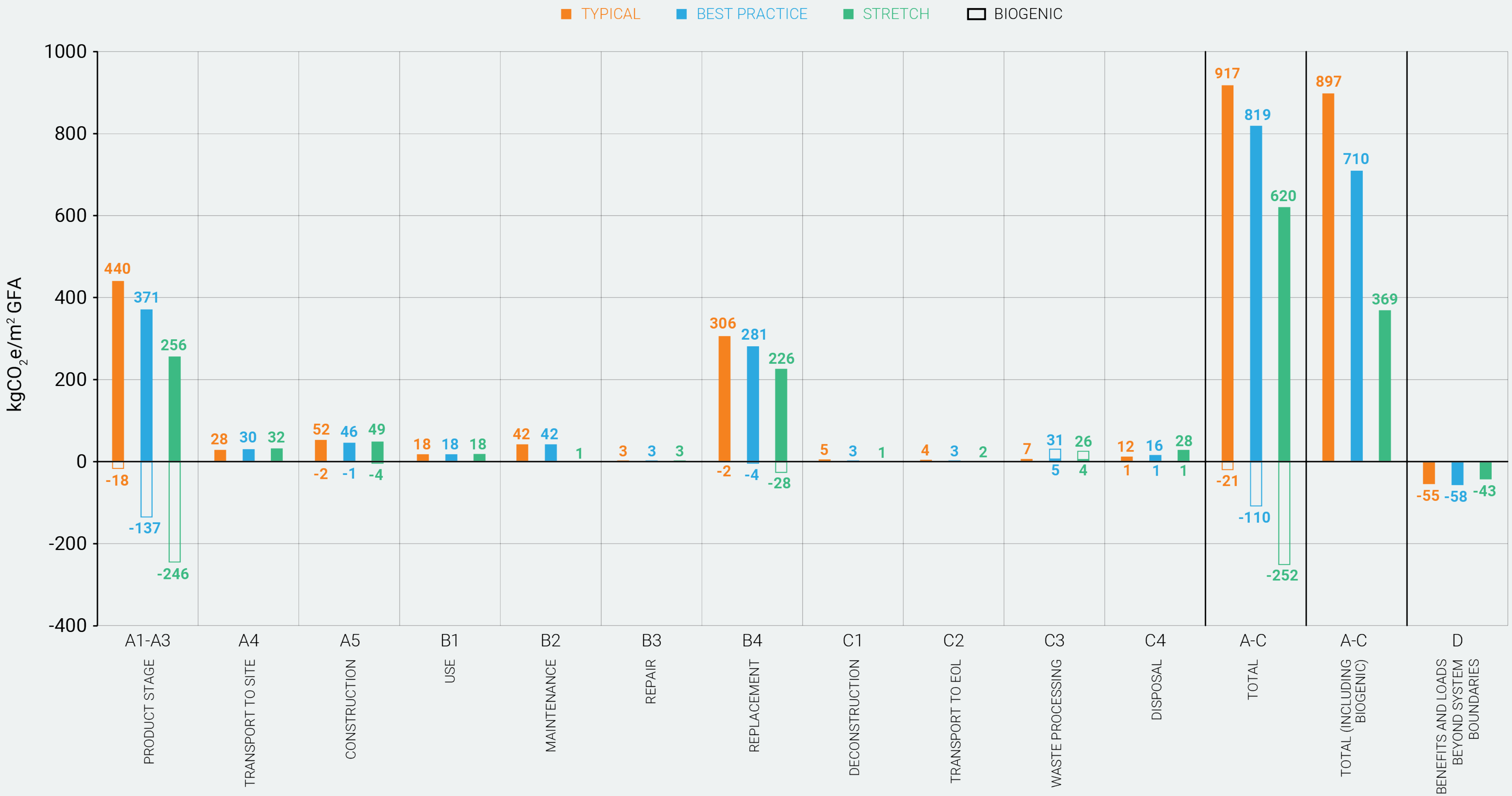

Figure 8. Whole of life embodied carbon emissions for the typical, best practice and stretch scenarios showing each life cycle stage.

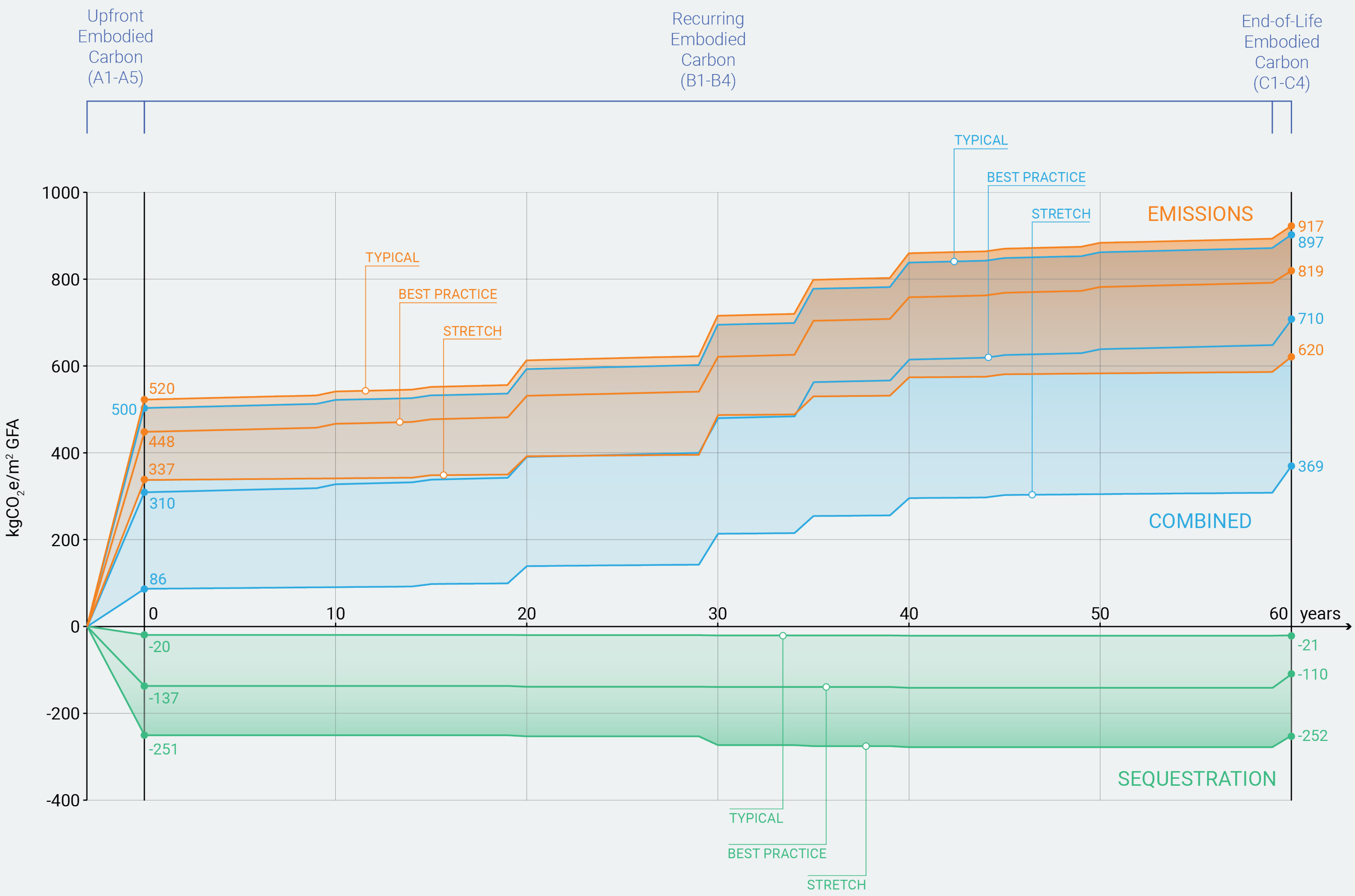

Figure 9. Whole of life embodied carbon emissions for the typical, best practice and stretch scenarios over the building's 60-year lifespan.

scenarios have been conducted for this LCA. The end-of-life stages are presented in more detail in Section 3.6.

The benefits beyond the building life cycle [D] are primarily due to the high recyclability of steel and aluminium components (Figure 8). However, as the scope of this LCA is a single life cycle and the fact that these benefits leave the context of the office building scenarios, this stage is excluded from any further analysis.

Figure 9 presents the whole of life [A-C] embodied carbon emissions over the 60-year lifespan of the office building. The purpose of doing so is to clearly illustrate when embodied carbon emissions are released and captured over time. At year zero when the building construction is complete, 54-57% of the whole of life [A-C] embodied carbon emissions or locked in (i.e. the upfront embodied carbon emissions). Each step-up in Figure 9 represents the embodied carbon emissions associated with replacing various building components [B4] based on their typical lifespans (see Section 3.5 for more detail). The sequestered carbon, shown in green, stays relatively stable throughout the building's life for all scenarios. This is primarily due to the assumption by Australian timber EPDs that the local timber components are landfilled at the end of their life, where only a very small fraction of the sequestered carbon is released. This is discussed in more detail in Section 3.6, which includes an alternative end-of-life scenario for these timber components instead of landfilling.

3.3. PRODUCT STAGE (A1-A3)

As mentioned previously, the product stage [A1-A3] accounts for the largest portion (41-48%) of whole of life [A-C] embodied carbon emissions for all office building scenarios. Using EPDs, the product stage embodied carbon impact of the typical scenario is 440kgCO_2e/m^2 GFA. The best practice product stage is 16% lower than typical at 371kgCO_2e/m^2 GFA, and the stretch and stretch combined sub-scenarios are 42% and 53% lower at 256kgCO_2e/m^2 GFA and 207kgCO_2e/m^2 GFA respectively (Figure 10).

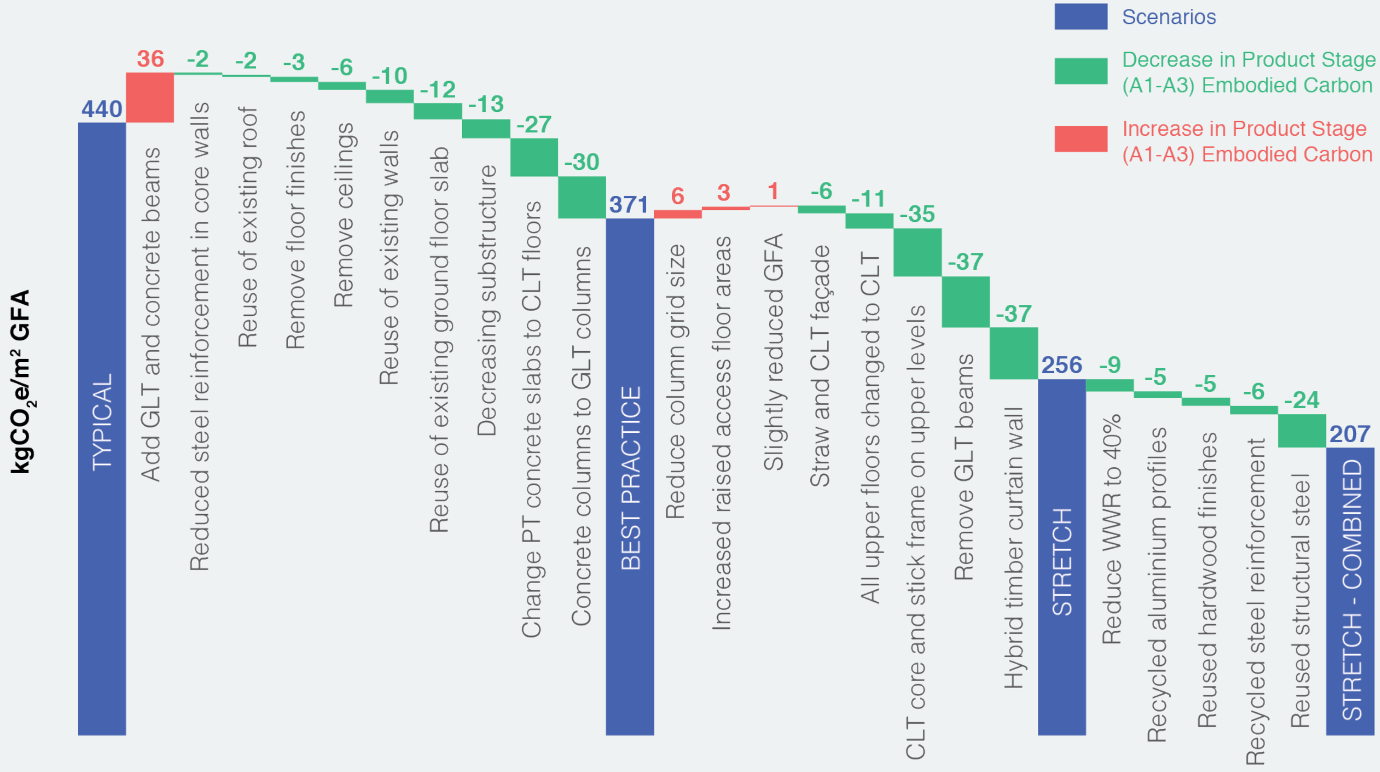

Figure 10. Design and product stage [A1-A3] embodied carbon changes between all office building scenarios using EPDs.

Figure 10 shows each of the key design changes between the office building scenarios and their associated increase and decrease in product stage [A1-A3] embodied carbon emissions using EPDs. The major product stage embodied carbon savings and emissions are generally associated with the building's structure across all scenarios. Moving from the typical to the best practice scenario, the addition of GLT and concrete beams adds 36kgCO_2e/m^2 GFA but decreasing the substructure and changing most of the floors to CLT and columns to GLT reduces the product stage embodied carbon impact by 70kgCO_2e/m^2 GFA (Figure 10). Moving from the best practice to the stretch scenario, the increased number of GLT columns adds 6kgCO_2e/m^2 GFA but changing the remaining floors and the structural core to CLT and integrating a lightweight timber frame for the top three floors reduces the product stage embodied carbon by an additional 83kgCO_2e/m^2 GFA (Figure 10). What this tells us is that an optimised timber structural arrangement, where beams can be omitted, has significant carbon reduction benefits. Additionally, changing the aluminium mullions in the curtain wall to hybrid timber and aluminium mullions also generate a significant reduction of 37kgCO_2e/m^2 GFA in product stage embodied carbon emissions (Figure 10).

Going beyond this to reduce the product stage embodied carbon emissions of the stretch scenario further becomes difficult. Simple material replacements for finishes and reducing the window-to-wall ratio have a relatively small impact. However, a more significant reduction was achieved through specifying reused structural steel members in the roof and internal walls (Figure 10). While this is not currently a widespread practice in Australia, it is anticipated that this could change soon in response to the growing adoption of circular economy principles by the building industry. While the reuse market grows in Australia however, a cultural shift towards 'slow' architecture may be required. This means the scale and speed of construction would become dependent on the availability of low-carbon and reusable materials and ensuring that these benefits are not monopolised to one building.

3.4. TRANSPORT TO SITE AND CONSTRUCTION (A4-A5)

Aligned with the RICS LCA principles and guidance (RICS, 2017), the transportation emissions of both office building scenario's components from their place of manufacture to the construction site [A4] were calculated using project specific data and assumptions. To do so, the manufacturing facilities were firstly identified for all products covered by the EPDs. As the location of the as-built office building is in Tasmania, national and international transportation of the building materials and components to site used a combination of truck, rail and shipping where necessary. International transport assumed truck transportation from the product's manufacturing facility to the closest international port[6].

The transportation emissions [A4] were calculated by multiplying the distances (km) for each transportation mode with the material or component mass in tonnes (t), which was determined from the detailed BIM models, and with their associated transport mode coefficient (kgCO_2e/tkm). The [A4] calculations for EPDs used the transport coefficients shown in Table 1. For the EPiC [A4] calculations, transport mode coefficients were used from Lenzen (1999), which are 0.03kgCO_2e/tkm for shipping and 0.37kgCO_2e/tkm for rigid trucks. Both these data sources are for Australian transportation, which was used for both national and international calculations.

For the EPD calculations, the transportation [A4] emissions accounted for 3-5% of the whole life cycle embodied carbon impact for all office building scenarios. Despite the relatively low overall embodied carbon impact, the transport emissions for the best practice and stretch scenarios were 7% and 14% more than the typical scenario respectively. As mentioned earlier, this is primarily due to the sourcing of European engineered timber for the GLT beams and columns for the best practice and stretch scenarios. As the overall building mass of the typical scenario is approximately 65% more than the best practice scenario and 182% more than the stretch scenario, this demonstrates the importance of sourcing local materials where possible. However, the local energy mix, availability of data and material quantity are key considerations when determining whether to source local or global manufacturers to reduce the embodied carbon of a building.

Table 1. Process-based transportation carbon coefficients (GBCA, 2022).

Freight Type	kgCO_2e/tkm	Source
Air, domestic	1.86	AusLCI v1.38
Air, international	1.65	AusLCI v1.38
Rail	0.024	AusLCI v1.38
Van, 3.5t gross weight	1.54	AusLCI v1.38
Truck, 3.5 to 16t gross weight	0.216	AusLCI v1.38
Truck, 16 to 28t gross weight	0.128	AusLCI v1.38
Truck, 28t gross weight	0.0719	AusLCI v1.38
Truck, 40t gross weight	0.0686	AusLCI v1.38
Ship, container ship	0.0161	Defra (2022)
Ship, bulk carrier	0.00354	Defra (2022)

As discussed in Section 1.2.3, the construction emissions [A5] for both scenarios were calculated from the sum of the on-site building construction emissions and the embodied carbon emissions from material wastage. As there was no project or Australian specific data available for the on-site building construction

[6] Shipping ports and distances were identified and calculated via https://sea-distances.org/

emissions, the RICS estimation of 40kgCO_2e/m^2 was used (RICS, 2023). The impact of construction material waste was calculated by multiplying the embodied carbon impact of the product stage [A1-A3], transport [A4] and end-of-life [C1-C4] for each material with the material wastage rates shown in Table 2. For materials or components not listed below, the material wastage rate was taken from the EPD or the manufacturer's website where possible. As the EPiC database only provides [A1-A3] impacts, the end-of-life impacts of material wastage were not included in the hybrid upfront carbon calculations that were presented previously in Section 3.1.

Table 2. Construction waste rates for selected materials (GBCA, 2022).

Product	Waste %
Aluminium	1%
Asphalt	4%
Bricks	5%
Concrete (in-situ)	4%
Concrete (precast)	0%
Glass	1%
Plasterboard	23%
Steel	1%
Timber (excl. CLT & GLT)	10%

For the EPD calculations, the construction [A5] emissions accounted for 5-6% of the whole life cycle embodied carbon impact for all office building scenarios. The construction emissions of the typical scenario were approximately 13% more than the best practice scenario and 6% more than the stretch scenario, which is likely due to material wastage associated with the increased quantities of in-situ concrete.

The combined transportation and construction embodied carbon emissions [A4-A5] account for 24% of the stretch scenario's upfront embodied carbon emissions and 13% of its whole of life embodied carbon emissions. This indicates that further substantial embodied carbon reductions could be achieved for the stretch scenario by using renewably powered construction equipment on site and electric vehicles for material transportation. However, as there was no site-specific data to support this approach, quantifying these potential embodied carbon reductions was not possible for this LCA.

3.5. USE STAGE (B1-B4)

The use stage modules [B1-B3] together represent 4-8% of the whole life cycle embodied carbon impact for all office building scenarios. The [B1] use stage emissions are primarily related to the leakage of refrigerant from the building's mechanical equipment. The emissions from maintenance [B2] are largely from cleaning the glass and carpet, and the repair [B3] emissions are related to the mechanical equipment. The replacement of carpet with hardwood flooring in the stretch scenario results in a 98% reduction in maintenance [B2] embodied carbon emissions compared to the typical and best practice scenarios.

The largest contributor to the use stage, and second largest contributor to the whole of life embodied carbon impact, for all scenarios is the emissions related to replacing building elements [B4] over the 60-year lifespan of the office building. For all office building scenarios, this accounted for 33-36% of the whole life cycle embodied carbon emissions. These replacement emissions were calculated by determining the number of replacements for each building element based on the lifespans shown in Table 3, and multiplying this by their associated whole life cycle carbon impact [A-C]. It was assumed that each building element was replaced life-for-like once the specified lifespan was reached as per the RICS LCA principles and guidance (RICS, 2017).

For all office building scenarios, replacements for the finishes, curtain wall, lighting and building services represent the major contributors to the [B4] emissions. This reinforces the importance to design and manufacture building elements to maximise their lifespans and/or be deconstructed and reused at the end of their lives, especially for elements with shorter lifespans like ceiling and flooring systems. This is particularly important in the context of an office building where tenancy and fit-out churn rates for FF&E can be quite high, but this is outside the scope of this study.

Table 3. Indicative component lifespans (RICS, 2017).

Building part	Building elements	Expected lifespan
Roof	Roof coverings	30 years
Superstructure	Internal partitioning and dry lining	30 years
Finishes	Wall finishes: Render/Paint	30/10 years respectively
	Floor finishes Raised Access Floor (RAF)/Finish layers	30/10 years respectively
	Ceiling finishes Substrate/Paint	20/10 years respectively
FF&E	Loose furniture and fittings	10 years
Services/MEP	Heat source, e.g. boilers, calorifiers	20 years
	Space heating and air treatment	20 years
	Ductwork	20 years
	Electrical installations	30 years
	Lighting fittings	15 years
	Communications installations and controls	15 years
	Water and disposal installations	25 years
	Sanitaryware	20 years
	Lift and conveyor installations	20 years
Façade	Opaque modular cladding e.g. rain screens, timber panels	30 years
	Glazed cladding/Curtain walling	35 years
	Windows and external doors	30 years

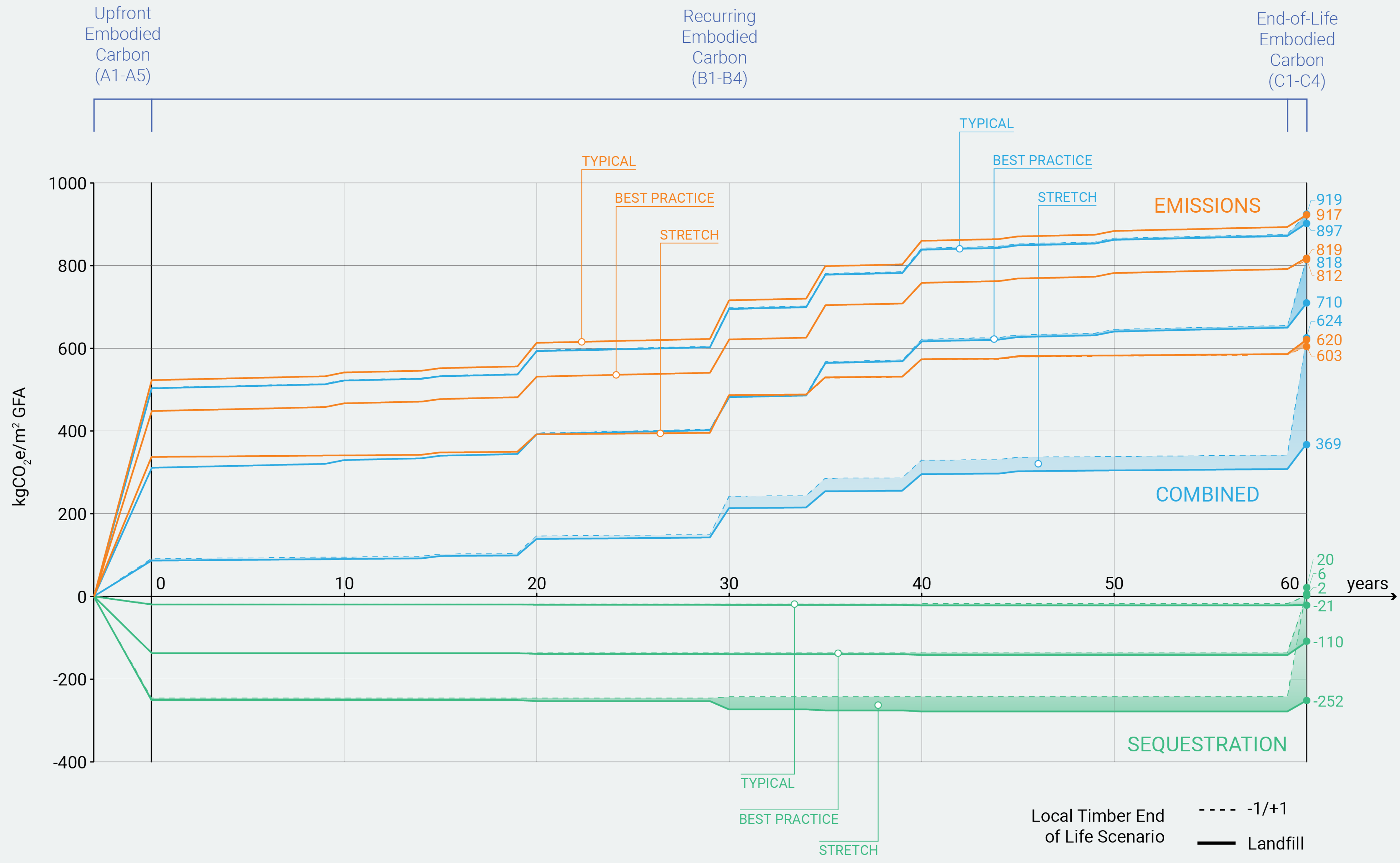

Figure 11. Comparison of different timber end-of-life scenarios and their associated embodied carbon impact for the typical, best practice and stretch scenarios.

3.6. END OF LIFE (C1-C4)

As mentioned in Section 3.2, the end-of-life impacts [C1-C4] account for 3-6% of the whole life cycle embodied carbon emissions for all office building scenarios. The embodied carbon impacts of deconstruction [C1], waste processing [C3] and disposal [C4] were calculated from multiplying the material quantity with the associated carbon coefficient from the EPDs. However, many product EPDs reported only product stage [A1-A3] impacts. For these products, data from equivalent product EPDs with whole-of-life [A-C] embodied carbon data was used in place of these modules.

Emissions related to the transportation of building materials and components to their end-of-life facility [C2] were calculated with the same transport coefficients presented in Table 1. As there was uncertainty related to the end-of-life destination for many building elements, a generic local transportation distance of 50km was used in alignment with the RICS LCA principles and guidance (RICS, 2017).

Although the end-of-life emissions are relatively insignificant for all office building scenarios, there can be significant variation depending on which end-of-life scenario is assumed. This may influence the benefits or loads beyond the system boundary [D], such as the avoided impacts from recycling metal components. It also has a significant impact on the quantity and speed in which biogenic carbon is released back into the atmosphere. For example, burning timber at the end of its life may offer energy recovery benefits, but the biogenic carbon stored within will be immediately released. Conversely, if timber is landfilled at the end of its life, research has shown that only a very small fraction of the timber will degrade over timespans as long as 500 years, and therefore will only release a tiny percentage of the biogenic carbon it has captured (Wang et al., 2011).

Figure 11 shows a comparison of different end-of-life scenarios for the local timber components for all office building scenarios. The solid line indicates the landfilling of local timber components, which was used to report the baseline embodied carbon results for each scenario in this LCA, and the dotted line indicates the -1/+1 approach to biogenic carbon. The -1/+1 method is used by EN15804, which is considered one of the most popular global standards governing the production of EPDs. This method argues that any biogenic carbon that is captured in the production stage for bio-based materials such as timber and straw will be released at the end of their lives irrespective of whether they are reused, recycled, incinerated or landfilled. The landfilling scenario represents a modified version of the -1/+1 method and is used in Australian and New Zealand EPDs for timber products.

If biogenic carbon is included in the whole of life embodied carbon calculations, these different end-of-life methodologies have a significant impact on each office building scenario's whole of life embodied carbon emissions. For the typical scenario, the -1/+1 approach represents an increase of 2% in whole of life embodied carbon emissions compared to landfilling local timber. For the best practice and stretch scenarios, with considerably higher local timber components (which excludes the European GLT columns), the -1/+1 approach represents increases in whole of life embodied carbon of 15% and 69% respectively when compared to landfilling (Figure 11) and when biogenic carbon is included.

3.7. STRETCH SUB-SCENARIOS

This study posed the question of what is the lowest embodied carbon office building possible in the Australian context, and what factors influence this?

The lowest whole of life embodied carbon emissions for an Australian office building within the scope of this LCA was 295kgCO_2e/m^2 GFA, which is the combined stretch sub-scenario including biogenic carbon in the calculations and landfilling local timber components at the end of their life (Figure 12). This represents a 67% reduction in whole of life embodied carbon compared to the typical Australian office building scenario using the same landfill scenario. If the -1/+1 end-of-life method is used for the same scenario, the lowest whole of life embodied carbon emissions is 550kgCO_2e/m^2 GFA, which represents a 40% reduction from the typical scenario using the same -1/+1 method (Figure 12).

However, Figure 12 illustrates how the whole of life embodied carbon emissions can vary substantially depending on methodological differences and design and material choices. Compared to the typical scenario, the best practice scenario represents an 11-21% reduction in whole of life embodied carbon emissions when including biogenic carbon and an 11% reduction when excluding biogenic carbon (Figure 12). The stretch scenario represents a 32-59% reduction in whole of life embodied carbon emissions from the typical scenario when including biogenic carbon and a 32-34% reduction when excluding biogenic carbon (Figure 12). The stretch sub-scenarios represent a 34-67% reduction in whole of life embodied carbon emissions from the typical scenario when including biogenic carbon and a 34-42% reduction when excluding biogenic carbon (Figure 12).

It is worth emphasising here again that the typical office building scenario used for this LCA can be already considered a relatively low embodied carbon building. Therefore, greater percentage reductions are likely possible when comparing against an inefficient typical office building scenario.

3.8. LIMITATIONS

There were several key limitations to calculating the embodied carbon emissions of the typical, best practice and stretch office building scenarios in this LCA:

- There were limited EPDs from Australia for various materials and components such as glass, which is a carbon intensive material.
- EPDs for some building components were only found in countries with higher renewable energy mixes than Australia (e.g. Sweden, Finland, etc.). Local products could therefore have higher overall impacts than these materials even despite their international transportation [A4] impacts.

- There was limited data for the building services components. UK data from CIBSE's TM65 tool was used for the mechanical equipment as Australian specific data was unavailable.
- The Australian timber sector EPDs report high embodied carbon data variability.
- The EPiC analysis may be less complete in terms of material quantities than the EPD data as EPiC does not include building components. Material breakdown percentages from relevant EPDs were used to calculate the carbon impact of these components.
- The replacement [B4] embodied carbon emissions assume that each material or component being replaced will have the same embodied carbon impact in the future as it does now, which is unlikely given building material decarbonisation efforts globally. Therefore, the embodied carbon results for this life cycle module are likely overestimated.
- The substructure and building services for the stretch scenario were assumed to be the same as the best practice scenario due to data availability. Further reductions in embodied carbon emissions for the stretch scenario could be achieved in these areas.
- All office building scenarios use the same on-site construction emissions [A5] from RICS due to data availability. It is likely that a stretch scenario could involve renewably powered construction equipment, meaning that further embodied carbon emission reductions are possible here.
- All scenarios include a large scope of inclusions (e.g. detailed building services) but the complete fit-out was not possible due to data availability. Fit-out can have a significant impact on the embodied carbon of office buildings due to higher material and tenancy churn rates.

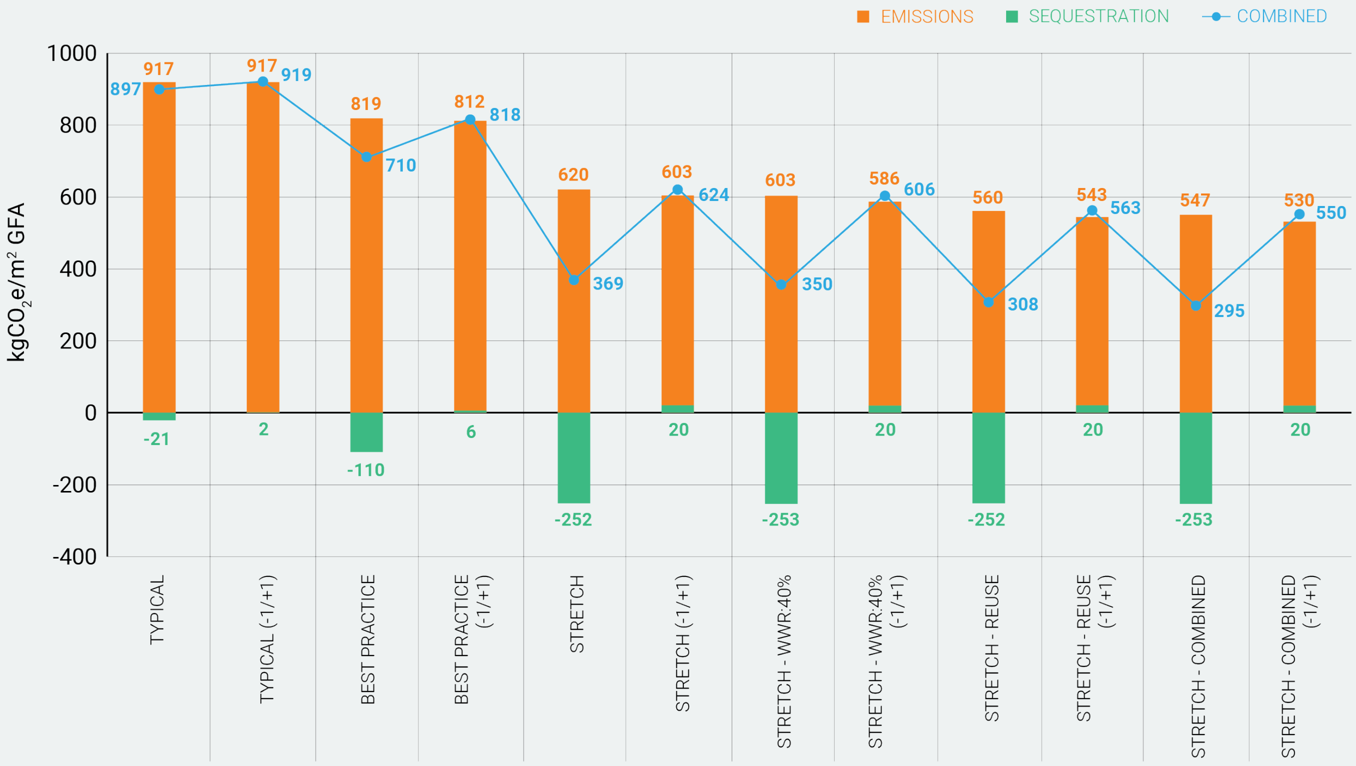

Figure 12. Whole of life [A-C] embodied carbon emissions for all scenarios using EPDs, including the +1/-1 timber end-of-life sensitivities.

- The key findings of this LCA are relevant to medium-rise office buildings in Australia but less so for high-rise office buildings due to increased structural requirements that are associated with increased building height.

Many of these limitations can be addressed through further sensitivity analysis in future work, especially for the variation of product stage [A1-A3] impacts for various building components and materials. However, this was outside the scope of this project.

4. CONCLUSION

This report has shown that substantially lower embodied carbon office buildings are immediately possible compared to typical office buildings in Australia. It has also shown that 'how low we can go' regarding embodied carbon emissions greatly depends on the embodied carbon data and methodology used to conduct the LCA. Important conclusions derived from the results of this LCA, many of which have important implications for the Australian buildings industry, include:

- The as-built Terrior office building used to generate the scenarios in this study can be considered a low embodied carbon office building in an Australian context.
- There are simple design and material changes that can effectively reduce whole of life embodied carbon emissions in Australian office buildings. However, significant reductions beyond 40% in upfront carbon [A1-A5] compared to a typical office building are more challenging and require more radical solutions that are novel in current building practices in Australia (e.g. hybrid curtain wall systems, small grids and straw insulation).
- A 35-45% reduction in upfront embodied carbon emissions is possible now compared to a typical Australian office building using EPDs, but only a 17% reduction is possible when using the EPiC database. This is due to significant differences in embodied carbon values for timber using EPDs and EPiC. The new NABERS and BASIX embodied carbon tools use EPDs and EPiC respectively, and these results suggest that this could lead to divergent approaches to reduce upfront embodied carbon, where timber construction is prioritised in commercial buildings and not in residential buildings.
- Biogenic carbon can contribute to significant embodied carbon reductions, but the impact is temporary and greatly depends on what end-of-life scenario is assumed. Although biogenic carbon should always be reported separately, this study has shown that we can achieve a nearly net-zero upfront embodied carbon office building temporarily without any offsets when biogenic carbon is included. This is highlighted to demonstrate that temporary net-zero upfront embodied carbon office buildings are within reach now, which is when embodied carbon reductions are most needed.
- The use of recycled and reused materials can lead to significant embodied carbon savings. However, this is highly dependent on a rapid scale up of the reuse market and 'slow' architecture in Australia and ensuring that these benefits are not monopolised to one building.
- While upfront carbon [A1-A5] is critical and has less uncertainties, it is important not to ignore the whole of life emissions, especially those associated with the replacement of components [B4], which can be equally significant. Designing and manufacturing components with shorter lifespans to be easily deconstructed and reused is an effective way to reduce the whole life cycle emissions of an office building.
- Curtain walls are significant embodied carbon contributors. Reducing the glazing quantities without negatively impacting solar access or thermal performance and using timber hybrid framing systems are effective ways to reduce the embodied carbon of curtain walls.

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APPENDIX 1 – BEST PRACTICE SCENARIO MATERIAL SCHEDULE

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
1	Substructure	Substructure	Foundations	Concrete Pile Footings	Concrete	InSitu (50MPa, 20%)	m3	195.9
2	Substructure	Substructure	Foundations	Concrete Pile Footings	Steel	Reinforcement - Hot Rolled	kg	13714.4
3	Substructure	Substructure	Foundations	Concrete Pile Caps	Concrete	InSitu (50MPa, 20%)	m3	33.9
4	Substructure	Substructure	Foundations	Concrete Pile Caps	Steel	Reinforcement - Hot Rolled	kg	3899.9
5	Substructure	Substructure	Foundations	Concrete Pile Caps	Plywood	Formwork	m2	106.6
6	Substructure	Substructure	Foundations	Concrete Ground Beams	Concrete	InSitu (50MPa, 20%)	m3	49.4
7	Substructure	Substructure	Foundations	Concrete Ground Beams	Steel	Reinforcement - Hot Rolled	kg	11358.8
8	Substructure	Substructure	Foundations	Concrete Ground Beams	Plywood	Formwork	m2	257.5
9	Substructure	Substructure	Structural Walls	Precast Concrete Walls	Concrete	Precast (50MPa, 20%)	m3	28.5
10	Substructure	Substructure	Structural Walls	Precast Concrete Walls	Steel	Reinforcement - Hot Rolled	kg	3129.8
11	Substructure	Substructure	Floors	On Grade Concrete Floor Slab	Concrete	InSitu (32MPa, 20%)	m3	77.4
12	Substructure	Substructure	Floors	On Grade Concrete Floor Slab	Steel	Reinforcement - Hot Rolled	kg	3868.5
13	Substructure	Substructure	Floors	On Grade Concrete Floor Slab	Plywood	Formwork	m2	54.8
14	Superstructure	Frame	Columns	Concrete Columns	Concrete	InSitu (50MPa, 30%)	m3	33.4
15	Superstructure	Frame	Columns	Concrete Columns	Concrete	Precast (50MPa, 30%)	m3	23.8
16	Superstructure	Frame	Columns	Concrete Columns	Steel	Reinforcement - Hot Rolled	kg	17164.1
17	Superstructure	Frame	Columns	Concrete Columns	Plywood	Formwork	m2	334.2
18	Superstructure	Frame	Columns	Steel Columns	Steel	Hollow Section	kg	6588.0
19	Superstructure	Frame	Columns	Engineered Timber Columns	Glue Laminated Timber		m3	74.1
20	Superstructure	Frame	Columns	Engineered Timber Columns	Softwood	Timber Joints (Filler)	m3	0.5
21	Superstructure	Frame	Beams	Concrete Beams	Concrete	InSitu (50MPa, 30%)	m3	72.0
22	Superstructure	Frame	Beams	Concrete Beams	Concrete	Precast (50MPa, 30%)	m3	69.2
23	Superstructure	Frame	Beams	Concrete Beams	Steel	Reinforcement - Hot Rolled	kg	31066.2
24	Superstructure	Frame	Beams	Concrete Beams	Plywood	Formwork	m2	527.5
25	Superstructure	Frame	Beams	Steel Beams	Steel	Structural - Hot Rolled	kg	2720.5
26	Superstructure	Frame	Beams	Steel Beams	Steel	Hollow Section	kg	564.3
27	Superstructure	Frame	Beams	Timber Beams	Glue Laminated Timber		m3	306.6
28	Superstructure	Frame	Beams	Timber Beams	Softwood	Timber Joints (Filler)	m3	0.3
29	Superstructure	Frame	Beams	Timber Beams	Steel	Structural Connections	kg	5198.2
30	Superstructure	Frame	Beams	Timber Beams	Aluminium	Structural Connections	kg	1983.0
31	Superstructure	Upper Floors	Floors	Concrete Floor Slabs	Concrete	InSitu (40MPa, 20%)	m3	486.8
32	Superstructure	Upper Floors	Floors	Concrete Floor Slabs	Steel	Reinforcement - Hot Rolled	kg	48677.9
33	Superstructure	Upper Floors	Floors	Concrete Floor Slabs	Steel	Formwork	kg	756.0
34	Superstructure	Upper Floors	Floors	Concrete Floor Slabs	Plywood	Formwork	m2	2375.9
35	Superstructure	Upper Floors	Floors	Engineered Timber Floors	Cross Laminated Timber		m3	1047.2
36	Envelope	Roof	Roof Structure	Concrete Roof Structure	Concrete	InSitu (40MPa, 20%)	m3	46.4
37	Envelope	Roof	Roof Structure	Concrete Roof Structure	Plywood	Formwork	m2	57.5
38	Envelope	Roof	Roof Structure	Concrete Roof Structure	Steel	Reinforcement - Hot Rolled	kg	4644.3
39	Envelope	Roof	Roof Structure	Concrete Roof Structure	Steel	Formwork	kg	2714.0
40	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Structural - Hot Rolled	kg	23712.0
41	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Light Gauge - Cold Rolled	kg	8805.5
42	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Plate - Cold Rolled	kg	165.1
43	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Hollow Section	kg	1200.7
44	Envelope	Roof	Non-Structural Roof Elements	Roof Sheet	Steel	Corrugated Roof Sheet	m2	1238.9

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
45	Envelope	Roof	Non-Structural Roof Elements	Roof Insulation	Glasswool Insulation	Roof	kg	3416.6
46	Envelope	Roof	Non-Structural Roof Elements	Roof Insulation	Extruded Polystyrene	Insulation	m2	47.5
47	Envelope	Roof	Non-Structural Roof Elements	Roof Safety Mesh	Stainless Steel	Wire Mesh	kg	385.3
48	Envelope	Roof	Non-Structural Roof Elements	Roof Membrane	Polypropylene	Waterproof Membrane	m2	1481.9
49	Envelope	Roof	Non-Structural Roof Elements	Roof Membrane	Polyvinyl Chloride	Waterproof Membrane	kg	459.1
50	Envelope	Roof	Non-Structural Roof Elements	Roof Capping	Aluminium	Capping	kg	955.9
51	Envelope	Roof	Non-Structural Roof Elements	Gutters	Stainless Steel	Box Gutter	kg	890.9
52	Superstructure	Stairs and Ramps	Stairs	Concrete Stairs	Concrete	Precast (40MPa, 20%)	m3	34.3
53	Superstructure	Stairs and Ramps	Stairs	Concrete Stairs	Steel	Reinforcement - Hot Rolled	kg	4281.3
54	Superstructure	Stairs and Ramps	Stairs	Steel Stairs	Steel	Structural - Hot Rolled	kg	2381.7
55	Superstructure	Stairs and Ramps	Stairs	Steel Stairs	Plywood	Backing	m3	0.5
56	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Wall Battens	kg	1821.4
57	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Hollow Section	kg	23976.5
58	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Wall Studs	kg	538.8
59	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Corrugated Roof Sheet	m2	271.8
60	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Plasterboard	Standard Lining	m2	501.1
61	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Plasterboard	Moisture Resistant Lining	m2	488.1
62	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Plasterboard	Fire Resistant Lining	m2	1633.2
63	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Aluminium	Cladding	m2	1176.1
64	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Glasswool Insulation	Walls	m2	1153.4
65	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Concrete	Parapet	m3	12.3
66	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Reinforcement - Hot Rolled	kg	183.9
67	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Glass	Double, Toughened	m2	3984.3
68	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Glass	Single, Toughened	m2	71.5
69	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Aluminium	Mullions	kg	12961.8
70	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Glasswool Insulation	Spandrel	m2	225.4
71	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Rockwool Insulation	Spandrel	m2	225.4
72	Envelope	Windows and External Doors	External Doors	Fire Door	Steel	Fire Door	m2	3.8
73	Envelope	Windows and External Doors	External Doors	Hinged Single Door	Steel	Single Door	m2	4.4
74	Envelope	Windows and External Doors	External Doors	Glass Door	Glass	Door	m2	32.1
75	Envelope	Windows and External Doors	External Doors	Glass Door	Aluminium	Door Framing	kg	8.5
76	Envelope	Windows and External Doors	External Windows	Skylight	Glass	Skylights	m2	70.1
77	Superstructure	Internal Walls and Partitions	Structural Walls	Precast Concrete Walls	Concrete	Precast (50MPa, 20%)	m3	300.0
78	Superstructure	Internal Walls and Partitions	Structural Walls	Precast Concrete Walls	Steel	Reinforcement - Hot Rolled	kg	97488.8
79	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Steel	Wall Battens	kg	909.0
80	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Steel	Wall Studs	kg	4938.2
81	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Standard Lining	m2	1098.7

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
82	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Moisture Resistant Lining	m2	110.0
83	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Fire Resistant Lining	m2	852.6
84	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Moisture and Fire Resistant Lining	m2	663.4
85	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Shaft Liner	m2	399.4
86	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Fibre Cement	Lining	m2	1067.4
87	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Glass	Balustrade	m2	44.6
88	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Glass	Internal Wall	m2	112.0
89	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Cross Laminated Timber		m3	4.9
90	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Glasswool Insulation	Walls	m2	1603.1
91	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	High Pressure Laminate	Toilet Partitions	m2	193.5
92	Superstructure	Internal Doors	Internal Doors	Fire Door	Steel	Fire Door	m2	64.1
93	Superstructure	Internal Doors	Internal Doors	Hinged Single Door	Steel	Single Door	m2	84.2
94	Superstructure	Internal Doors	Internal Doors	Hinged Double Door	Steel	Double Door	m2	34.2
95	Finishes	Wall Finishes	Wall Feature Finishes	Wall Feature Finishes	Cross Laminated Timber		m3	0.4
96	Finishes	Wall Finishes	Wall Feature Finishes	Tiles	Ceramic	Wall Tiles	m2	1318.6
97	Finishes	Floor Finishes	Floor Finishes	Tiles	Ceramic	Floor Tiles	m2	265.2
98	Finishes	Floor Finishes	Floor Finishes	Floor Membrane	Polypropylene	Waterproof Membrane	m2	715.2
99	Finishes	Floor Finishes	Floor Finishes	Floor Membrane	Polyvinyl Chloride	Waterproof Membrane	kg	711.1
100	Finishes	Floor Finishes	Floor Finishes	Carpet	Nylon Carpet	Tiles	m2	5822.5
101	Finishes	Floor Finishes	Floor Finishes	Screed	Concrete	Screed	m3	66.7
102	Finishes	Floor Finishes	Floor Finishes	Raised Access Floor	Reinforced Plasterboard and Steel	Raised Access Floor	m2	3554.6
103	Finishes	Floor Finishes	Floor Finishes	Roof Deck	Aluminium	Qwickbuild Structure	kg	93.9
104	Finishes	Floor Finishes	Floor Finishes	Roof Deck	Hardwood		m3	1.0
105	Finishes	Floor Finishes	Floor Finishes	Landscape Terrace Insulation	Extruded Polystyrene	Insulation	m2	233.7
106	Finishes	Ceiling Finishes	Ceiling Finishes	Suspended Ceiling	Plasterboard	Ceiling	m2	285.0
107	Finishes	Ceiling Finishes	Ceiling Finishes	Suspended Ceiling	Cross Laminated Timber		m3	13.3
108	Finishes	Ceiling Finishes	Ceiling Finishes	Suspended Ceiling	Steel	Ceiling Structure	m2	285.0
109	Finishes	Ceiling Finishes	Ceiling Finishes	Terrace Soffit	Hardwood		m3	5.3
110	Services	Services	Plumbing Fixtures	WC	Ceramic	Sanitary	kg	1161.5
111	Services	Services	Plumbing Fixtures	Urinal	Ceramic	Sanitary	kg	716.6
112	Services	Services	Plumbing Fixtures	Sink	Ceramic	Sanitary	kg	589.2
113	Services	Services	Plumbing Fixtures	Tap	Brass	Mixers	kg	84.1
114	Services	Services	Hydraulic Services	Pipes	Copper	Pipes	kg	1031.4
115	Services	Services	Hydraulic Services	Pipes	High-Density Polyethylene	Pipes	kg	211.1
116	Services	Services	Hydraulic Services	Pipes	Steel	Pipes	kg	612.6
117	Services	Services	Hydraulic Services	Pipes	Unplasticised Polyvinyl Chloride	Pipes	kg	2533.1

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
118	Services	Services	Mechanical Services	Ducts	Steel	Ducts	kg	10365.2
119	Services	Services	Mechanical Services	Air Terminals	Aluminium	Air Terminals	kg	924.7
120	Services	Services	Mechanical Services	Pipes	Copper	Pipes	kg	1416.4
121	Services	Services	Mechanical Services	Pipes	Steel	Pipes	kg	4.1
122	Services	Services	Mechanical Services	Pipes	Unplasticised Polyvinyl Chloride	Pipes	kg	163.4
123	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Outdoor Unit - 300	no	6.0
124	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Outdoor Unit - 450	no	8.0
125	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Indoor Unit	no	47.0
126	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Branch Controller	no	22.0
127	Services	Services	Mechanical Services	A/C Split System	A/C Split System	Outdoor Unit	no	6.0
128	Services	Services	Mechanical Services	A/C Split System	A/C Split System	Indoor Unit	no	6.0
129	Services	Services	Mechanical Services	Air Handling Unit	Air Handling Unit		no	1.0
130	Services	Services	Fire Services	Pipes	Steel	Pipes	kg	22682.4
131	Services	Services	Fire Services	Pipes	Unplasticised Polyvinyl Chloride	Pipes	kg	12.2
132	Services	Services	Fire Services	Sprinkler	Copper	Fire Sprinklers	kg	128.5
133	Services	Services	Electrical Services	Cable Trays and Ladders	Steel	Cable Trays	kg	4699.0
134	Services	Services	Electrical Services	Conduits	Unplasticised Polyvinyl Chloride	Electrical Conduits	kg	161.3
135	Services	Services	Electrical Services	Lighting Fixtures	Linear Suspended Lighting Fixture		no	901.0
136	Services	Services	Electrical Services	Lighting Fixtures	Linear Surface Mounted Lighting Fixture		no	338.0
137	Services	Services	Electrical Services	Lighting Fixtures	Downlight		no	109.0
138	Services	Services	Electrical Services	Solar Panels	Solar Panels		m2	127.0
139	Services	Services	Transportation	Lift	Lift		no	2.0

APPENDIX 2 – TYPICAL SCENARIO MATERIAL SCHEDULE

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
1	Substructure	Substructure	Foundations	Concrete Pile Footings	Concrete	InSitu (50MPa, 20%)	m3	324.3
2	Substructure	Substructure	Foundations	Concrete Pile Footings	Steel	Reinforcement - Hot Rolled	kg	22700.5
3	Substructure	Substructure	Foundations	Concrete Pile Caps	Concrete	InSitu (50MPa, 20%)	m3	33.9
4	Substructure	Substructure	Foundations	Concrete Pile Caps	Steel	Reinforcement - Hot Rolled	kg	3899.9
5	Substructure	Substructure	Foundations	Concrete Pile Caps	Plywood	Formwork	m2	106.6
6	Substructure	Substructure	Foundations	Concrete Ground Beams	Concrete	InSitu (50MPa, 20%)	m3	49.4
7	Substructure	Substructure	Foundations	Concrete Ground Beams	Steel	Reinforcement - Hot Rolled	kg	11358.8
8	Substructure	Substructure	Foundations	Concrete Ground Beams	Plywood	Formwork	m2	257.5
9	Substructure	Substructure	Structural Walls	Precast Concrete Walls	Concrete	Precast (50MPa, 20%)	m3	28.5
10	Substructure	Substructure	Structural Walls	Precast Concrete Walls	Steel	Reinforcement - Hot Rolled	kg	3129.8
11	Substructure	Substructure	Floors	On Grade Concrete Floor Slab	Concrete	InSitu (32MPa, 20%)	m3	312.4
12	Substructure	Substructure	Floors	On Grade Concrete Floor Slab	Steel	Reinforcement - Hot Rolled	kg	15619.8
13	Substructure	Substructure	Floors	On Grade Concrete Floor Slab	Plywood	Formwork	m2	117.0
14	Superstructure	Frame	Columns	Concrete Columns	Concrete	InSitu (50MPa, 30%)	m3	226.8
15	Superstructure	Frame	Columns	Concrete Columns	Steel	Reinforcement - Hot Rolled	kg	68026.2
16	Superstructure	Frame	Columns	Concrete Columns	Plywood	Formwork	m2	1673.1
17	Superstructure	Frame	Columns	Steel Columns	Steel	Hollow Section	kg	6588.0
18	Superstructure	Frame	Columns	Concrete Beams	Concrete	InSitu (50MPa, 30%)	m3	72.0
19	Superstructure	Frame	Columns	Concrete Beams	Plywood	Formwork	m2	527.5
20	Superstructure	Frame	Columns	Concrete Beams	Steel	Reinforcement - Hot Rolled	kg	15845.4
21	Superstructure	Frame	Beams	Steel Beams	Steel	Structural - Hot Rolled	kg	2720.5
22	Superstructure	Frame	Beams	Steel Beams	Steel	Hollow Section	kg	564.3
23	Superstructure	Upper Floors	Floors	Concrete Floor Slabs	Concrete	InSitu (40MPa, 20%)	m3	1374.5
24	Superstructure	Upper Floors	Floors	Concrete Floor Slabs	Steel	Reinforcement - Hot Rolled	kg	106211.0
25	Superstructure	Upper Floors	Floors	Concrete Floor Slabs	Plywood	Formwork	m2	6567.0
26	Envelope	Roof	Roof Structure	Concrete Roof Structure	Concrete	InSitu (40MPa, 20%)	m3	67.3
27	Envelope	Roof	Roof Structure	Concrete Roof Structure	Plywood	Formwork	m2	57.5
28	Envelope	Roof	Roof Structure	Concrete Roof Structure	Steel	Reinforcement - Hot Rolled	kg	5201.9
29	Envelope	Roof	Roof Structure	Concrete Roof Structure	Steel	Formwork	kg	2769.3
30	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Structural - Hot Rolled	kg	23712.0
31	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Light Gauge - Cold Rolled	kg	8805.5
32	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Plate - Cold Rolled	kg	165.1
33	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Hollow Section	kg	1200.7
34	Envelope	Roof	Roof Structure	Timber Roof Structure	Softwood	Roof Trusses	m3	9.0
35	Envelope	Roof	Non-Structural Roof Elements	Roof Sheet	Steel	Corrugated Roof Sheet	m2	1238.9
36	Envelope	Roof	Non-Structural Roof Elements	Roof Insulation	Glasswool Insulation	Roof	kg	4045.5
37	Envelope	Roof	Non-Structural Roof Elements	Roof Insulation	Extruded Polystyrene	Insulation	m2	47.5
38	Envelope	Roof	Non-Structural Roof Elements	Roof Safety Mesh	Stainless Steel	Wire Mesh	kg	385.3
39	Envelope	Roof	Non-Structural Roof Elements	Roof Membrane	Polypropylene	Waterproof Membrane	m2	1481.9
40	Envelope	Roof	Non-Structural Roof Elements	Roof Membrane	Polyvinyl Chloride	Waterproof Membrane	kg	459.1

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
41	Envelope	Roof	Non-Structural Roof Elements	Roof Capping	Aluminium	Capping	kg	955.9
42	Envelope	Roof	Non-Structural Roof Elements	Gutters	Stainless Steel	Box Gutter	kg	890.9
43	Superstructure	Stairs and Ramps	Stairs	Concrete Stairs	Concrete	Precast (40MPa, 20%)	m3	34.3
44	Superstructure	Stairs and Ramps	Stairs	Concrete Stairs	Steel	Reinforcement - Hot Rolled	kg	4281.3
45	Superstructure	Stairs and Ramps	Stairs	Steel Stairs	Steel	Structural - Hot Rolled	kg	2381.7
46	Superstructure	Stairs and Ramps	Stairs	Steel Stairs	Plywood	Backing	m3	0.5
47	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Wall Battens	kg	1821.4
48	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Hollow Section	kg	23976.5
49	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Wall Studs	kg	538.8
50	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Corrugated Roof Sheet	m2	271.8
51	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Plasterboard	Standard Lining	m2	501.1
52	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Plasterboard	Moisture Resistant Lining	m2	488.1
53	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Plasterboard	Fire Resistant Lining	m2	1633.2
54	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Aluminium	Cladding	m2	1176.1
55	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Glasswool Insulation	Walls	m2	1153.4
56	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Concrete	Parapet	m3	12.3
57	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Reinforcement - Hot Rolled	kg	183.9
58	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Brick		kg	456653.0
59	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Cement	Mortar	kg	96302.1
60	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Glass	Double, Toughened	m2	3984.3
61	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Glass	Single, Toughened	m2	71.5
62	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Aluminium	Mullions	kg	12961.8
63	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Glasswool Insulation	Spandrel	m2	225.4
64	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Rockwool Insulation	Spandrel	m2	225.4
65	Envelope	Windows and External Doors	External Doors	Fire Door	Steel	Fire Door	m2	3.8
66	Envelope	Windows and External Doors	External Doors	Hinged Single Door	Steel	Single Door	m2	4.4
67	Envelope	Windows and External Doors	External Doors	Glass Door	Glass	Door	m2	32.1
68	Envelope	Windows and External Doors	External Doors	Glass Door	Aluminium	Door Framing	kg	8.5
69	Envelope	Windows and External Doors	External Windows	Skylight	Glass	Skylights	m2	70.1
70	Superstructure	Internal Walls and Partitions	Structural Walls	Precast Concrete Walls	Concrete	Precast (50MPa, 20%)	m3	300.0
71	Superstructure	Internal Walls and Partitions	Structural Walls	Precast Concrete Walls	Steel	Reinforcement - Hot Rolled	kg	97488.8
72	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Steel	Wall Battens	kg	909.0
73	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Steel	Wall Studs	kg	4938.2
74	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Standard Lining	m2	1098.7

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
75	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Moisture Resistant Lining	m2	110.0
76	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Fire Resistant Lining	m2	852.6
77	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Moisture and Fire Resistant Lining	m2	663.4
78	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Shaft Liner	m2	399.4
79	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Fibre Cement	Lining	m2	1067.4
80	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Glass	Balustrade	m2	44.6
81	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Glass	Internal Wall	m2	112.0
82	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Cross Laminated Timber		m3	4.9
83	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Glasswool Insulation	Walls	m2	1603.1
84	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	High Pressure Laminate	Toilet Partitions	m2	193.5
85	Superstructure	Internal Doors	Internal Doors	Fire Door	Steel	Fire Door	m2	64.1
86	Superstructure	Internal Doors	Internal Doors	Hinged Single Door	Steel	Single Door	m2	84.2
87	Superstructure	Internal Doors	Internal Doors	Hinged Double Door	Steel	Double Door	m2	34.2
88	Finishes	Wall Finishes	Wall Feature Finishes	Wall Feature Finishes	Cross Laminated Timber		m3	0.4
89	Finishes	Wall Finishes	Wall Feature Finishes	Tiles	Ceramic	Wall Tiles	m2	1318.6
90	Finishes	Floor Finishes	Floor Finishes	Tiles	Ceramic	Floor Tiles	m2	265.2
91	Finishes	Floor Finishes	Floor Finishes	Floor Membrane	Polypropylene	Waterproof Membrane	m2	1509.0
92	Finishes	Floor Finishes	Floor Finishes	Floor Membrane	Polyvinyl Chloride	Waterproof Membrane	kg	711.1
93	Finishes	Floor Finishes	Floor Finishes	Carpet	Nylon Carpet	Tiles	m2	5822.5
94	Finishes	Floor Finishes	Floor Finishes	Screed	Concrete	Screed	m3	66.7
95	Finishes	Floor Finishes	Floor Finishes	Raised Access Floor	Reinforced Plasterboard and Steel	Raised Access Floor	m2	5158.5
96	Finishes	Floor Finishes	Floor Finishes	Roof Deck	Aluminium	Qwickbuild Structure	kg	93.9
97	Finishes	Floor Finishes	Floor Finishes	Roof Deck	Hardwood		m3	1.0
98	Finishes	Floor Finishes	Floor Finishes	Landscape Terrace Insulation	Extruded Polystyrene	Insulation	m2	233.7
99	Finishes	Ceiling Finishes	Ceiling Finishes	Suspended Ceiling	Plasterboard	Ceiling	m2	285.0
100	Finishes	Ceiling Finishes	Ceiling Finishes	Suspended Ceiling	Steel	Ceiling Structure	m2	6247.9
101	Finishes	Ceiling Finishes	Ceiling Finishes	Terrace Soffit	Hardwood		m3	5.3
102	Finishes	Ceiling Finishes	Ceiling Finishes	Suspended Ceiling	Steel	Ceiling Panels	m2	5962.9
103	Finishes	Ceiling Finishes	Ceiling Finishes	Ceiling	Steel	Ceiling	m2	272.8
104	Services	Services	Plumbing Fixtures	WC	Ceramic	Sanitary	kg	1161.5
105	Services	Services	Plumbing Fixtures	Urinal	Ceramic	Sanitary	kg	716.6
106	Services	Services	Plumbing Fixtures	Sink	Ceramic	Sanitary	kg	589.2
107	Services	Services	Plumbing Fixtures	Tap	Brass	Mixers	kg	84.1
108	Services	Services	Hydraulic Services	Pipes	Copper	Pipes	kg	1031.4
109	Services	Services	Hydraulic Services	Pipes	High-Density Polyethylene	Pipes	kg	211.1
110	Services	Services	Hydraulic Services	Pipes	Steel	Pipes	kg	612.6
111	Services	Services	Hydraulic Services	Pipes	Unplasticised Polyvinyl Chloride	Pipes	kg	2533.1
112	Services	Services	Mechanical Services	Ducts	Steel	Ducts	kg	10365.2
113	Services	Services	Mechanical Services	Air Terminals	Aluminium	Air Terminals	kg	924.7
114	Services	Services	Mechanical Services	Pipes	Copper	Pipes	kg	1416.4

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
115	Services	Services	Mechanical Services	Pipes	Steel	Pipes	kg	4.1
116	Services	Services	Mechanical Services	Pipes	Unplasticised Polyvinyl Chloride	Pipes	kg	163.4
117	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Outdoor Unit - 300	no	6.0
118	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Outdoor Unit - 450	no	8.0
119	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Indoor Unit	no	47.0
120	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Branch Controller	no	22.0
121	Services	Services	Mechanical Services	A/C Split System	A/C Split System	Outdoor Unit	no	6.0
122	Services	Services	Mechanical Services	A/C Split System	A/C Split System	Indoor Unit	no	6.0
123	Services	Services	Mechanical Services	Air Handling Unit	Air Handling Unit		no	1.0
124	Services	Services	Fire Services	Pipes	Steel	Pipes	kg	22682.4
125	Services	Services	Fire Services	Pipes	Unplasticised Polyvinyl Chloride	Pipes	kg	12.2
126	Services	Services	Fire Services	Sprinkler	Copper	Fire Sprinklers	kg	128.5
127	Services	Services	Electrical Services	Cable Trays and Ladders	Steel	Cable Trays	kg	4699.0
128	Services	Services	Electrical Services	Conduits	Unplasticised Polyvinyl Chloride	Electrical Conduits	kg	161.3
129	Services	Services	Electrical Services	Lighting Fixtures	Linear Suspended Lighting Fixture		no	901
130	Services	Services	Electrical Services	Lighting Fixtures	Linear Surface Mounted Lighting Fixture		no	338
131	Services	Services	Electrical Services	Lighting Fixtures	Downlight		no	109.0
132	Services	Services	Electrical Services	Solar Panels	Solar Panels		m2	127.0
133	Services	Services	Transportation	Lift	Lift		no	2.0

APPENDIX 3 – STRETCH SCENARIO MATERIAL SCHEDULE

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
1	Substructure	Substructure	Foundations	Concrete Pile Footings	Concrete	InSitu (50MPa, 20%)	m3	195.9
2	Substructure	Substructure	Foundations	Concrete Pile Footings	Steel	Reinforcement - Hot Rolled	kg	13714.4
3	Substructure	Substructure	Foundations	Concrete Pile Caps	Concrete	InSitu (50MPa, 20%)	m3	33.9
4	Substructure	Substructure	Foundations	Concrete Pile Caps	Steel	Reinforcement - Hot Rolled	kg	3899.9
5	Substructure	Substructure	Foundations	Concrete Pile Caps	Plywood	Formwork	m2	106.6
6	Substructure	Substructure	Foundations	Concrete Ground Beams	Concrete	InSitu (50MPa, 20%)	m3	49.4
7	Substructure	Substructure	Foundations	Concrete Ground Beams	Steel	Reinforcement - Hot Rolled	kg	11358.8
8	Substructure	Substructure	Foundations	Concrete Ground Beams	Plywood	Formwork	m2	257.5
9	Substructure	Substructure	Structural Walls	Precast Concrete Walls	Concrete	Precast (50MPa, 20%)	m3	28.5
10	Substructure	Substructure	Structural Walls	Precast Concrete Walls	Steel	Reinforcement - Hot Rolled	kg	3129.8
11	Substructure	Substructure	Floors	On Grade Concrete Floor Slab	Concrete	InSitu (32MPa, 20%)	m3	77.4
12	Substructure	Substructure	Floors	On Grade Concrete Floor Slab	Steel	Reinforcement - Hot Rolled	kg	3868.5
13	Substructure	Substructure	Floors	On Grade Concrete Floor Slab	Plywood	Formwork	m2	54.8
14	Superstructure	Frame	Columns	Engineered Timber Columns	Glue Laminated Timber		m3	235.0
15	Superstructure	Frame	Columns	Engineered Timber Columns	Steel	Structural Connections	kg	24874.5
16	Superstructure	Upper Floors	Floors	Engineered Timber Floors	Cross Laminated Timber		m3	1651.5
17	Envelope	Roof	Roof Structure	Timber Roof Structure	Cross Laminated Timber		m3	63.0
18	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Structural - Hot Rolled	kg	23712.0
19	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Light Gauge - Cold Rolled	kg	8805.5
20	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Plate - Cold Rolled	kg	165.1
21	Envelope	Roof	Roof Structure	Steel Roof Structure	Steel	Hollow Section	kg	1200.7
22	Envelope	Roof	Non-Structural Roof Elements	Roof Sheet	Steel	Corrugated Roof Sheet	m2	1605.4
23	Envelope	Roof	Non-Structural Roof Elements	Roof Insulation	Glasswool Insulation	Roof	kg	3416.6
24	Envelope	Roof	Non-Structural Roof Elements	Roof Insulation	Extruded Polystyrene	Insulation	m2	47.5
25	Envelope	Roof	Non-Structural Roof Elements	Roof Safety Mesh	Stainless Steel	Wire Mesh	kg	385.3
26	Envelope	Roof	Non-Structural Roof Elements	Roof Membrane	Polypropylene	Waterproof Membrane	m2	1481.9
27	Envelope	Roof	Non-Structural Roof Elements	Roof Membrane	Polyvinyl Chloride	Waterproof Membrane	kg	459.1
28	Envelope	Roof	Non-Structural Roof Elements	Roof Capping	Aluminium	Capping	kg	955.9
29	Envelope	Roof	Non-Structural Roof Elements	Gutters	Stainless Steel	Box Gutter	kg	890.9
30	Superstructure	Stairs and Ramps	Stairs	Timber Stairs	Cross Laminated Timber		m3	34.3
31	Superstructure	Stairs and Ramps	Stairs	Steel Stairs	Steel	Structural - Hot Rolled	kg	2381.7
32	Superstructure	Stairs and Ramps	Stairs	Steel Stairs	Plywood	Backing	m3	0.5
33	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Softwood	Wall Studs	m3	21.5
34	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Steel	Corrugated Roof Sheet	m2	271.8
35	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Plasterboard	Fire Resistant Lining	m2	1253.6
36	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Aluminium	Cladding	m2	1316.3
37	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Straw	Insulation	m3	375.1
38	Envelope	External Walls	Non-Structural External Walls	Non-Structural External Walls	Cross Laminated Timber		m3	12.3
39	Envelope	External Walls	Structural External Walls	Structural External Walls	Cross Laminated Timber		m3	57.3

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
40	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Glass	Double, Toughened	m2	4077.2
41	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Hardwood	Mullions	m3	17.5
42	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Aluminium	Mullion Cover	kg	2230.1
43	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Glasswool Insulation	Spandrel	m2	215.4
44	Envelope	Windows and External Doors	Curtain Wall	Curtain Wall	Rockwool Insulation	Spandrel	m2	215.4
45	Envelope	Windows and External Doors	External Doors	Fire Door	Steel	Fire Door	m2	3.8
46	Envelope	Windows and External Doors	External Doors	Hinged Single Door	Steel	Single Door	m2	4.4
47	Envelope	Windows and External Doors	External Windows	Skylight	Glass	Skylights	m2	70.1
48	Superstructure	Internal Walls and Partitions	Structural Walls	CLT Internal Wall	Cross Laminated Timber		m3	300.0
49	Superstructure	Internal Walls and Partitions	Structural Walls	Timber Stick Framing	Softwood	Wall Studs	m3	5.7
50	Superstructure	Internal Walls and Partitions	Structural Walls	Timber Stick Framing	Straw	Insulation	m3	22.7
51	Superstructure	Internal Walls and Partitions	Structural Walls	Timber Stick Framing	Plasterboard	Standard Lining	m2	405.0
52	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Steel	Wall Battens	kg	909.0
53	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Steel	Wall Studs	kg	4938.2
54	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Standard Lining	m2	1098.7
55	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Moisture Resistant Lining	m2	110.0
56	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Fire Resistant Lining	m2	852.6
57	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Moisture and Fire Resistant Lining	m2	663.4
58	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Plasterboard	Shaft Liner	m2	399.4
59	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Fibre Cement	Lining	m2	1067.4
60	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Cross Laminated Timber		m3	4.9
61	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	Glasswool Insulation	Walls	m2	1603.1
62	Superstructure	Internal Walls and Partitions	Non-Structural Internal Walls	Non-Structural Internal Walls	High Pressure Laminate	Toilet Partitions	m2	193.5
63	Superstructure	Internal Doors	Internal Doors	Fire Door	Steel	Fire Door	m2	64.1
64	Superstructure	Internal Doors	Internal Doors	Hinged Single Door	Steel	Single Door	m2	84.2
65	Superstructure	Internal Doors	Internal Doors	Hinged Double Door	Steel	Double Door	m2	34.2
66	Finishes	Wall Finishes	Wall Feature Finishes	Wall Feature Finishes	Cross Laminated Timber		m3	0.4
67	Finishes	Wall Finishes	Wall Feature Finishes	Tiles	Ceramic	Wall Tiles	m2	1318.6
68	Finishes	Floor Finishes	Floor Finishes	Tiles	Ceramic	Floor Tiles	m2	265.2

Item	Category 1	Category 2	Building Element	Type	Material	Material Detail	Unit	Quantity
69	Finishes	Floor Finishes	Floor Finishes	Floor Membrane	Polypropylene	Waterproof Membrane	m2	466.8
70	Finishes	Floor Finishes	Floor Finishes	Floor Membrane	Polyvinyl Chloride	Waterproof Membrane	kg	318.5
71	Finishes	Floor Finishes	Floor Finishes	Timber Flooring	Hardwood		m3	112.0
72	Finishes	Floor Finishes	Floor Finishes	Screed	Concrete	Screed	m3	46.6
73	Finishes	Floor Finishes	Floor Finishes	Raised Access Floor	Reinforced Plasterboard and Steel	Raised Access Floor	m2	6157.9
74	Finishes	Floor Finishes	Floor Finishes	Roof Deck	Aluminium	Qwickbuild Structure	kg	625.0
75	Finishes	Floor Finishes	Floor Finishes	Roof Deck	Hardwood		m3	3.8
76	Finishes	Floor Finishes	Floor Finishes	Landscape Terrace Insulation	Extruded Polystyrene	Insulation	m2	20.2
77	Finishes	Ceiling Finishes	Ceiling Finishes	Suspended Ceiling	Plasterboard	Ceiling	m2	265.2
78	Finishes	Ceiling Finishes	Ceiling Finishes	Suspended Ceiling	Cross Laminated Timber		m3	19.4
79	Finishes	Ceiling Finishes	Ceiling Finishes	Suspended Ceiling	Steel	Ceiling Structure	m2	265.2
80	Finishes	Ceiling Finishes	Ceiling Finishes	Terrace Soffit	Hardwood		m3	5.0
81	Services	Services	Plumbing Fixtures	WC	Ceramic	Sanitary	kg	1161.5
82	Services	Services	Plumbing Fixtures	Urinal	Ceramic	Sanitary	kg	716.6
83	Services	Services	Plumbing Fixtures	Sink	Ceramic	Sanitary	kg	589.2
84	Services	Services	Plumbing Fixtures	Tap	Brass	Mixers	kg	84.1
85	Services	Services	Hydraulic Services	Pipes	Copper	Pipes	kg	1031.4
86	Services	Services	Hydraulic Services	Pipes	High-Density Polyethylene	Pipes	kg	211.1
87	Services	Services	Hydraulic Services	Pipes	Steel	Pipes	kg	612.6
88	Services	Services	Hydraulic Services	Pipes	Unplasticised Polyvinyl Chloride	Pipes	kg	2533.1
89	Services	Services	Mechanical Services	Ducts	Steel	Ducts	kg	10365.2
90	Services	Services	Mechanical Services	Air Terminals	Aluminium	Air Terminals	kg	924.7
91	Services	Services	Mechanical Services	Pipes	Copper	Pipes	kg	1416.4
92	Services	Services	Mechanical Services	Pipes	Steel	Pipes	kg	4.1
93	Services	Services	Mechanical Services	Pipes	Unplasticised Polyvinyl Chloride	Pipes	kg	163.4
94	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Outdoor Unit - 300	no	6.0
95	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Outdoor Unit - 450	no	8.0
96	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Indoor Unit	no	47.0
97	Services	Services	Mechanical Services	Hybrid VRF System	Hybrid VRF	Branch Controller	no	22.0
98	Services	Services	Mechanical Services	A/C Split System	A/C Split System	Outdoor Unit	no	6.0
99	Services	Services	Mechanical Services	A/C Split System	A/C Split System	Indoor Unit	no	6.0
100	Services	Services	Mechanical Services	Air Handling Unit	Air Handling Unit		no	1.0
101	Services	Services	Fire Services	Pipes	Steel	Pipes	kg	22682.4
102	Services	Services	Fire Services	Pipes	Unplasticised Polyvinyl Chloride	Pipes	kg	12.2
103	Services	Services	Fire Services	Sprinkler	Copper	Fire Sprinklers	kg	128.5
104	Services	Services	Electrical Services	Cable Trays and Ladders	Steel	Cable Trays	kg	4699.0
105	Services	Services	Electrical Services	Conduits	Unplasticised Polyvinyl Chloride	Electrical Conduits	kg	161.3
106	Services	Services	Electrical Services	Lighting Fixtures	Linear Suspended Lighting Fixture		no	901.0
107	Services	Services	Electrical Services	Lighting Fixtures	Linear Surface Mounted Lighting Fixture		no	338.0
108	Services	Services	Electrical Services	Lighting Fixtures	Downlight		no	109.0
109	Services	Services	Electrical Services	Solar Panels	Solar Panels		m2	127.0
110	Services	Services	Transportation	Lift	Lift		no	2.0

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