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Increasing Wood Based Office Fit-out for Sustainable Life Cycle Benefits

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Level 11, 10-16 Queen Street
Melbourne VIC 3000, Australia
T +61 (0)3 9927 3200 E info@fwpa.com.au
W www.fwpa.com.au

Forest & Wood Products Australia

Increasing Wood Based Office Fit-out for Sustainable Life Cycle Benefits

Prepared for

Forest & Wood Products Australia

by

Professor Perry Forsythe & Associate Professor Grace Ding

Forest & Wood Products Australia Limited
Level 11, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9927 3200 F +61 3 9927 3288
E info@fwpa.com.au
W www.fwpa.com.au

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Researcher/s:
Professor Perry Forsythe and Associate Professor Grace Ding

School of the Built Environment
Faculty of Design Architecture and Building
University of Technology Sydney

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Forest & Wood Products Australia Limited
Level 11, 10-16 Queen St, Melbourne, Victoria, 3000
T +61 3 9927 3200 F +61 3 9927 3288
E info@fwpa.com.au
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1 Introduction

In large multi-tenanted office buildings there is a common cycle of "fitout-stripout" which occurs regularly over the life of a building. Unfortunately, the physical waste and recurring embodied energy and greenhouse gas emissions (GHG) associated with this cycle are largely ignored. Wood based design solutions are well-placed to provide improved sustainability outcomes which better meet the arising needs and responsibilities of the property industry. This report provides an evidence-based research that aims to quantify and qualify specific aspects of the above problem, and then use this to develop design concepts that aim to solve the problem in a way that allows the property industry to reimagine office fitout using sustainably driven wood based approaches.

2 Context and Key Issues

There is an important need to focus on sustainability spanning the overall life cycle of existing buildings. This is because the vast majority of the stock in Australia relates to existing rather than new buildings – new buildings represent only a 2% injection into the stock each year (Bullen 2007). The existing building market is also thought to be as much as eight times greater than the size of the new construction market (Davies 2005).

Office buildings occupy a significant component of the overall building stock. For instance, Sydney City Council help quantify the scale of office building development via their cyclic and detailed floor space survey covering the Sydney city area (City of Sydney 2012). For instance, the 2012 findings indicate that the total building area of 35,285,393m² (consisting of 26,148 buildings) involves 8,098,936m² of office building area, being 23% of the total building area. They identify that this represents the second largest contributor to overall building usage within the city area. The survey also found that nearly 60% of all workers were accommodated in open-plan office arrangements.

As mentioned, a key issue concerning offices is the way that fitout occurs many times over the life of an office building, thus causing a fitout-stripout cycle that is repeated many times and subsequently offers a poor result in sustainability terms. For instance, fitout is similar to a short life consumable because in multi-storey office buildings it is non-structural and is typically installed and stripped out according to the rotating needs of new tenants, thus creating large amounts of physical waste and in building life cycle terms, creating large amounts of recurring embodied energy/GHG. Subsequently, in measuring the scale of the problem two issues are important: "lease churn", being how often tenants come and go from a building; and more specifically "fitout churn", being how often the above fitout-stripout cycle occurs.

Despite the obvious nature of this sustainability problem, measuring it and placing it in context within the overall building sustainability framework appears to have remained somewhat hidden. Here, the stripout process typically escapes the normal methods of capturing industry specific waste measurement data (Hyder 2011). For instance, drawing again on Sydney City Council for situational context, development applications for retrofit may apply under a "small scale commercial category" which is approved on the basis of being complying development and susbequently misses the normal requirements under new construction for a formal waste management plan, hence reducing the need to commit to specific reuse and recycling strategies when the old fitout is striped.

Waste from stripout has also been difficult to classify and quantify at an overarching industry level, because it often escapes the normal mechanisms used for measuring construction and demolition waste. For instance, as reported by the Australian Government's Department of the Environment and Energy, the "construction and demolition (C&D) waste stream usually covers only some of the generation, disposal and recycling of C&D wastes, as these materials can also be found in the municipal solid waste (MSW) and commercial and industrial (C&I) streams, or as hazardous wastes" (Department of the Environment and Energy, 2013). Consequently, even though the C&D waste stream represents the greatest amount of waste generated (66%), there is a high likelihood that stripout waste may not be appropriately recognised in this stream due to the nature of common waste auditing processes.

Another part of the waste management problem revolves around the physical constraints and speed required of the stripout process which impacts on the ability to cost effectively salvage materials and allow flow-on into secondary markets, thus meaning that too much stripout waste goes to landfill.

In terms of a life cycle view of office buildings, there is concern that the fitout-stripout cycle has not been fully considered in terms of the amount of embodied energy/carbon arising from the recurring nature of this cycle. For instance, many life cycle assessment (LCA) studies adopt an overly simplistic view that assumes a single office fitout that comes as part of the new construction of the building, but does not acknowledge that fitout recurs many times over the life of the building. Subsequently, its impact is often not fully take into account in life cycle assessment studies.

Finally, the fitout process often involves a complex and fragmented group of players that can cause unwanted sustainability consequences. At the base of this, tenants typically rent the office space from the building owner and then take responsibility for providing the fitout but even so, the omnipresent "make good clause" in leasing agreements can inadvertently cause triple waste as a function of the overarchig process. This is a contractual obligation whereby the outgoing tenant must remove their fitout including partitions, furniture, finishes and certain building services, followed by the reinstatement of the pre-lease fittings, fixtures and finishes (RICS 2009). This reinstated fitout may then be removed and changed again when a new tenant comes into the building. The cycle will then repeat itself again when they eventually leave and another new tenants leases the space. The Royal Institution of Chartered Surveyors (RICS) rightly makes the point that the previously described process includes many iterations of waste thus reducing the ability to provide sustainable solutions for office buildings (RICS 2009). In addition, many other players are involved in the delivery of services associated with the fitout-stripout cycle including designers, capital works teams, tenancy teams, property managers, project managers, fitout contractors and stripout contractors. The degree of fragmentation means that the visibility of decisions made at fitout stage may not pass through to saving on waste and recurring embodied energy/carbon at stripout stage.

The previous discussion provides the main components for a model Figure 1 that presents this sustainability problem concerning the fitout-stripout cycle, and the subsequent need to close the sustainability loop.

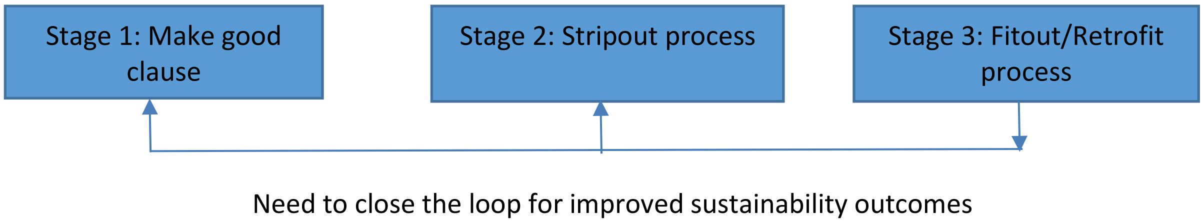

Figure 1: The fitout-stripout cycle associated with fitout churn, and the related sustainability loop problem

Given the above, a reimagined view of wood based fitout could be developed to better address the above needs. Such research is consistent with Forest and Wood Producst Australia's investment strategy in promoting the LCA and carbon benefits of wood used in commercial buildings, and in encouraging low carbon building policies. Further, many studies demonstrate the potential opportunities and benefits of using wood in construction for its environmental advantages over other materials (Nolan 1994; Goetzl & McKeever 1999; O'Connor et al. 2004; McKeever et al. 2005; Bayne & Taylor 2006). It would seem that the same potential could be realised in office fitout situations as well.

3 Objectives

Given the above, the objectives of this project were to undertake research to provide an evidence base for developing wood based design concepts that aim to improve sustainability outcomes for office based fitout (thus closing the aforementioned sustainability loop). To this end, the report is divided into four parts which address specific objectives as follows:

- Part 1: Understand lease and fitout churn trends – undertake research to quantify and qualify lease churn and fitout churn in multi-tenanted CBD office buildings.
- Part 2: Understand reasons for physical waste from office stripout – undertake research to quantify and qualify the typical physical waste streams arising from office stripout processes including attention to reuse, recycling and landfill.
- Part 3: Present designs concepts that respond to research findings whilst concurrently meeting other fitout design needs.
- Part 4: Undertakes a life cycle assessment comparing wood office fitout design concepts with traditional office fitout construction.

For each of the above parts involving research, a self-contained literature review, research method, data analysis and findings are presented. Conclusions from each part progressively add to the evidence-based surrounding the usefulness regarding the development of design concepts created by the project.

4 Part 1: Lease and Fitout Churn

4.1 Leasing and Fitout Churn Literature

Lease “churn” is the term used by facilities professionals to describe the continuous cycle of moves by tenants from one office lease or workspace, to another. It commonly happens at the end of a tenant’s lease period. As described in Figure 1, leaving a lease triggers a process that often leads to waste and embodied energy/GHG emissions.

Authors such as Brittain, Jaunzens and Davies (2004) found a building lease/tenant churn rate of 30% per year in the UK. With reference to a survey by the International Facility Management Association (IFMA) across 291 companies in 2002, a mean churn rate of 41% for all types of facilities was reported (IFMA 2002).

IFMA (2002) categorise office moves into three types: box moves, furniture moves and construction moves. Of note, the main areas of relevance to this research is concerned primarily with complete stripout as typically occurs via a mix of both furniture and construction moves including removal of floor coverings, partitions, workstations, office equipment, furniture and potentially ceilings as well.

It is evident from the literature that there are different methods of measuring fitout churn. For instance, authors such as Tucker and Treloar (1994) speak of it in terms of the number of replacement fitouts (e.g. 5.6 years) over the life of a building. In a more recent Australian study, Roussac, McGee and Milne (2008) reported a 10 year turn around based on a property management portfolio with specific sustainability objectives.

Clearly, office buildings in functional terms are not static. A major reason influencing this perspective concerns market conditions especially in the commercial building category (Choukry 1992). For instance, research by Douglas (1996) indicates that commercial buildings (including office buildings) over a 50-year period, change at a rate of more than double that of institutional buildings and to a lesser extent residential buildings.

In the Australian context, the office building stock in big cities can be considered as “mature” insofar as the age of the stock is already undergoing continual and cyclic upgrade. For instance in Sydney, the average age of office buildings is 28 years (LaSalle 2005).

As presented in Table 1, a commercial building has typically six layers of change operating at different life cycles, in which the interior layout, furniture and equipment have the shortest/fastest life cycle renewal, defined in the table as being 3-7 years (Douglas 1996). Other authors come up with similar but slightly longer periods where for instance Duffy et al. (1993) and Neufert (1994) put forward the life span of fixtures, fitout and furniture for commercial buildings as roughly five to seven years (Duffy, Laing & Crisp 1993; Nuefert 1994).

Table 1: The six layers of change in office buildings

Layers	Typical Life span (Years)
Site	Permanent
Structure	30-300
Envelope	20
Services	7-20
Interior layout	3-7
Furniture and equipment	3-7

Source: Douglas 1996

Some companies calculate their churn rate by measuring the number of square metres on the floor affected by changes. Therefore when companies report their churn rates, they frequently use single numbers to include many different kinds of churn (Ryburg 1996).

Treloar et al. (1999) take a different approach for the purposes of calculating recurring items in LCA studies where they define churn as the number of times an item is replaced over the life of a facility and it is not the number of times per year. Consequently, if a component is never substituted, the churn rate will be 0% and if the component is substituted one time only in the life span of the building, the churn rate will be 100%. Notwithstanding this somewhat less intuitive approach, the findings of Treloar et al. (1999), as presented in Table 2, also demonstrate the high churn rate of certain fitout items. For instance, in the case of "fixtures, furniture and equipment" they have a churn rate of 560% which means 5.6 churns over the life of the building. If this is applied to a theoretical life span of 60 years (as is common), then this would equate to a 10.7 year churn period.

Table 2: Churn rates for elements in commercial buildings

Building elements	Churn rates (%)
Structural elements	0
Walls	20
Ceiling finishes	100
Wall finishes	400
Floor finishes	200
Engineering services	80
Fixtures, furniture and equipment	560

Source: Treloar et al. 1999

4.1.1 Office Property Classifications in Australia, and the Impact on Fitout

The value and quality of office buildings directly impacts on where tenants want to go, how long they will stay in their lease, how much they want to pay for leased space and the sustainability rating of such space. The Property Council of Australia (PCA), being the leading advocate for the property industry, provides a "Guide to office building quality" which allows building owners to self-rate their office stock into categories such as "Prime" grade, "A" grade, "B" grade and so on (http://www.propertycouncil.com.au/Web/EventsServices/ResearchData/Information Products/Web/Events Services/Research Services/ItemDetail.aspx?iProductCode=0105065). Lower quality spaces typically attain lower rental levels and have lower capital values.

The above approach is widely used by the supply side, demand side and sustainability advocates in the property industry. For instance, Sydney City Council's *Better Buildings Partnership* who champion sustainability objectives under a partnership arrangement with the property industry, refer to the PCAs guide as the preferred standard when choosing new office space (http://www.betterbuildingspartnership.com.au/assets/2013/08/BBP-Site-Selection-Briefs-Templates.pdf, page 3). Similarly, the Green Building Council of Australia (GBCA) state that premium grade buildings are now synonymous with high "Green Star" rated buildings (https://www.gbca.org.au/news/gbca-media-releases/premium-equals-green-in-property-council-of-australias-new-guide-to-office-build/33715.htm). It would therefore seem that sustainable office fitout is more likely to be aligned with high-end "prime" office stock than under lower ranked categories.

Interestingly, more academically focused research in this area indicates simiar findings insofar as superior quality office spaces appear to be regularly adapted (more so than lower grade stock) in order to retain their perceived value (Wilkinson 2011 & 2012; Wilkinson & Remoy 2011).

4.1.2 The Green Star Rating System for Office Fitout Projects

There is now significant demand among major property owners, property managers and tenants for sustainable buildings (especially in higher end office building stock). In the Australian context, the GBCA and their voluntary Green Star rating system represents the most commonly sought after assessment instrument used to score the sustainability of office buildings. For some time, building owners have sought a rating for the base building but in more recent times and of specific relevance to this study, the relatively new Green Star "interiors" tool is used to score fitouts (thus allowing both building owner and tenants to agree upon targeted sustainability standards). For instance, there is a connection between the two insofar as a high base building score may mean that the building owner will want tenants to comply at the same level regarding their fitout, in order to maintain consistency across the overall building.

The interiors tool has obvious relevance to how fitout will be designed in order to achieve a targeted Green Star score. This involves 9 impact categories shown in Table 3 below, of which "materials" is clearly the largest scoring category (24 points out of the 110 point total). It provides guidance to this research in terms showing how best to accrue points for wood based fitout-stripout design concepts, in a way that provides realisable value to tenants and/or building owners.

Table 3: Core impact categories relating to the Green Star "interiors" tool

Categories	**Maximum Available Points Interiors Rating Tool**
Management	13
Indoor Environment Quality	23
Energy	20
Transport	7
Water	5
Materials	24
Land use and Ecology	5
Emissions	3
Innovation	10
Maximum Available Points	**110**

Of note, scoring under the "materials" category is determined by joining a number of items from column one together (refer Table 4), according to a number of separately prescribed sequencing scenarios. To avoid unnecessary detail, these prescribed scenarios are not provided here, but instead, it can be said that high scoring items within each sequence have the greatest impact on the overall score from each sequence.[1] Of note, the two main items include comparative life cycle assessment (18 points) and product transparency and sustainability (19 points).

- Comparative life cycle assessment: Points are awarded based on the extent of environmental impact reduction and for fitout, this is likely to mainly be proven via reduced embodied energy.
- Product transparency and sustainability: here, a "product sustainability value" (PSV) of reused / recycled materials is calculated in percentage terms of the Project Contract Value (PCV) which is then multiplied by available points (19) to arrive at "Points Awarded". For reference, an Excel version of this tool is available at (http://new.gbca.org.au/green-star/rating-system/interiors).

Table 4: Extract from Green Star "interiors" tool (V1.0) for scoring points in the "materials" category

Pathways	Sl. No.	Materials			24
Life Cycle Impacts	1	To reward the reduction of the environmental impacts of building materials and methods for the whole fitout over its entire life cycle.	19.1	Comparative Life Cycle Assessment	18
			19.2	Additional Life Cycle Impact Reporting	1
Responsible Building Materials	2	To reward projects that include building materials that are responsibly sourced or have a sustainable supply chain.	20.1	Wood	1
			20.2	Cables, Pipes, Floors and Blinds	1
Sustainable Products	3	To encourage sustainability and transparency in product specification.	21.0	Product Transparency and Sustainability	19
Construction and Demolition Waste	4	Fixed Benchmark	22A	Reduction of Construction and Demolition Waste – Fixed Benchmark	3
	5	Percentage Benchmark	22B	Reduction of Construction and Demolition Waste – Percentage Benchmark	1

What can be taken from the above is simply that design concepts generated by this project should be easily accountable in the above point scoring system in order to provide a realisable value proposition for building owners and tenants. Of note, this includes the *life cycle assessment* approach – as undertaken in detail, in Part 3 of this report. Further, *Product transparency and sustainability*, is achievable via the careful design of wood based fitout with a view to ensuring high levels of reuse and recycling.

4.1.3 Moves in Leasing and Design to Reduce the Impact of Fitout Churn

As alluded to previously, organisations such as the Better Buildings Partnership (BBP) work under a partnership model that aims to pull together the major players in the property industry to create and facilitate solutions that will systematically work towards improving the sustainability of City of

[1] Unfortunately, the category for "construction and demolition waste" only contributes 1-3 points and so whilst this can also add to the point score tally, it is not as effective in accruing points as the main categories mentioned.

Sydney's office buildings. Of particular note to this study, BBP members currently represent over 50% of the office floor space across Sydney's CBD (http://www.betterbuildingspartnership.com.au/about/) hence making them not only a valuable means of obtaining access to information from members, but also in actively improving fitout sustainability outcomes. BBPs multifaceted approach to implementing sustainability principles spans a number of inter-related dimensions of relevance to this study including:

- The development of specific clauses with that can be easily inserted into "best practice" leasing agreements including a dedicated stream of clauses pertaining to addressing office building consumption, waste and recycling (http://www.betterbuildingspartnership.com.au/resource/bbp-model-clauses/).
- Guidelines for office stripout including attention to procurement, systems and waste management reporting (http://www.betterbuildingspartnership.com.au/resource/stripout-waste-guidelines-procurement-systems-and-reporting). This item is dealt with more fully under Part 2 of this report which deals specifically with stripout waste management.
- Guidelines that focus on designing out waste from construction. Key principles include: design for Reuse and Recovery; Design for Off Site Construction; Design for Materials Optimisation; Design for Waste Efficient Procurement; and Design for Deconstruction and Flexibility (http://www.modular.org/marketing/documents/DesigningoutWaste.pdf).

The last of these three items is of specific interest because it begins to identify the problem that if you do not design to manage churn and the incumbent stripout waste, then you will not be able reduce waste or cut down on energy/GHG emissions. It is therefore not surprising that leading property industry organisations such as The Royal Institution of Chartered Surveyors (RICS) adopt similar advocacy, particularly in terms of designing out waste and how to achieve this in the context of the previously discussed "make good" clause. For instance, their recommendations as taken from their "Greening Make Good" Handbook (http://jgoddardco.com/J_G_%26_Co_Web/Home_files/RICS%20Greening%20Make%20Good%20Australia.pdf) include:

- Avoid removing/replacing base building services, equipment or finishes if possible.
- Use free standing and modular fitout to avoid damage to base building.
- Maximise "open plan" layouts.
- Consider wireless data systems, low embodied energy and recycled materials.
- Lease integrated fitout or previous tenant fitout.
- Landlord can test the market with existing fitout – reducing waste.

Similar themes are also provided in the academic literature by authors such as Steiner (2006) who advocates: designing for reconfigurability, designing using a generic method for flexibility and interchangeability; expanding the use of mobile and/or transformable furniture. The same is true for advocacy among large office property owners. As an example, Investa, who manage in excess of 1,000,000 m^2 of high quality office building stock (http://www.investa.com.au/office/about-investa-office/our-business/), have a stated preference for "green leasing" across their entire office tenant base (http://www.investa.com.au/sustainability/about-sustainability/engaging-tenants/) and are committed to similar fitout design guidelines to those mentioned above, that aim to encourage high levels of sustainability and minimal levels of waste (http://cdn.sydneybetterbuildings.com.au/assets/Green-Lease-Guide-Investa.pdf.)

A key issue that can be taken from the above discussion is that in the past, office fitout has been unnecessarily designed for a single use, permanent fitout rather than something that can be deconstructed and reconfigured for reuse, thus causing a pathology leaning towards landfill. Reuse potentially retains more of the value of the original product because it limits the amount of change and extra work and additional embodied energy/GHG involved in bringing it back to market; recycling involves more work because it involves more reprocessing and generally results in feedstock that must compete with new raw materials in existing manufacturing processes.[2] In addition, low level recycling such as animal bedding, garden mulch or even recovery for fuel, likely requires approval under State Government environmental protection legislation – such as a resource recovery order or resource exemption – as required in NSW (see details at http://www.epa.nsw.gov.au/wasteregulation/recovery-exemptions.htm).

What can be concluded from the previous literature is that the basic sustainability problem arising from high levels of fitout churn is simply that it creates large amounts of waste and in addition creates large amounts of recurring embodied energy/GHG as associated with the fitout-stripout churn cycle. For instance, the literature to date suggests that fitout churn ranges from 3 – 10.7 years with an average hovering somewhere around the 7 year mark. Other directions from the review include the need to ensure that fitout design incorporates the ability to enable easy reuse to enable higher recovery during stripout processes. Further, such designs must be realisable within the assessment framework of sustainability measurement tools such as Green Star "interiors" in order to represent realisable value to tenants and building owners. Such issues must be dealt with and integrated into wood based fitout design solutions. It is relevant for this study to gather its own data (as detailed further below) with a view to finding out more, about the nature of lease and fitout churn.

4.2 Lease and Fitout Churn Research Methods

Methods for quantifying both lease and fitout churn were found to be limited due to the context of commercial privacy issues and limited publicly available data. In order to mitigate against weaknesses in any one approach, a multipronged approach to quantifying lease and fitout churn was used. The primary approach was to take advantage of large scale leasing data and then use this to filter down to a more refined understanding of the churn problem. Each method is elaborated upon more fully under respective headings below.

4.2.1 Method 1: A Large Leasing Dataset Relating to Sydney CBD Office Buildings

As mentioned previously, tenants (lessees) are typically responsible for installing fitout and then stripping it out in accordance with the lease agreement with the building owner.[3] In particular, the completion of a lease (when the lease is not being renewed) typically triggers a fitout churn via the previously mentioned "make good clause". Lease term is therefore important in terms of inducing a fitout churn. Since a large dataset was made available to the research team by the abovementioned

[2] Including related feedstock quality control standards which may reduce the ability to fully utilise the recovered materials.

[3] Here, it is relevant to point out that the term lessee and tenant are often synonymous but may also occasionally differ under certain specifics such as sub-tenanting arrangements – for ongoing simplicity the term lessee and tenancy are used synonymously unless stated otherwise.

BBP, it was used to quantify various aspects of lease duration. With regard to this, the BBP dataset is primarily constituted by an amalgam of:

- Sydney City Council's 5 yearly floor space and employment survey using 2012 data (http://www.cityofsydney.nsw.gov.au/learn/research-and-statistics/surveying-our-community/floor-space-and-employment-survey/2012-fes-overview-and-summary-reports).
- Office leasing data registered with the New South Wales Land and Property Information office (http://www.lpi.nsw.gov.au/), collected between January and June 2014.
- BBPs own internal survey concerning uptake of the previously mentioned leasing clauses, collected between January and June 2014.

Of note, only tenants occupying buildings having 45% or more office space were included in the study. The data included lease start date, lease finish date, lease duration and lease area.

4.2.2 Method 2: Leasing History from a Selective Sample of Individual Buildings

This involved a detailed leasing history of 3 large office buildings (drawn from a commercial leasing database) focusing on long leases drawn from prime grade buildings in Sydney CBD, over 45 storeys, and at least 28 years old. It aimed to add to Method 1 by not just identifying the lease term but in addition, gain and understanding of how often leases were renewed or extended because this effectively increases the time between lease churns (and potentially the time between fitout churns as well). Due to the nature of the leasing data available, certain assumptions were necessary during the analysis of this data including: that all parts of a leased area were renewed or extended at the same time; that the leaseholder occupied the lease area as distinct from subletting it to others; that the lessee only made a decision at the end of the lease to extend or renew.

4.2.3 Method 3: Fitout Churn Survey among Property Professionals

A targeted survey was undertaken among office property industry professionals including supply side participants such as property manager owners, property managers, property consultants, sustainability managers, fitout-stripout contractors and client side (tenants). They were primarily asked to define a time period for fitout churn (i.e. the period between fitout-stripout events). This approach aimed to see how closely this fitout churn data matched the data from Methods 1 and 2. For instance, it was found that detailed fitout churn data was very difficult to obtain due to privacy issues and the lack of well-defined records. So by finding out if this relatively small sample of such data, tracked similarly in duration to the lease term data (Method 1) and/or the more expansive leasing history data (Method 2), it would be possible to see if these latter sources could be used as a reasonable proxy for fitout churn. For instance Method 1 in particular, is based on a large dataset, thus making it a desirable option to use as a proxy for the purposes of generalising fitout churn periods more broadly.

Leading on from the above, tenants were asked specifically about fitout churn in terms of the last period of time between significant office fitout-stripout events (including workstations, partitions, and floor finishes replacement) for a specific Prime Grade property that they occupied within a targeted Sydney CBD (as identified from the Method 1 dataset). Their responses were recorded against the area they actually occupied in the abuilding including small (<1000m^2), medium (1000-5000m^2) and large (>5000m^2) office area categories. A screening process was established to eliminate minor lessees and as a result, 168 entries were found appropriate for the research. However when contacted, the majority of the lessees were unavailable to take part in the interview due primarily to aforementioned privacy issues or lack of detailed records. Ultimately, 28 lessees participated in the interviews between November 2015 and January 2016 but only 11 were able provide the level of information required. Some interviews took place at the tenant's office and some were undertaken via telephone interview.

Other participants (property manager owners, property managers, property consultants and fitout-stripout contractors, sustainability managers) were asked the same question but based on their general expectations (for Prime Grade or A Grade buildings) about fitout churn periods. For instance, they were asked to estimate the typical fitout-stripout period for all three area categories. To improve the validity of responses, participants with less than 5 years' experience in the office property industry, were excluded from the analysis. 19 responses were gathered during a targeted property industry seminar in June 2016 at the University of Technology Sydney. Of these, a number provided a "don't know" response, contained missing data, or did not meet the minimum experience requirements, thus leaving 9 usable responses.

Given the above, the usable sample involved 21 responses of which 11 were tenants and 10 were other participants.

4.3 Findings on Leasing and Fitout Churn

4.3.1 Trends in Leasing and Lease Term that Impact on Fitout Churn

Given that the research team had access to BBPs raw data (refer Method 1), it was possible to draw upon and extend analysis of the sample, primarily using descriptive statistics. This aimed to mainly uncover a basic profile of tenants, buildings and leasing arrangements. In general, there was a focus on prime buildings as the prior literature review tends to suggest that these buildings may be adapted more regularly than lower grade buildings. From the sample and based on previous interrogation of the data by BBP[4] it can be said that:

- There was a total of 528 office buildings (including prime and non-prime buildings) in the Sydney CBD. Prime buildings only occupy 13.4% of the total number of buildings but represent a much larger 47.2% of the total (internal) floor area.
- Even though prime buildings occupy a large area, they are tenanted by only 17.6% of the total commercial (CM) offices tenancies.[5] For instance, there are 5,796 CM tenancies of which 1240 relate to prime office space (17.6%).
- Prime buildings are mainly constituted by large businesses (of over 200 workers) being 60.1%.
- Prime building stock accommodates the majority of office workers being 53.5% of all workers in office buildings.
- Over 80% of leases in prime buildings have best practice leasing. Standard practice leases now include nearly half of the BBP Model Lease Clauses (44%).
- Model clauses relating to "consumption, waste and recycling" ranked as the highest priority for large prime tenants and landlords.

From the above, it is concluded that a small number of relatively large prime buildings represent almost half of the office building area in the CBD. It would also seem that these large buildings are occupied more by large tenancies than small. These groups also appear to have a vested interest in model leasing clauses including those involved in addressing consumption, waste and recycling.

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[4] The following segmentation analysis originally came from the BBPs Leasing Index Study (http://cdn.sydneybetterbuildings.com.au/assets/2015/12/Better_Buildings_Partnership_Leasing_Index_Results.pdf). These findings have since been verified and simplified by UTS for the purposes of this study.

[5] CM tenancies represents all tenancies above ground with an office space component.

Subsequently, this data tends to support the focus on prime building stock because the most impact can be obtained by influencing a relatively small number of large property owners and large tenants, who own and occupy large amounts of office space.

Building on these conclusions and alluded to previously, the sample provided by BBP stratified the size of tenants by internal area classifications including large (>5000m^2), medium (1000-5000m^2) and small lessees (<1000m^2). UTS undertook further analysis around this theme of classification based on reduced sample taken from the overall BBP dataset for prime leases (n=268). For instance, Table 5 shows details about the total number of prime building tenancies and how many are represented by the reduced sample according to the three tenancy categories. As an example, it shows that for large tenants, the reduced sample represents a large proportion (83%) – thus indicating it to be highly representative of the actual population of large tenancies which as per earlier discussions, represents a key category of interest.

Table 5: Stratified sample of tenants in prime office buildings according to tenancy size

Tenancy size	Number of tenants		% population represented by sample
	Reduced sample studied	Population of all Prime leases	
Large	70	84	83.3
Medium	99	315	31.4
Small	99	841	11.8
Totals	**268**	**1240**	

Similarly, Table 6 shows the proportion of total prime building floor area that is represented in the reduced sample by small, medium and large tenants. Similar representation patterns are apparent. From this, it can also be seen that large tenants occupy the vast majority of prime office space area (for instance, 1,404,684m^2 of area represents 61% of total of prime area). When coupled with the

Table 5 data, it can also be seen that these large tenants only represent a small proportion of the population total (for instance 84 tenants represents only 10% of the total number of prime tenancies).

Table 6: Internal area (Net Lettable Area) represented by the sample of prime building tenants

Tenancy size	Total internal area		% population represented by sample
	Reduced sample studied	Population of all Prime leases	
Large	1,112,743	1,404,684	79.2
Medium	177,324	618,735	28.7
Small	39,587	269,852	14.7
Totals	**1,329,654**	**2,293,271**	**57.9**

Since the percentage of internal area represented by the sample is similar to the percentage of lessees represented, it suggests that the size of space within each category is representative. In other words, the sample is not heavily weighted with particularly large or small tenancies.

From the distribution of lease term lengths by tenancy category (refer Figure 2), the mean lease length from the data can be categorised as follows:

- The large tenancies mean value is 8.9 years (n=69, standard deviation = 3.4).
- The medium tenancies mean value is 8.0 years (n=96, standard deviation = 3.2).
- The small tenancies mean value is 5.1 years (n=97, standard deviation = 1.95)

This suggests that small lessees (<1000m^2) have the shortest leases, and large lessees (>5000m^2) have the longest leases. It would therefore seem that large lessees want to commit to longer periods, probably due to the unwanted cost of relocating, moving and re-establishing business at a new location (including fitout).

Taking the analysis further, Table 7 shows that there is a statistically significant correlation between floor area (per floor area category) and tenancy term length. For instance, for small tenancies, the Pearson Correlation was 0.404 (0.01) and for large tenancies the Pearson Correlation was 0.469 (0.01).

Table 7: Correlation analysis between lease floor area and term length (N=sample size; Sig=significance level)

Correlation between Internal Area and Term Length			
Tenancy Size	Pearson Correlation	Sig. (2-tailed)	N
Small Tenancies	0.404**	0.000	97
Medium Tenancies	-0.073	0.481	96
Large Tenancies	0.469**	0.000	68
** Correlation is significant at the 0.01 level (2-tailed).			

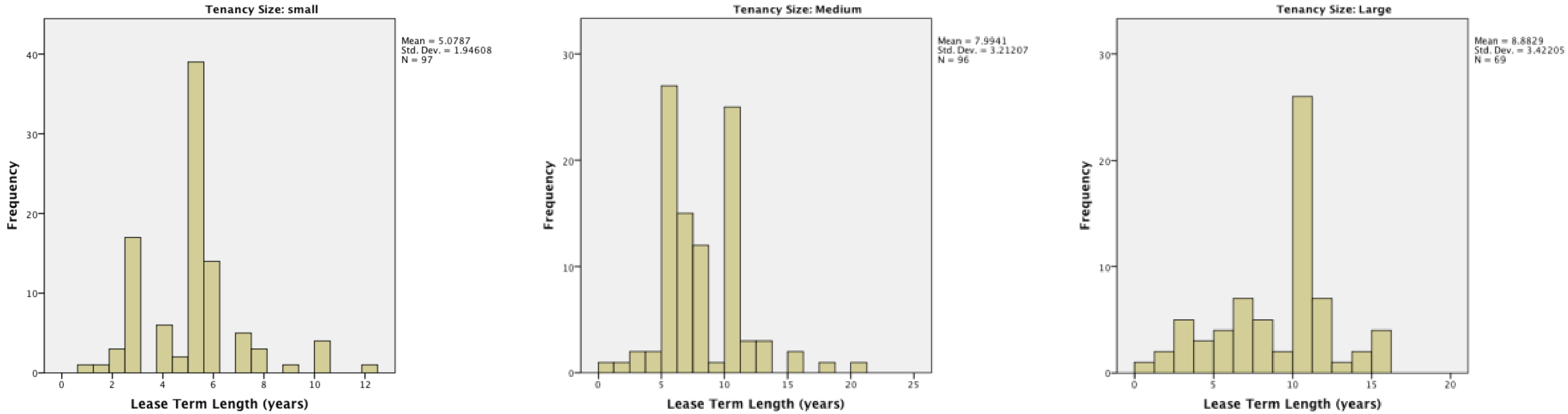

Figure 2: Frequency distribution of lease term length for small, medium and large tenants in prime buildings

4.3.2 Leasing Trends within Specific Prime Buildings

Using the tenant lease history data provided for the three specific buildings (refer Method 2), the lease renewal or turnover of internal area was examined. To be consistent with the BBP data, tenants were classified according to the total internal area occupied within a building. Due to missing information, some tenants could not be classified or there was not enough information to determine the entire history of occupancy of a particular space. Details are shown in

Table 8: Summary of tenancy size distribution

	Tenancy size				Total
	Not assigned	Large	Medium	Small	
Number of tenants	45	16	53	157	271
Distribution of data sample distribution		7.1%	23.5%	69.5%	
Prime building population		6.8%	25.4%	67.8%	

From this dataset it can be seen from Figure 3 that the mean values for each tenancy size category are notably similar to those for the reduced BBP dataset (shown in brackets below). For instance:

- The large tenancies mean value is 9.07 (8.9 years).
- The medium tenancies mean value is 6.7 years (8.0 years).
- The small tenancies mean value is 4.1 years (5.1 years).

Referring to Table 9, of particular interest is what action the lessees took when the end of a lease was reached. Although the sample size for large and medium lessees is small, the percentages give some indication of trends in direction. The larger the lessee type, the more likely they are to renew or extend their lease. Also, the smaller the lessee type, the more likely they are to leave when their lease ends (hence the make good clause will be triggered and therefore a retrofit will take place). Due to missing information, some lessees could not be classified or there was insufficient information available to determine the entire history of occupancy of a particular space.

Table 9: Renewal or turnover (departure) from leases

Tenant Type	Total that have come to the end of a lease	% that have renewed or extended at least once	% that have only turned over	% Renewed or extended before turning over	% that have eventually turned over (not current tenants)
Large	8	100%	0%	38%	38%
Medium	29	59%	41%	17%	59%
Small	82	34%	66%	16%	82%

Each pair of percentages was tested for statistical significance. All pairs were found to be significant for the percentage of lessees that have renewed or extended their lease at least once. From this we can conclude that the larger the lessee type, the more likely they are to renew or extend their lease. Also, all pairs were significant for the percentage that turned over after the first lease was up. This shows that the smaller the lessee type, the more likely they are to turn over when their lease ends. There are no significant differences in the proportions of lessees that renewed or extended before turning over. There is a higher overall churn rate for small lessees than for either medium or large lessees.

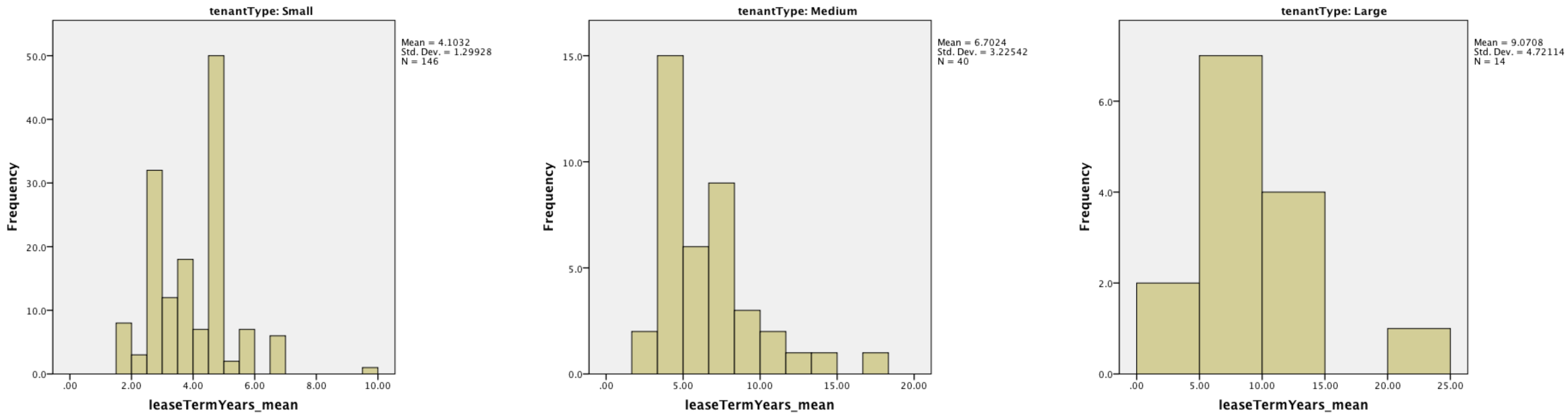

Figure 3: Distribution of term length by tenancy category

4.3.3 Survey Findings about Fitout Churn

Table 10 presents results from the survey data associated with Method 3 which specifically deals with fitout churn. As mentioned previously, this method aimed to fill a gap insofar as linking the previous quantification (of lease term lengths and/or lease renewal history) with the fitout churn period. For instance, even though lease term may commonly induce a fitout churn, this is not always the case where tenants renew or require intermediate fitout works. Subsequently, it would be good to help confirm the fitout churn period to see how closely these match the likes of the lease term period. If a strong match is found then it is easier and more useful to use lease terms as proxy for fitout churn, as such data is generally easier to obtain and generalise across a broader population. It also provides greater confidence in the overall findings from the 3 combined research methods

As mentioned, the sample of 21 responses included 11 tenants providing actual fitout churn data on a targeted Sydney CBD premises that they occupy; a further 10 supply side participants from various property backgrounds and with reasonable depth of industry experience (involved directly in leasing and fitout) gave informed estimates of the fitout churn period. Findings are summarised in Table 10 below.

In general, these findings suggest a very similar period to the previously presented Method 1 findings (represented for comparison in brackets below).

- The large tenancies mean value is 9.6 (8.9 years).
- The medium tenancies mean value is 8.5 years (8.0 years).
- The small tenancies mean value is 4.9 years (5.1 years).

It would therefore seem that indeed, lease term length provides a reasonably accurate proxy for the fitout churn period (for the type of office buildings under investigation).

Table 10: Summary of survey data on fitout churn

Participant ID	Role of participant	Participant's years of experience	Fitout churn Period		
			Small tenancies (<1000m²)	Medium tenancies (1000-5000m²)	Large tenancies (>5000m²)
1	Tenant	10	-		10
2	Tenant	10	-	8	
3	Tenant	6	-		14
4	Tenant	15	-		9
5	Tenant	10	-	11	-
6	Tenant	5	-	9	-
7	Tenant	9	-	12	-
8	Tenant	5	-	7	-
9	Tenant	10	-	12	-
10	Tenant	5	-	12	-
11	Tenant	7	-	12	-
12	Supply side participant	18	6	7	8.5
13	Supply side participant	6	5	10	15
14	Supply side participant	17	5	8	10
15	Supply side participant	10	5	6	7.5
16	Supply side participant	6	5	8	7
17	Supply side participant	30	3	5	10
18	Supply side participant	20		5	7
19	Supply side participant	5	4	5	7
20	Supply side participant	33	5	7	10
21	Supply side participant	28	6	-	-
Averages		**12.62**	**4.9**	**8.5**	**9.6**

4.4 Conclusions about Lease and Fitout Churn

Three research methods were used to help provide an overall picture of lease term length and fitout churn. In a combined sense, these methods provide reasonably consistent findings and from this, it is concluded that lease term length is a reasonably accurate proxy for the fitout churn period (whereby lease term length is easier to obtain and quantify using relatively large datasets, than fitout churn data, and can be generalised across a broader population).

The data generally showed that prime buildings were the area of most interest to sustainable fitout. In general, it was found that for these buildings, tenancy size (in terms of area leased) influences lease term length. For simplicity, a focus has been placed on small and large tenants whereby, small tenants (<1000m²) have shorter term lease and a lower likelihood of lease renewal, and subsequently at the end of an average lease term (5.1 years), the make good clause will be triggered and there will subsequently be a high likelihood of a fitout churn. As a result, fitout churn for small tenants in prime buildings is likely to be in the order of 5.1 years. Of note, this is somewhat similar to the lower end range of authors such as Duffy, Laing & Crisp 1993 and Nuefert 1994. Lease term for large tenants (>5000m²) is longer with an average of 8.9 years and in addition, a higher chance of lease renewal which may extend their overall period of occupancy in the building. Even so, based primarily on the research in Method 3, it is considered that despite this longer occupation of a building, there will still be a degree of intermediate fitout undertaken which will again result in a fitout churn average that is similar to the lease term average (i.e. 8.9 years). This figure is more aligned with the upper range of figures provided in the literature. For instance, Duffy, Laing & Crisp 1993, Nuefert 1994 and LaSalle (2005) all suggest an upper range of seven years.

Of note, the above findings (i.e. 5.1 years for small and 8.9 years for large tenants) have been used in LCA analysis for the period that fitout is expected to last before churn occurs, as detailed in Part 4 of this report.

5 Part 2: Waste from Office Stripout

5.1 Stripout Waste Literature

Australia has one of the highest rates of waste generation per capita in the world and this is expected to grow with increasing population and prosperity – construction and demolition (C&D) waste continues to be one of the key contributors within this situation (ABS 2012). Whilst many studies have been undertaken on quantifying waste from construction sites and how to reduce it (examples include Skoyles 1976; Forsythe & Marsden 1999; Crowther 2000; Formoso et al. 2002; Kharrufa 2006; Tam & Tam 2006; Formoso et al. 2002; Poon, Yu & Jaillon 2004; Ekanayake & Ofori 2004), relatively little quantitative research into office fitout waste is available.

Of the small number of offerings specifically concerning fitout waste, Li and Yang (2014) state that material waste from retrofit contains significant potential for reusing and recycling but only in the order of 27% of total waste from stripout is recovered. At a more specific level, the Institute of Sustainable Futures (Wilmot, McGee & Milne 2014) undertook a study that looked at waste streams specific to office stripout, based primarily on interview data from those involved in stripout and salvage processes. The study found that four factors were consistently mentioned as significantly influencing the level of resource recovery including: time, cost, transport distances and contamination. As the authors of the work point out, stripout and demolition choices are typically oriented towards the quickest and most familiar options; in many instances, new materials are relatively cheap compared to the effort and cost of reuse and recycling options (including salvage, handling and transport); for recovery to be cost effective, there must be a simple process to sell and recover it. Other prominent issues from the Institute of Sustainable Futures report include:

- Scant consideration of “end of life” specification of products.
- Resistance to the use of second hand materials from a quality and aesthetics perspective.
- Limited uptake of product stewardship schemes.
- Demand in the construction industry for salvaged materials is relatively low except where the core material has reasonably high value such as metals and to a lesser extent glass.
- There is still a high level of waste that goes to landfill.

Workstations are a good illustration of the problems in the system. For instance, multiple materials bonded together in wood panel products increase the cost and reduce the practicality of recycling procedures. For reuse, such assemblies need to be assessed, dismantled, transported, cleaned, repaired, upgraded, stored, transported back, and reassembled. The industry must also be prepared to buy the product so that there is sufficient turnover to make a business out of it. The problem is, that often a new workstation can be purchased at a similar price and the specifiers knows they can get the quantity and finishes they want, in a known time frame.

Using similar research methods, Hardie, Miller and Khan (2011) conducted a survey to investigate the waste management of office refurbishment projects in Australia. Of note, the authors mention the reluctance of participants to provide detailed information. Table 11 summarises their results which as above, suggest that high proportions of fitout related items go to landfill. Even so, their data suggests that partitions and workstations provide higher amounts of reuse and recycling than the above study, albeit that is unclear if this relates purely to the metal chassis which are commonly cut away from the wood panel component because as mentioned previously, metals achieve high recycling prices and in the case of workstations the metal can be cut away from the wood quickly and simply.

Table 11: Summary of waste management of office refurbishment projects

Items	Landfill	Recycle offsite	Reuse office site	Reuse onsite
Doors	100	0	0	0
Door hardware	94	6	0	0
Mirrors	88	12	0	0
Suspended ceiling	48	4	22	26
Partition walls	40	10	24	26
Glazed partitions	34	16	25	25
Joinery	95	0	4	1
Workstations	22	8	35	35
Electrical fittings	85	5	5	5
Balustrades	82	18	0	0

Source: Hardie, Miller & Khan 2011

5.1.1 Moves to Improve Reuse and Recycling from Office Stripout

At a general level, some State Governments in Australia have had an influence on reducing C&D waste to landfill with the introduction of landfill levies (Crowther 2000; ABS 2006). These levies are paid on each tonne of waste tipped at landfill and have proven moderately successful in making reuse and recycling options more inviting – especially where heavy weight materials are involved. Even so, the relatively light weight of wood tends to mean that the same tipping cost penalties do not apply and consequently, there is less pressure on stripout demolishers to search for reuse or recycling options for wood, under these circumstances.

The BBP recently released office stripout waste guidelines (2015) as a means of trying to affect change in a way that is driven by office building owners and tenants, but links down the supply chain through to fitout and stripout contractors.

Their research indicates that stripout works from an individual office case study created 63 tonnes of waste per 1000m^2 (BBP 2015). They cite similar figures from the UK where 6.2 tonnes per 100m^2 (being the same as 62 tonnes per 1000m^2) is mentioned as indicative stripout waste expectation (WRAP 2014). They extrapolate this under the stated assumption that 10% of CBD leases are renewed each year, which equates to approximately 25,000 tonnes of waste from office stripout being generated every year in Sydney's CBD alone. Further, under normal practice, they assert that only 18% is being recycled and 2% reused.

BBPs guidelines (2015) serve to address central issues to the stripout/waste problem from multiple perspectives that influence the ability to reuse, refurbish, recycle, recover waste materials, as shown in Table 12.

Table 12: Extract from BBP stripout guidelines

Role	Concern
CEO, Fund Manager, Investment Manager	Embedding stripout waste recovery targets and best practice in contracts
	Cost of setting 60 ~ 80% stripout waste recovery targets
	Calculating potential environmental outcomes
	Reputation / evidencing CSR outcomes
Tenant, Tenant Representative, Project Manager	Preparing for an upcoming stripout / refurbishment
	Mapping out destinations for stripout resources
	Understanding waste acceptance requirements in recovery facilities
	Preparing for site access by material reprocessors, charities, etc.
Head Contractor or a Demolition Contractor	Complying with or assigning stripout waste recovery targets
	Creating an inventory of materials by recovery path
	Disposal of waste by recovery path
	Reporting and evidencing waste recovery outcomes
Site Manager	Preparing for selling or gifting of furniture; Disassembling with care
	Organising onsite access for external parties (material reprocessors, charities, etc.)
	Coordinating storage for overnight removals
	Organising waste streams in accordance to destination and acceptance criteria
Risk Manager (owner or other site controlling entity)	Preparing for site access by material reprocessors, charities, etc.
	Determining insurance coverage of non-core staff whilst onsite
Resource Recovery Facility Operator	Inform future customers of contact details, acceptance criteria and commercial terms
	Facilitate customer reporting needs

Their expectations for "good practice" are also described in terms of 10 operational steps as shown in Table 13, below. It is notable that it is the intention of the Guidelines to achieve at lease at minimum diversion from landfill of 60% and up to 80%. These rates are thought to be significantly higher than what is commonly achieved in current day practice.

Table 13: Good practice extract from BBP stripout guidelines

1	Set a 60% to 80% target diversion rate	Set a 60% to 80% target diversion rate in your internal processes and your contracts.)
2	Agree the conditions of the make good settlement early	Agree the conditions of the make good settlement early. Determine responsibility for the removal of fixed and loose furniture and allocate responsibility for optimising reuse. (See the BBP Model Lease Clauses)
3	Create an inventory and code by recovery pathway	Ensure visibility of inventory and coding through the entire stripout process. Use “return to manufacture, reuse, upcycle, gift, recycle, waste to energy, or industrial feedstock”.
4	Review contamination thresholds of resource receivers	Understand load acceptance criteria by resource receivers
5	Prepare for stripout	Prepare by educating all relevant staff on targets, streams and materials acceptance compliance. This can include the outgoing tenant, the asset manager, building managers, and contractors.
6	Arrange site access / material removal by third parties	Arrange site access / material removal by third parties.
7	Ensure demolition contractors are briefed / resourced for stream separation and careful disassembly	Use the Principal requirements to ensure this is included in the contract.
8	Remove items by stream and store or dispose of separately	Remove items by stream and store or dispose of separately.
9	Conduct regular compliance and contamination checks and report	Conduct regular compliance and contamination checks and report.
10	Ensure use of pre-used items in refit	Ensure (and specify in contractual documents) that the refit should include pre-used items where possible (e.g. when recommissioned floor or ceiling tiles or in the fitout guide requirements on tenancy design).

Note: The above extract has minor modifications to remove internal referencing within the source document

These guidelines have only recently been published but aim to set up best practice for implementation within the stripout industry, as driven by building owners and tenants.

5.2 Stripout Waste Research Methods

From the previous discussion it is apparent that fitout churn (as primarily induced by lease churn) creates multiple iterations of waste over the life of the building. Subsequently, there is a need to quantify this and in addition, there is the need to determine what becomes of the waste materials on each occasion. For instance, in order to build on the scant literature available, there is a need to know how much is reused, recycled, or sent to landfill.

To find out more about this issue, data about the key waste materials arising from office stripout (including wood applications) and the proportions assigned to landfill, reuse and recycling, have been derived from a number of different data sources as follows.

5.2.1 Method 1: Quantification of Waste from Active Stripout Sites

This method aimed to quantify (by weight) waste streams from active stripout projects. A sample of 9 projects was studied. All data relates to Sydney CBD office building stripout projects. The emphasis of data gathering purposely focused upon prime grade office buildings (i.e. multi-storey office buildings in high lease cost locations) relating to tenants and their associated net lettable area (NLA) within the base building. The data was gathered according to quantification of the stripout waste streams including differentiation of landfill, recycling and reuse of waste materials (measured in tonnes). The data was drawn from contractors' auditing of waste streams using standardised methods of reporting including weighbridge documentation.

Projects were generally selected in terms of representing relatively normal (typical) stripout practices as perceived by the contractors involved. The opportunity also arose to obtain data from a more detailed project where specific effort went into reducing waste to landfill. Here, it is important to point out that the scope of work obviously changes from one project to the next, but in general, all projects were significant stripouts involving significant areas, and not just "box moves" or small miscellaneous works but back to base stripouts (including partitions, floor coverings, workstations, furniture, and ceilings).

Further, there were minor occasions where the scope of works occasionally included items unrelated to office fitout (e.g. excavated materials) and so the data was cleaned of these items in order to provide a more consistent and comparable findings.

5.2.2 Method 2: Qualification of Stripout Waste from Targeted Interviews

Semi-structured, face to face interviews were undertaken from November to December 2015, with companies directly involved in the stripout process. Interviews typically lasted approximately 60 minutes and utilised semi open questions about typical stripout processes, qualification of materials that went to landfill, reuse, and recycling. The questions aimed to understand the main business model, procurement and site processes used in undertaking stripout work. Participants included:

- Stripout contractors – where directors and senior managers of 6 of the main stripout companies servicing the Sydney CBD area were interviewed.
- Supply chain clients – where mid to senior managers of 2 leading fitout contractors, 2 large property owners, and 2 large property managers[6] were interviewed.

[6] Some property owners contract out property management services

5.3 Findings on Stripout Waste

5.3.1 Waste Quantification from Stripout Projects

Reading from Table 14, it can be seen that the quantitative data from stripouts relates to some 65,148m^2 of NLA and generated 4149 tonnes of waste. This equates to 63.7 tonnes per 1000m^2 of office area which closely matches the 63 tonnes per 1000 m^2 (Australia) and 62 tonnes per 1000m^2 (United Kingdom) mentioned earlier in the literature review section of this report. These findings are important insofar as the previously reported Australian data, was only based on a single case study (BBP 2015), and so these results not only support the previous study but in addition provide greater confidence in being able to generalise the results further (where applied to CBD office buildings).

Table 14: Key quantities of projects using traditional (normal) stripout waste management

No	Net lettable area	Waste generated (tonnes)	Reused (tonnes)	Recycled (tonnes)	Landfill (tonnes)	% reuse or recycling	Waste Generation kg / m²	Workstations and furniture included
1	23,400	774.4	-	399.4	375.020	51.6%	33.1	Yes. Included in mixed waste.
2	9,503	891.6	9.5	536.2	345.840	61.2%	93.8	Yes. Mentioned separately.
3	1,400	149.4	-	19.1	130.300	12.8%	106.7	Yes. Included in mixed waste.
4	5,130	462.8	-	135.5	333.8	28.9%	91.5	Yes. Included in mixed waste.
5	1,330	32.1	-	3.4	28.720	10.5%	24.1	Yes. Included in mixed waste.
6	1,330	34.7	-	8.2	26.580	23.5%	26.1	Yes. Included in mixed waste.
7	1,180	43.1	-	3.0	40.180	6.9%	36.6	Yes. Included in mixed waste.
8	18,875	1,660.6	28.1	334.3	1,298.22	21.8%	88.0	Yes. Some donated as well.
9	3,000	100.4	-	41.9	58.520	41.7%	33.5	Yes. Included in mixed waste.
Overall totals	**65,148**	**4,149.1**	**37.6**	**1481**	**2,637.18**	**36.60%**	**63.7**	

Drawing again on Table 14, it can be seen that the sample as a whole only averaged 36.6% of waste being directed towards reuse and recycling, whilst the far greater component of 63.4%, was sent to landfill. Of note, the best case scenario occurred in project 2 where stronger efforts were made to reduce waste landfill and resulted in an approximate reversal of the above, where 61.2% of waste was directed towards reuse and recycling, whilst only 38.8%, was sent to landfill.

The obvious question arising from this is simply, which materials were saved and which went to landfill. Based on the data in Table 15, it can be seen that by far the largest component of 54.13% was mixed waste, followed distantly by a number of separated waste streams for reuse and recycling processes including metals (19.13%), hard-core fill (8.89%), plasterboard (5.73%), workstations (4.71%), and miscellaneous wood (3.62%). However, these latter figures are not necessarily representative of the total amount of wood products in the stripout process. For instance, referring back to Table 14, it is apparent that workstations and furniture were largely included in the mixed waste stream and therefore the above 4.71% percentage is only reflective of workstations and furniture separated for reuse or recycling (as reflected in "donated" workstations and furniture), but not the entire amount of wood waste from the overall sample. Unfortunately, it must therefore be concluded that for this subgroup, the primary amount of workstations and furniture are part of mixed waste which most likely goes to landfill. Specific reasons for this are apparent from site observations and also the interview data discussed in more detail under the following heading.

Of additional note, the stripout figures reflects fitout practices that have taken place in the past, as distinct from the present. With the more recent proliferation of open plan office design (which implicitly means more workstations and more furniture) there will likely be larger amounts of wood panel products used in the future. With this, there will be greater pressure in acting on the above to divert wood panel products away from mixed waste and landfill.

A key issue therefore, is to make wood panel products easier to reuse and recycle.

Table 15: Materials breakdown

Waste Material Types	NLA (sqm)	Wastes (MT) per stream	Waste per stream as % of Total	Reused (MT)	Re-cycled Off-site (MT)	Landfill (MT)	% Reuse / Recycling	Waste Generation kg / sqm
Hard Fill - Concrete, Brick, Wall / Floor Tiles etc.	65,148.00	369.490	8.89%	-	369.490	-	100.00%	5.67
Ceiling Tiles	65,148.00	20.000	0.48%	-	-	20.000	0%	0.31
Glass	65,148.00	77.490	1.86%	-	77.490	-	100.00%	1.19
Wood	65,148.00	150.260	3.62%	-	0.760	149.500	0.51%	2.31
Plasterboard	65,148.00	238.260	5.73%	-	238.260	-	100.00%	3.66
Mixed Waste / Non-putrescible	65,148.00	2,249.510	54.13%	-	-	2,249.510	0%	34.53
Metal	65,148.00	794.860	19.13%	-	794.860	-	100.00%	12.20
Insulation	65,148.00	1.000	0.02%	1.000	-	-	100.00%	0.02
Electrical / Electronic / E-Waste	65,148.00	0.020	0.00%	-	0.020	-	100.00%	0.00
Carpet	65,148.00	39.080	0.94%	-	-	39.080	0%	0.60
Asbestos	65,148.00	19.880	0.48%	-	-	19.880	0%	0.31
Workstations / Furniture	65,148.00	195.740	4.71%	36.550	-	159.190	18.67%	3.00
Totals		**4,155.590**	**100.00%**	**37.550**	**1,480.880**	**2,637.160**	**36.54%**	**63.79**

Note: percentages for re-use/recycling represent the amount of a waste stream that went to a dedicated recycler. Other waste from this stream could have also gone to mixed waste. Further, as discussed under 5.3.3.3, the waste sent to recycling may result in an inderterminant amount, going to landfill as part of refinement and separation processes.

5.3.2 Themes from Interview Data

Insights about the methods, experience and attitudes of about stripouts provides greater depth of meaning to the previous quantitative data – especially in terms of the cost economics, work flow, and the logistics that apply during stripout processes. In many instances, contractors found that it is easiest and most cost effective for all but high value recyclables (e.g. metals), to go to landfill. They perceive that on many jobs, landfill is often in the range of 65-80% (note: this is broadly consistent with the previously presented quantitative data in Table 14). Even so, they also perceive that the motivation for greater reuse and recycling must come from their clients which could see the landfill proportion decrease considerably. For instance, reuse and recycling must at least be cost neutral relative to landfill, if decision making is left to them. Only by acknowledging where cost differences occur, is it possible to redesign fitout in a way that favours improved outcomes. Here, significant time, process and space constraints are imposed on the stripout process. Lost time on stripout equates to lost floor space rental revenues (for tenant or building owner) so time related liquidated damages clauses may be used to ensure speed in the stripout process. Unfortunately, this tends to become a primary barrier in waste reuse and recycling terms. Common themes from the interview data (supported by related site observations) which expand on the above, include:

- **There must be tangible value in reuse/recycling relative to landfill fees:** Most stripout contractors acknowledged that metals, glass and to some extent plasterboard are worth recycling if existing in sufficient critical mass (see below), and if separation and transport costs are cheaper than landfill costs. Of note, double handling during cartage of recyclables can be a problem to the cost economics of reuse and recycling. For instance, if recycling depots are not able to accept materials during non-office hours (which is when the work is mainly done) then cartage may become a two part process where bins need to be temporarily stored in a yard then taken to a recycler during normal business hours the next day. In contrast, mixed waste typically goes straight to landfill (potentially via a transfer station which may be conveniently close to the location of the stripout). Here, composite materials that cannot be easily separated into homogenous material groups, and materials that lack critical mass, typically go to landfill (including wood panel products). Other materials that lack recycling value such as ceiling tiles and carpet/underlay rolls often go to landfill (note: approximately 50% of carpet tiles may be recycled where tile manufacturers have a take back program).
- **The need for critical mass to facilitate economies of scale:** As alluded to above, there must be a large enough amount of a specific waste stream to make it worthwhile separating and sending waste to reuse or recycling depots. For instance, one contractor mentioned that projects in the order of 10 tonne or less generally have insufficient mass to substantiate source separation and so the entirety goes to landfill, as mixed waste. For higher value waste (such as metals and glass), some contractors build critical mass within their yard by aggregating small amounts from various sites until they have a full load which is then taken to the recycling depot.
- **Undertaking noisy work after hours ultimately incurs extra costs and influences how work processes take place**: Tenancy agreements in office buildings dictate that very little construction noise can be made during office hours e.g. grinding metal workstation legs into pieces, sawing plasterboard and table tops into pieces to fit in with the goods lift etc. Consequently, much work takes place after office hours and may incur overtime labour rates. The fact that work is done at night also impacts on work flow including goods lift

usage, loading zone usage and cartage processes (refer to items below for further details). There is potentially some advantage in being able to shift some work processes to normal office hours but only if this involves quiet work (existing items in this category include removing carpets, ceiling tiles and certain dismantling work) and results in overall cost and efficiency savings (refer to following item for details).

- **The necessity for coordinated process efficiency:** In terms of process, workers typically breakdown down assemblies (in place) into mixed or separated waste streams according to reuse/recyclability potential and according to the ability to effectively fill bins in a timely fashion (trolleys or wheeled bins of approximately 1m^3 capacity are commonly used).[7] Care in dismantling only takes place where high reuse value is readily achievable. Bins for each waste stream are typically stored in groups or conga lines at each floor level, near the goods lift, until there is sufficient to send the entire line down to the loading bay to create a full truck load. Lift time and truck time will be prioritised accordingly, to remove these waste streams, as detailed below:
    - **The necessity for unimpeded (after hours) access to the goods lift**: The goods lift is critical and central to the productivity of moving stripout materials from the work level to the loading bay – hence the need for working outside normal office hours. Each lift cycle should be fully laden and this dictates work flow. Carrying "air" in terms of carrying large volumetric items such as workstations, is not cost effective.
    - **Trucks need unimpeded (after hours) access to the loading bay**: As above, after hours work planning provides the appropriate requirements for trucks to occupy the loading bay (typically located in the basement) for extended periods. Loads may be taken to nearby transfer stations (open for long hours) or holding yards (near to the CBD) to facilitate fast shuttle times back to site, in order to coordinate with onsite processes. Long haul trips are avoided and can be costly e.g. driver, fuel, road time, traffic time and tip time. Even though the likes of close-by transfer stations tend to come at higher tipping costs, they may provide better process efficiency for the project overall. Truck loads must be fully laden in order to be cost effective (carrying volumetric items is avoided).
- **Realising the extra labour and practical problems associated with volumetric furniture and work station items:** As alluded to above, a consistent theme is the avoidance of salvaging slow and awkward volumetric assemblies (such as workstations) because the process is costly and does not return sufficient savings in reuse or recycling income. For instance, it is difficult to move such objects along corridors, into goods lifts and then into trucks. Lift efficiency drops significantly and cartage is expensive. All aspects of the above processes are slowed by virtue of the need for care so as not to damage and devalue the items being recovered. This tends to mean that for workstations, the high value metal chassis is typically removed for recycling whilst the wood benchtop (typically MDF with difficult to recycle overlying laminate finishes) is cut into small panels to fit into mixed waste bins for cartage offsite.
- **The cost of storage, administration and marketing for resale of items:** Materials targeted for reuse (e.g. workstations) often involve the need for temporary storage followed by the subsequent need for administration, marketing and sales costs, associated with reselling the salvaged products/materials. These costs often make it not worthwhile going down this

[7] In a limited number of instances there may be temporary storage in the carpark for skips that can be picked up later by trucks.

pathway. A potential remedy that is not necessarily available on many projects, involves selling direct from the site where the stripout is taking place or gifting the likes of workstations to non-profit organisations.

- **Tenants often do not want to get involved in organising stripout, so they negotiate a financial arrangement with the building owner to take care of it:** Importantly, this means that the building owner may develop may long term relationships with stripout contractors, thus enabling the establishment of improved procedures for reuse and recycling processes, which in turn foster markets for sustainable reuse and recycling markets.

Given the above, any redesign of wood based workstations and furniture for improved reuse and recycling, must fit in with the above conditions and processes in order to be successful. Of specific note, the following appear important: increasing critical mass, simple site separation, flat or compressed handling of materials, making handling a quiet process, and homogenous materials as distinct from composite materials that are hard to recycle.

5.3.3 Others Involved in the Reuse and Recycling Chain

5.3.3.1 The Perspective of Sustainable Office Furniture Specialists

Apart from stripout companies and in response to the increasing growth in open plan design, one of the fitout companies interviewed specialised in a sustainable office furniture driven approach. Office Spectrum (http://officespectrum.com.au/) focuses on minimising the carbon footprint of companies by removing, repurposing and retro-fitting office furniture including workstations, screens and partitions. They can seamlessly remove, upgrading and repurposing existing workstations in a way that provides overall cost savings and minimises workplace disruption. Of note, the company has an Environmental Management System (EMS) in place and is ISO 14001 certified. They also have Good Environmental Choice Australia (GECA) licences for all of their workstations and a GECA licence for eco-refurbished workstations and furniture. Their emphasis on supplying eco-refurbished workstations and furniture can be instrumental in achieving the likes of 5 and 6 star ratings under the Green Building Council's "interiors" program.

Within this context, the company purchases used workstations from stripouts where able to repurpose them and on sell them, or where able to blend the parts with their own workstation systems. Some important points that they use to attain the above include:

- The furniture should be designed in a way that allows the benchtop to be easily separated from the rest of the assembly. For instance, this can become a site replaceable item (for each fitout churn) and is especially possible where the support chassis is less effected by wear and tear, changes less with fashion, and are less seen by users.
- There is the need to be able to flat pack and store furniture both during stripout processes and then for keeping parts in stock during repurposing processes.
- Being able to resurface workstations and other furniture quickly and effectively is useful, but uncommon under common design approaches.
- There is a need to notionally separate "front-of-house" and "back-of-house" office furniture. There is much greater potential to use repurposed furniture in back-of-house areas
- There is a significant need to design systems that have minimal different parts, simple parts and readily available parts. This also facilitates the reconfigurability of workstations.
- Clients are worried about the quality control factor concerning reused/recycled materials i.e. will it look like new or will it have scratches everywhere?

- Interior designers want to use things that are continually different, otherwise their client will think they are not providing a value-add to the design process. Allowing some degree of customisation at each reuse is therefore potentially a good approach.
- Surface mounted hardware that does not require machining into the partition/furniture/door blank improves the potential for reuse.

5.3.3.2 Donated Office Furniture for Repurposing

Companies such as Good360 (http://good360.org.au/) are an example of a not-for-profit enterprise who redistribute donated fitout to charities and similar organisations. They primarily manage the logistics and broker an arrangement with the building owner, whereby office furniture is gifted to the charity. This enables the owner of to execute a tax write-off for any remaining value left on that furniture. Their approach ostensibly saves tenants (and building owners) the cost of landfill fees arising from the office stripout process. It requires organisation and implementation of a dedicated pickup location within the property – usually at the very beginning of the stripout process – where transport contractors can pick up the donated furniture. Project management and logistics skills are central to their operational needs. Timing is crucial and whilst building owners want to help, there are still problems in terms of time constraints, make good constraints, and working in a coordinated way with the stripout contractor. There is also a problem in matching the supply of furniture from a given property, with what is needed by the charities they service. There is often an imbalance and often an oversupply of furniture that cannot be met by their demand base.

5.3.3.3 Strategic Thinking about Closed Loop Recovery

Large office property owners such as GPT are gradually moving towards closed loop recovery (meaning the same resources can be used over and over again in the same product line). In this context, lesser concepts such as "down-cycling" and one-off "reuse" have the problem where end of life outcomes are less clear, and may only temporarily divert waste from landfill. With this in mind, companies such as GPT are actively shifting from inputs-based (waste at the point of disposal) to outcomes-based reporting (follows the waste all the way to its end destination) (Ford 2014). This latter approach effectively shifts the boundaries of how waste data is being reported.

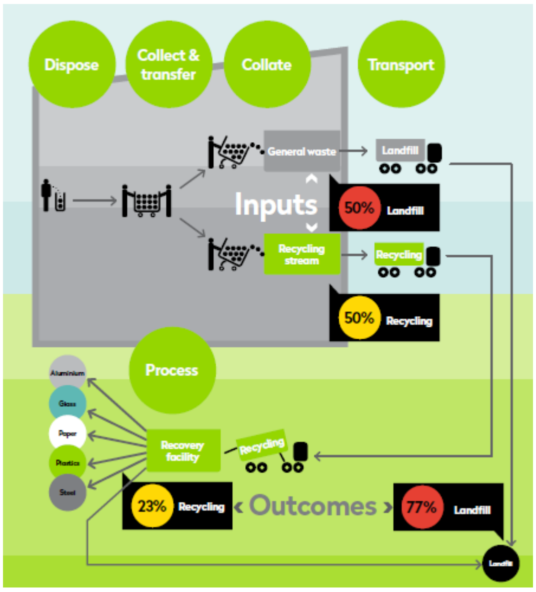

Figure 4: Taking the Rubbish Out of Recycling Data (Ford 2014, p. 77)

Their internal review processes indicate that much of the input-based reporting does not give a true indication of outcome results, hence their reason to change towards a closed loop approach. For instance the example in Figure 4 shows that reported recycling (based on input data) drops from 50% to 23% (based on output data). This can occur for many reasons but an obvious problem is that contaminated materials cannot be fully recycled and subsequently have a high likelihood of a certain proportion ending up at landfill as distinct from being recycled. Another problem is that waste reporting methods are usually according to waste material type which often doesn't describe the outcome of the process and so progress against closed loop objectives are not normally reported (Ford 2014). Ford (2014) states that outcomes-based reporting accurately tracks and categorises information about the destination of disposed items. Of note, he identifies three grading outcomes as follows:

- A-grade – Meets the closed loop objectives; may be used over and over again, constantly being returned to the same production cycle, and; can be recovered without any consequent hazardous material build-up in the environment.
- B-grade – Downcycled to a lower value product; have a limited number of recovery cycles, and; produce valueless by-products after several recycling cycles.
- C-grade – Recovered products are those which are produced in a waste diversion process but are only available for a single additional application.

The report identifies that it is difficult to understand the true outcome of a waste stream if it is mixed with a variety of items (Ford 2014). Subsequently, any reconceptualisation of wood office fitout should consider the need for easy site separation and the avoidance of wood being included in mixed waste. For instance this could be achieved by fitout purposely designed for disassembly. In addition, the above approach flags the need for using more homogeneous materials.

5.4 Conclusions about Waste from Office Stripout

Approximately 65% of office waste typically goes to landfill, most being mixed waste and often including wood products from workstations and other furniture in the mixed wastes stream. A key part of the problem for wood is the volumetric nature of furniture which makes it expensive and impractical to handle, transport and store; it is also difficult to either reuse, convert to recycling products or utilise in resource recovery scenarios. Wood is also a relatively small quantity (in weight terms) which provides insufficient critical mass to justify dedicated reuse/recycling streams. Even so, as Green Star certification, green leasing, BBP contract clauses and similar sustainability measures gather in momentum, there will be increasing pressure on the fitout and stripout sectors to provide less wasteful solutions that conform to score-able criteria such as the Green Star “interiors” tool. With appropriate design with reuse and recycling mind, there is potential for wood to fair well under such scoring systems.

Subsequently, wood needs to be an underpinning material in fitout that concurrently refines its potential for reuse and recycling markets. It is concluded that in terms of strategic design criteria (coupled with findings from the previous lease and fitout churn study), concepts need to include:

Materiality and Configurability

- Incorporating more wood in fitouts to create sufficient critical mass for reuse and recycling practices to develop.
- Designing for reuse and recycling at the beginning of the fitout process.
- Using a relatively homogenous palette of materials.
- Using a minimal kit of parts.
- Developing multipurpose scalable components.
- Designing for reconfigurability to extend reuse options.
- Developing assemblies that allow incorporation of services (e.g. cabling).

Deconstructability

- Ensuring fast knockdown from volumetric to flat and stackable.
- Avoiding special dismantling tools.
- Ensuring compact stacking to optimise goods lift usage and efficient truck cartage.
- Ensuring wood panels and workstation tops are easily separated from the support frames beneath.
- Creating quiet deconstruction methods to allow more work during normal office hours.

Critical Handling

- Ensuring fast stripout that ensures flow from breakdown-to-lift, lift-to-truck, and truck-to-depot.

Changes in Fitout Style and Scope

- Open plan offices are becoming the norm and allow greater utilisation of a furniture based design approach.
- Broadening wood based tender packages to compress and simplify the supply chain.

Of note, these criteria have been actively used in the design concepts that follow.

6 Part 3: Office Fitout Design Concepts

This section presents design concepts that respond to the previous research findings whilst concurrently meeting other normal fitout design needs. The concepts are shown in summary here but are presented in more detail in a dedicated Design Guide – "Reimagining Wood Based Office Fitout Systems – Design Criteria and Design Concepts" (Forsythe et al. 2017). The Design Guide should be read in parallel with this document in order to provide full context. The main focus in the design process was on key fitout items that constitute the major proportion of fitout works/costs including: partitions, workstations, ceiling tiles for suspended ceilings, and furniture (including shelf, storage units, pedestals and miscellaneous tables). An overview is provided in Figure 5. Each is dealt with in more detail under the following subheadings.

Figure 5: Key office fitout product areas

6.1 Wood Partition Walls – A Modular Hollow Core System

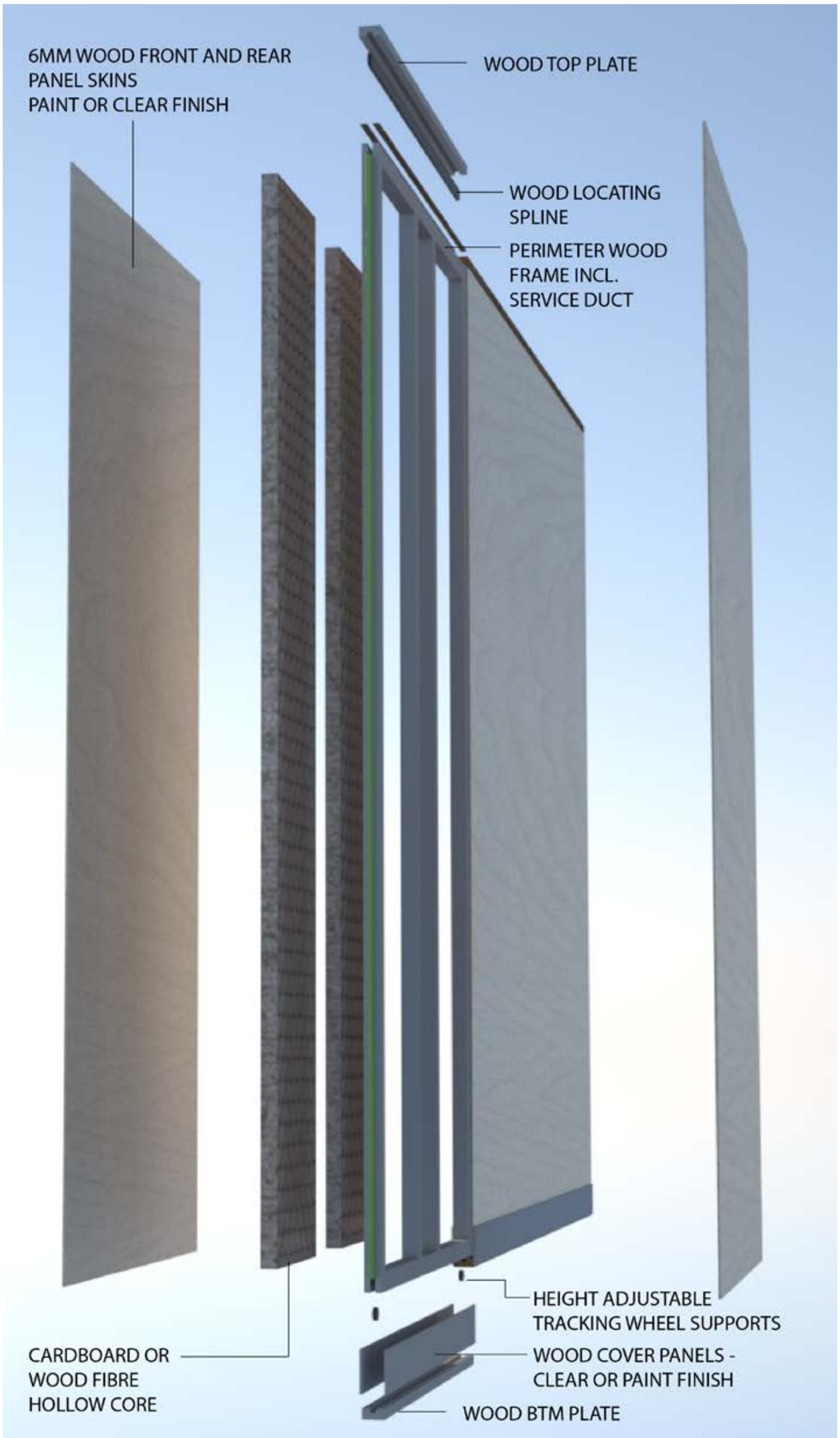

Figure 6: Wood partition panel concept, UTS 2016

The concept for a new wood based partitioning system (refer to Figure 6 and Figure 7) was a response to the past reliance on multiple materials and trades to construct steel stud and plasterboard partition systems. The new approach compresses this requirement by introducing a hollow core, modular, wood panel – similar to hollow core door technology. It is designed so that it can be used interchangeably as wall partitions, workstation partitions or workstation benchtops and does not require permanent structures or walls to be demolished at each churn in fitout. Whilst the outer skins for such panels can be pitched at competing with common plasterboard finishes using the likes of hardboard, this system also lends itself to higher grade finishes such as plywoods with high end decorative veneers, for higher specification situations. Some key features include:

- It is simple to install/deconstruct and is able to be reused without depending on multiple trades.
- It utilises a homogenous wood oriented material palette to improve reuse and recycling consisting of wood skins, wood frame, minimal (starch based) glue and expanded cardboard filling.
- It aims to leverage existing manufacturing businesses – primarily the door manufacturing industry discussed further below.
- The above system does not rely on a lengthy construction process and is flexibly respondent by the nature of its materials and construction technology.

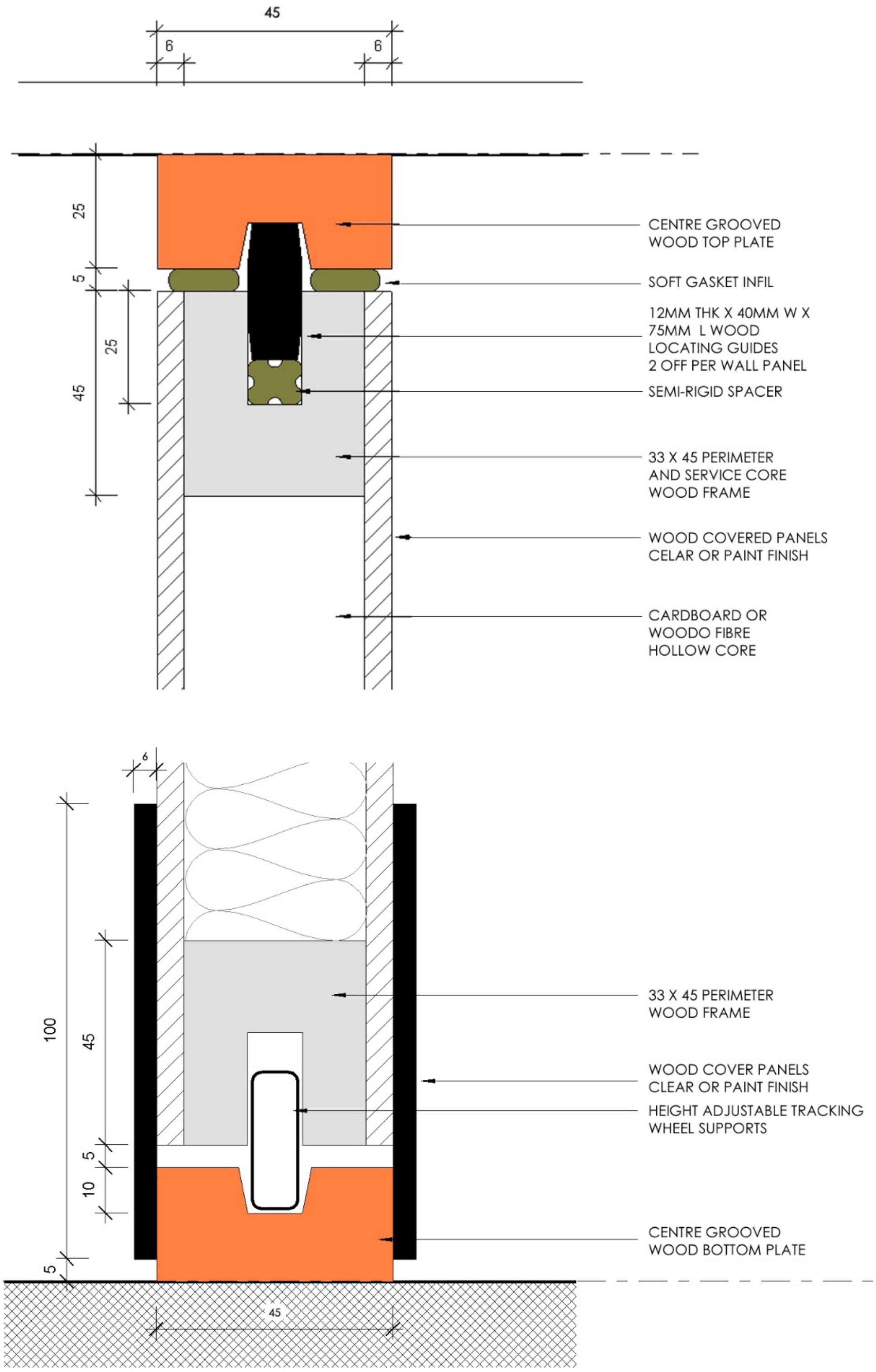

Figure 7: Section showing key materials for hollow core partition system

Figure 8: Example of shared use of hollow core panels for workstation tops and partition walls

Figure 9: Concept workstation model

6.2 Workstations Using a Reconfigurable Kit of Parts

The design driver for the workstation (refer to Figure 8 and Figure 9) was to afford the owner quick disassembly and reassembly without the need for specialist tools or trades people by utilising an interchangeable kit of parts and a homogenous material palette.

Most workstations are constructed of an array of materials bought together to function as a work surface with some privacy. Steel, MDF, laminates, glues, rubber, and fabric form a common material palette of a workstation. These materials serve a role but can generally be seen as a hierarchy of material from steel as support, MDF/laminate as working surface, rubber as protective material, and fabric as image (colour). Whilst there is a slim chance that the workstation would be relocated/reused at the end of its life, it is more likely that the combination of all these materials collectively render the system obsolete, regardless of it quality, resulting in the cost of the repurposing of a workstation being higher than the cost of its landfill disposal.

The design driver for this workstation was therefore to reduce the workstation to structural and functional necessity with corresponding material application.

Finally, having a whole life means that the designers considered the full extent of the life of the workstation from the time it is considered on the plan, through the changes in business activity during its use, through to the time the stripout team is assessing how they will shift a fitout from a tenancy, and beyond to alternative wood based reuses. To do this, the design focused on structure and surface as follows:

- The working surface adopts the hollow core panel manufacture discussed previously (including the previously stated options for aesthetics and customisation).
- A fresh approach to structure is taken via the use of simple wooden dowels (typically 25mm dia.) coupled with 3D printed joiner sleeves which collectively make a simple space frame to support the working surface.

6.3 Furniture Using Open Source Designs

The UTS designers looked towards general loose furniture and storage to supplement the main fitout items above. The focus was on back-of-house applications which represented the main opportunity for increased use of wood products. Here, it was realised that general office furniture and storage lends itself to higher volume repetition as it applies across the tenancy and is closely related in function and size to workstations. Preference was given to Computer Numeric Cutting (CNC) methods that make use of digital files to allow automated cutting. Slot and tab designs mean that there is very little need for other parts or components – even door hinges can be machined into the wood base design which keeps things very simple for both assembly and disassembly.

Designs for loose furniture and storage were found as open source files on the internet. One company in particular, operate as an online studio for individual furniture designers working with wood panel products and CNC routing. Open Desk (2016a; 2016b; 2016c) has open source files that have been incorporated into this project (https://www.opendesk.cc/). These designs were also converted as part of this project, into parametric files so that the furniture could become scalable in size to meet a much wider multitude of needs that could be utilised by individual fitout designers. Designs included shelving, pedestal units and miscellaneous tables. All were cut from 12mm plywood.

Figure 10: CNC made furniture by UTS using Open Desk designs (Finn Lockers; Half Sheet Table; Zero Pedestal)

6.4 Ceiling Tiles and Existing Products

Further to the above, it was evident that certain already existing, off-the-shelf wood products, complimented and added to the above design concepts. This primarily concerned ceiling tiles, as used in suspended ceiling applications.

Many office ceiling tiles are predominately mineral fibre products that are imported from China or the USA. They are a cheap surface that offers good acoustic performance. Plywood products (e.g. 12mm plywood with acoustic backing fabric) have potential as an alternative and should be considered where resilience, aesthetics and potential reuse capacity come into play or where ceiling tiles provided as part of the base building, remain in place from one tenant to the next.[8]

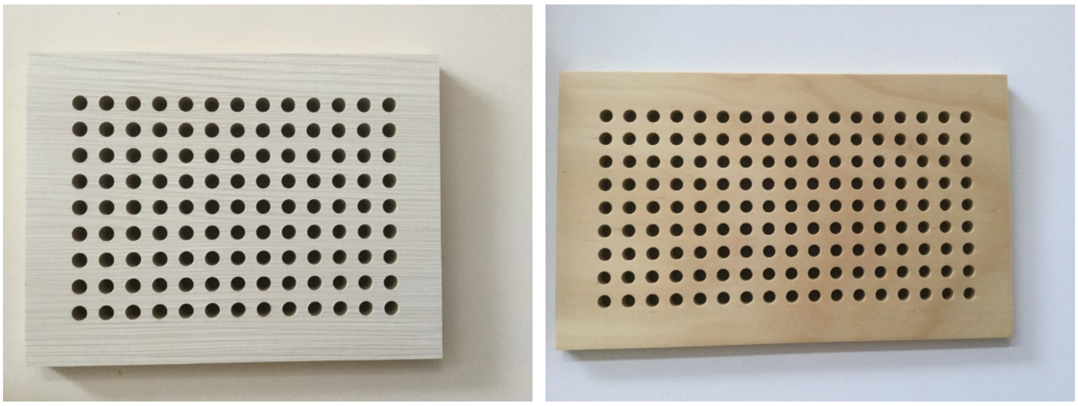

Figure 11: Ceiling tile example (Keystone Acoustics)

[8] UTS manufactured their own standard 1195x595mm ceiling tiles from 9mm hardboard. Whilst this material exhibits good recyclability potential – due to using natural lignin as a binder instead of glue – machining properties need to be improved as machining of slots and holes tends to result in furry edge.

7 Part 4: Life Cycle Assessment Comparison of Wood Design Concepts with Traditional Office Construction

The above wood based design concepts were used as a basis for comparison with traditional office fitout as discussed and dealt with under the following headings.

7.1 Life Cycle Assessment Literature

The most appropriate and accepted method used to produce a holistic assessment of the environmental impacts associated with a product is Life Cycle Assessment (LCA) (Cole 1998; Junnila, Horvath & Guggemos 2006; Horne, Grant & Verghese 2009). Cole (1998) states that LCA is the only legitimate basis on which to compare alternative materials, components and services in buildings.

LCA originated in 1969 when Coca Cola conducted the first LCA study to compare the difference between using plastic and glass bottles (Arup 2007). The reasons for the development of LCA were associated with the generation of waste and the depletion of non-renewable resources and energy supply (Klopffer & Grahl 2014). It was not until the late 1980s and early 1990s that LCA models began a process of standardisation and developed the first ISO 14040 series to standardise the guidelines and principles on the LCA methodology (SETAC 1993).

Lei, Zhifeng and Fung (2003) describe LCA as a quantitative method used to assess the environmental burdens of products or systems over their entire life cycle. LCA models are used to measure the total impact of a product on the environment from when the raw materials are extracted all the way through to when the product or system is disposed to landfill (Xing, Xu & Jun 2008; Singh et al. 2011). All the processes of a product or service that compose a product system make up its life cycle and can, therefore, be compared to other product systems that perform an equivalent function but more environmentally friendly (SETAC 1993).

Lei, Zhifeng and Fung (2003) state that LCA studies have numerous useful applications in providing data and information associated with the burden that products have on the environment and potentially have the ability to implement a trade-off analysis to achieve a genuine reduction in overall environmental impacts, rather than just a simple shift of impact (Puettmann & Wilson 2005; Page 2006). LCAs are also used by manufacturers to work out ways to make their production processes more efficient as well as guiding suppliers of inputs for their products to act in a more environmentally sustainable way.

Challenges associated with LCAs for buildings are that they contain a number of stages and each of these stages has a number of variable inputs including material suppliers, manufacturing processes, delivery modes, energy suppliers, maintenance and demolition stages (Lee, Tae & Shin 2009). In addition to these challenges specific to construction, there are also limitations such as unknown system boundaries, imperfect data, adaptability issues and high costs (Lei, Zhifeng & Fung 2003). As there are many different LCA models available, they are each prone to particular challenges so the method should be chosen to suit the product or system environment (Lee, Tae & Shin 2009).

7.2 Life Cycle Assessment Research Method

LCA has been applied to assess environment impacts of products, systems and buildings but there has not been any study on office fitout to examine environment impacts (i.e. in the use of materials in fitout projects). The LCA study in this project is the first of its kind. Assessing environmental impacts of fitout project follows a similar approach to many products, but the end of life stage is different. Office fitout will not only end when the building comes to an end of its useful life but may also end at the end of a lease agreement when a fitout churn occurs. As discussed in the previous sections a common lease period is approximately 5 to 8.9 years with an option to renew the lease for another term. As discussed previously, at the end of the lease, if no renewal occurs, there will need for it to be stripped out. When a new tenant moves in, the office fitout cycle will start again.

To avoid unnecessary subjectivity around the product boundaries required of an LCA study, the boundary will be based on “cradle-to-grave”, which means that all the waste will be disposed of at the end of the lease. This is primarily assumed because of the complexity and uncertainty in calculating the reprocessing resources and energy inputs required, where materials are sent to different and largely unknown locations for reuse and recycling. Therefore in order to retain simplicity, no reuse or recycling is considered in the LCA study for either the wood based or traditional approach to office fitout.

In addition, during the tenancy period, office fitout may be changed or modified as a result of business expansion, maintenance need or change of government regulations. The extent and frequency of this is hard to ascertain with certainty and therefore this part of the study has been undertaken using different scenarios, as dealt with in Section 7.3.3 below.

In general, conducting an LCA study on office fitout is more complex than an LCA study on other products, systems or buildings as there is a high uncertainty on understanding the intent of tenants and their business models, and when and what will trigger the fitout churn. The research in this study has been developed to fill the gap in the research area.

7.2.1 System Analysis

As mentioned, the research adopts the LCA methodological approach to assess the environmental impact of wood versus traditional office fitout in commercial buildings. Today’s environmental performance not only refers to the final product but the entire value chain along with a product as developed, manufactured, delivered, used and retired.

The system boundary applied in the study was cradle-to-grave, which means that the impacts of the raw material extraction, the manufacture of building products, their transport, the construction phase, and the final disposal of the product after its useful life were considered. The operating phase is not included in the study as energy consumption and emissions are less related to operating energy for fitout construction projects. For instance, unlike other product systems, which consume considerable amounts of energy and process materials during their use phase, office fitout and furniture products do not depend on these kind of inputs in order to fulfil their intended functions. Further, the short life span of office fitout means it is unlikely that these materials will require replacement during the lease period. As such, impacts related to operating activities are not evaluated in the study. Figure 12 presents the system boundary for the project.

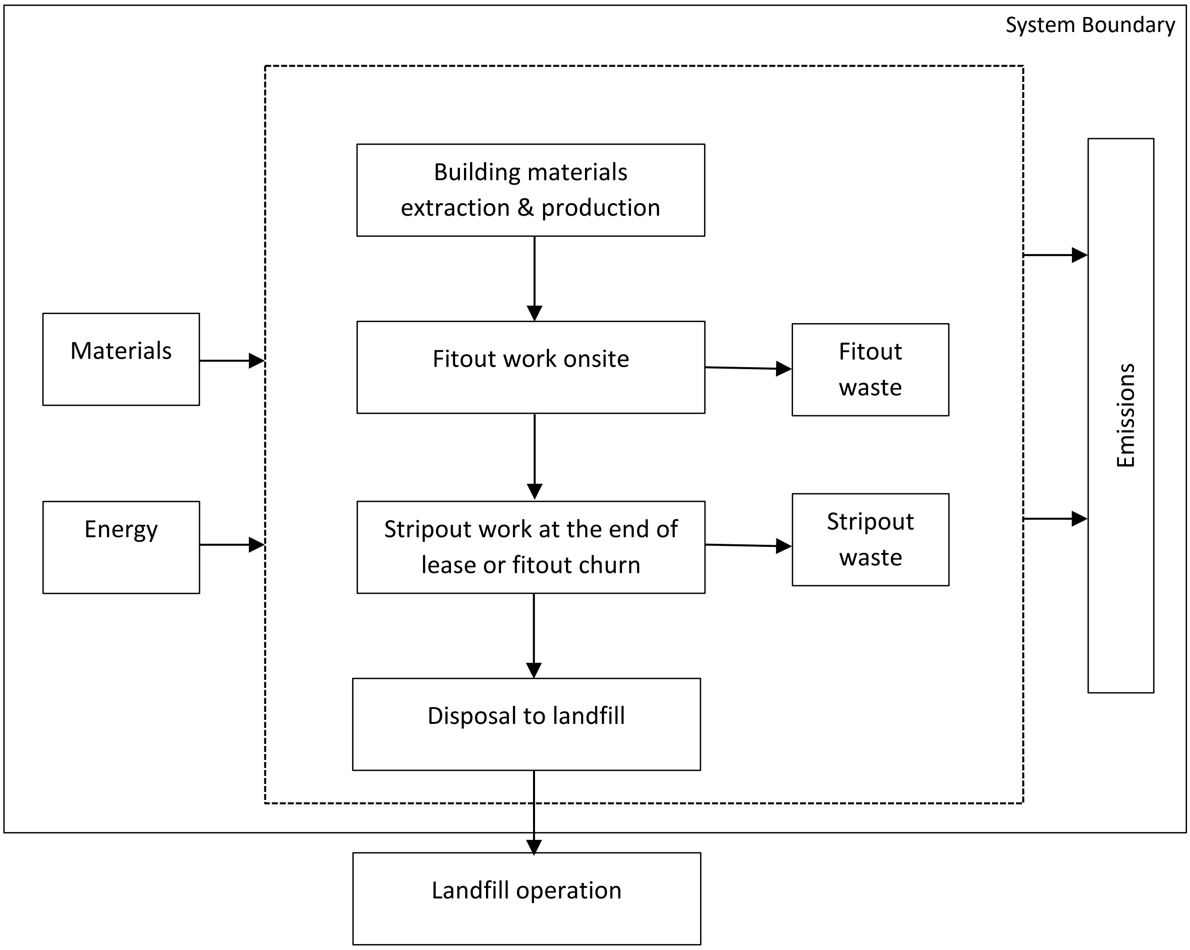

Figure 12: The system boundary for the study

The main objective of the study was to assess the environmental impact of office fitout and LCA as used to assess the inputs of resources in a unit process and to determine the outputs to the environment. The project focused specifically on the material and energy flows, and Global Warming Potential (GWP) as the main issues that were measured in the project. In addition to focusing on quantifying life cycle energy consumption in terms of material and energy flows, GWP was also a key item measured from the project sample. GWP is commonly used to illustrate the climatic impact of different gases. The Intergovernmental Panel on Climate Change (IPCC) characterisation factors are commonly used to assess the relative impact of different GHGs contributing to the problem of climate change. Generally, carbon dioxide (CO_2) is adopted as the reference standard for GHG effects (IPCC 2006).

The GWP value was used to convert different types of gases into a carbon dioxide equivalent ($CO_{2\text{-}e}$) for a 100-year time horizon. The metrics used for the assessment of GWP have been expressed in the unit of kilograms of carbon dioxide equivalents per function unit ($kgCO_{2\text{-}e}$). GHG was calculated purely with reference to CO_2, methane (CH_4) and nitrous oxide (N_2O) because the remainder are seldom emitted in the construction process (Cole 1998). The GWP values for CO_2, CH_4 and N_2O are 1, 25 and 298 respectively (IPCC 2006).

The study was undertaken in accordance with the ISO 14040/44 and subsequently includes all upstream and downstream emissions and wastes in office fitout activities. In this context the functional unit for the study was set to the whole fitout office space in an existing office building which acts as a reference point to measure performance of the functional outputs of the product system. Therefore the system investigated was limited to fitout activities for office buildings in Sydney, Australia (note: this excludes the building structure and finishes to the base building, and modification to existing engineering services to the fitout spaces). Therefore an investigation was conducted to collect data on the design and material quantities for office fitouts including finishes to wall, floor and ceiling, partitioning (internal wall), doors, and office furniture.

Once materials and energy were determined, a list of environmental profiles associated with each unit process was established using the LCI database from GaBi (www.gabi-software.com/australia/databases/us-lci-database) and eTool (www.etoolglobal.com). In addition, and as appropriate, other government published literature was also used e.g. IPCC (2006), DCCE (2010) and DEH (2006a & 2006b) publications.

For the purpose of undertaking the analysis the impact categories were determined to best represent issues relating to office fitout activities. The life cycle energy consumption and GHG emissions were quantified on a cradle-to-grave approach on the following basis:

- Initial embodied energy and associated GHG emissions for all the processes and materials pertaining to fitout projects were calculated and multiplied with the energy intensity and GHG emission factors. Initial embodied energy is defined as the total energy used to produce building materials, including extracting and then transporting raw materials to factories and then the finished products to the site, and the onsite operation energy (Treloar 1997).
- Energy consumption and associated GHG emissions for fuel combustion from transportation of materials to sites and disposal of construction and demolition waste to landfill in relation to lease or fitout churn.
- Maintenance and replacement as likely to be required during the operating phase. However there is virtually no maintenance or replacement required as the life span of most materials used in office fitout have a longer life span than the lease or churn period. Therefore during the operating phase only minor cleaning or repair may be required which are considered insignificant in the study and therefore they are excluded from the study.
- At the end of life stage, which is equivalent to the lease or fitout churn, whole or part of the office fitout are to be demolished and disposed to landfill. There is potential recycling opportunity for the fitout materials but the nature of what the reprocessing path, including the next life cycle of these materials, is uncertain. Therefore the study boundary has been kept to the cradle-to-grave and leaving the potential reuse and recycling to further research.

In addition there are no major plants or equipment involved in office fitout activities. Small tools are excluded from the study, as they are insignificant compared to heavy machinery and fuel for plant and equipment. Human energy consumption is also excluded due to inadequate data to calculate the energy intake of particular trade people. Transport of workers to and from the site is also excluded, as information for particular individual workers such as distance to work and the types of vehicle used was beyond the scope of this study.

7.2.2 Data Collection

Pre-tender estimate reports of 36 office fitout projects were collected from consulting companies specialising in office fitout in Sydney, NSW. These projects represented recently completed fitout projects situated either in Grade A or Premium buildings. A screening process was developed in examining each project in terms of size (nett lettable area – NLA), nature of work, location and tenant type. This screening process identified twenty projects located in the Sydney CBD of various sizes and tenant types to reflect the different nature and details of fitout activities.

The twenty projects were classified into three groups in accordance with the BBP survey categories: large (NLA >5,000m^2), medium (NLA 1,000 - 5,000m^2) and small (NLA <1,000m^2). The twenty case studies of fitout projects included three large tenants, five medium tenants and twelve small tenants. Table 16 summarises details of these projects. From the table these projects include two tenants from the public sector and eighteen tenants from the private sector.

Table 16: Summary of LCA projects

Project ID	NLA (m^2)	Contract Sum ($)	$/m^2 (NLA)	Office Tenant Type
Large (NLA >5,000m^2)				
1	5,010	11,726,210	2,350	Bank
2	5,474	8,496,576	1,552	Local council
3	10,342	20,277,532	1,961	Utility Company
Medium (NLA 1,000 - 5,000m^2)				
4	1,027	467,000	455	Property
5	1,750	920,000	526	Superannuation
6	2,649	4,225,000	1,595	Local council
7	3,034	2,402,000	792	Commercial
8	3,459	3,305,000	955	Commercial
Small (NLA <1,000m^2)				
9	323	288,000	892	Property
10	361	302,000	837	Property
11	417	333,000	799	Investment
12	450	343,001	762	Engineering
13	533	408,500	766	Property
14	620	550,000	887	Mortgage
15	630	640,000	1,016	Recruitment
16	640	454,500	710	Commercial
17	650	149,000	229	Commercial
18	655	612,000	934	Consultant
19	665	695,000	1,045	Construction
20	727	433,000	596	IT

Pre-tender estimate reports were received for all the projects and simple floor plans for some projects were provided. However no construction drawings and detail floor plans were available for examination at the time of the research. The pre-tender estimate reports were presented in an industry standard cost plan format which includes a description of each item, unit and quantity. Therefore the initial task was to convert these pre-tender estimates into a spreadsheet format so that an inventory dataset for the LCA study could be established for each project.

A life cycle inventory analysis was undertaken to quantify relevant inputs and outputs of the study. These inputs and outputs include resources and releases to air, water and land associated with the system. Interpretations may be drawn from these data and the data also constitutes the input to the life cycle impact assessment (ISO 2006). The study included collecting data with regards to materials used for fitout of each office space and fuel consumption for transporting materials to sites and disposing waste to landfill.

Data quality requirements were driven by the needs of the study. Some specific aspects relation to the study and prompted by ISO 14040 include:

- Time-related coverage – projects used in the study were completed office fitout projects in the last four years;
- Geographical coverage – projects used in the study were located in the Sydney CBD;
- Technology coverage – projects reflect traditional office fitout design and construction;
- Consistency and reproducibility of the methods used throughout the LCA – The methods used in the study are in accordance with the ISO 14040/44 which are realistically consistent and repeatable;
- Source of data and their representativeness – the data gathered for the study is thought to be representative of a small sample of projects that were available at the time of the study only; and
- Precision, completeness and representativeness of the data – the data is only representative of small sample sets which are limited to office fitout projects in the Sydney CBD region.

To estimate the work in respect to resources and energy required for office fitout activities the quantities of all materials used in fitout construction were analysed from the pre-tender estimate reports and categorised into industry standard building element format relevant to office fitout projects which includes internal walls (partitioning), floor finishes, wall finishes, ceiling finishes and furniture. A summary of various materials used by weight for the office fitout projects is presented in Table 17. The construction process of fitout projects is different from the construction process of new buildings as the building structure and base building finishes are not involved. For fitout activities the outgoing tenants will normally be responsible for reinstating the office space as the pre-lease condition. Therefore the construction process of fitout projects include the following fitout and stripout cycle:

- Construction of partitioning (internal wall) to form cellular office layout to suit business needs;
- Relaying finishes to floor e.g. carpet, vinyl or tiles, repainting/re-tiling to wall, replacing suspended ceiling e.g. plasterboard or aluminium framed;
- Relaying office furniture to suit business activities;
- Demolishing office fitout and deposing to landfill at the end of the lease or fitout churn; and
- Fuel consumption from transportation of materials to sites and disposal of waste to landfill.

Engineering services are normally modified to suit the cellular office layout in providing ventilation, heating and cooling to offices. The higher the cellular the layout the higher will be the modification. The modification of engineering services are not commonly detail designed at the pre-tender stage and therefore a lump sum allowance is commonly used to allow for the expenses of engineering services. Modification of engineering services is hard to determine as details will only be revealed when wall and ceiling coverings are removed. Detail works are usually developed when the fitout work starts on site. No drawings or other details with regards to the modification of engineering services were received and they, therefore, are excluded from the study. In addition small tools are excluded for the study as they are insignificant. Human energy consumption is also excluded due to inadequate data to calculate the energy intake of particular trade people. Transport of workers is also excluded as information for particular individual workers such as distance for him to work and the types of vehicles used was beyond the scope of this study.

From Table 17, glass (45%) and plasterboard (29%) are the two most commonly used materials in the fitout projects, representing a total of 74% of the total mass of material used and followed by wood (8%) and steel (6%). The layout of these fitout projects is mainly cellular (observed from some floor plans received and from the ratio of internal wall to NLA analysis detailed in Table 23) which means that more internal partitioning and associated finishes and doors are required. This is reflected in the high use of glass and plasterboard in Table 17. In addition, none of the projects in the sample applied for Green Star "interiors" assessment.

These projects used a traditional approach in the design of office fitout. Internal walls/partitions were constructed out of metal stud and plasterboard for general office areas and aluminium framed glazed partitions for meeting rooms or offices for senior management. Wall finishes were paint to plasterboard linings and ceramic tiles to wet areas. Floor finishes were carpet (with underlay) to general office and meeting areas, and vinyl or tiles to utility rooms such as kitchens and toilets. Suspended ceilings were either in plasterboard with paint finish or perforated aluminium panel to targeted office areas. Engineering services were modified to suit the cellular office layout in providing ventilation, heating and cooling to offices.

Fixed and loose office furniture were included e.g. purpose made reception counters, lockers, shelving, mail room joinery and so forth. They were intentionally designed to suit the usage and the purpose of business for individual organisation. After analysing these cases there was no commonality identified in the fixed furniture in the sample projects. Loose furniture was more repetitious and included workstations, chairs and pedestals as common types of office furniture used across the twenty case studies.

Table 17: Summary of material use for the case study projects

Project ID	Glass	Plbd	Fibre cement	Wood	Cement	Sand	Steel	Alum	Carpet & underlay	Vinyl	Tile	Stone	Waterpf	Insul	Paint	Total
Large size (NLA >5,000m²)																
1	140,770	33,340		1,520	17,480	8,390	2,740	1,040	3,140		2,310	2,410		370	1,280	214,790
2	153,600	63,050		109,260			5,310	1,130	660	6,760				5,850	1,810	347,430
3	37,410	179,270	4,120	22,010	2,090	1,100	47,470	8,950	9,160	9,440	13,850	11,240		10,440	2,060	358,610
Medium size (NLA 1,000-5,000m²)																
4	8,430	9,710		1,110			2,260	130	1,740	950	180			620	300	25,430
5	28,100	19,730		700			4,350	390	3,400	490				1,160	570	58,890
6	38,900	53,450		2,260			13,350	210	5,150		4,420		670	3,550	920	122,880
7	101,930	37,880		1,110			6,660	180	5,730		2,760		70	1,670	440	158,430
8	118,820	36,300		1,810	5,700	2,740	3,560	490	240	2,940		13,140		110	710	186,560
Small size (NLA <1,000m²)																
9	13,200	4,280		890			980	130	590	40				240	140	20,490
10	12,360	4,680		550			360	120	680	170				260	140	19,320
11	14,160	7,100		570			1,420	180	810	80				350	210	24,880
12	19,100	4,960		1,190			1,200	200	900	160				280	160	28,150
13	20,780	6,710		370			1,500	190	1,040	80				370	200	31,240
14	16,730	7,070		360			1,570	170	970					360	100	27,330
15	28,380	7,560		440			1,500	270	1,120	250				400	220	40,140
16	11,780	6,940		660			1,570	180	1,060	340				370	210	23,110
17	9,390	3,480		50			890	80	1,300					260	110	15,560
18	6,920	6,320		320			1,520	70	1,100	570				390	190	17,400
19	22,780	10,730		1,850			2,280	300	1,230	300				490	330	40,290
20	6,810	10,060		690			2,100	160	1,440	50				540	300	22,150
Total	**810,350**	**512,620**	**4,120**	**147,720**	**25,270**	**12,230**	**102,590**	**14,570**	**41,460**	**22,620**	**23,520**	**26,790**	**740**	**28,080**	**10,400**	**1,783,080**
% of total	**45.45**	**28.75**	**0.23**	**8.28**	**1.42**	**0.69**	**5.75**	**0.82**	**2.33**	**1.27**	**1.32**	**1.50**	**0.04**	**1.57**	**0.58**	**100**

Note:
All materials are presented in kg.
Plbd – Plasterboard
Alum – Aluminium
Waterpf – Waterproofing
Insul – Insulation (Rockwool)

7.3 Life Cycle Assessment Findings

7.3.1 Analysis of Embodied Energy and GHG Emissions by Elements

Table 18 and Figure 12 summarise the initial embodied energy for the twenty case studies in terms of megajoule (MJ) and megajoule per NLA (MJ/m^2) by element. The energy consumption in the table includes initial embodied energy for the extraction of raw materials through to the energy input in the manufacturing of construction materials, and the transportation energy required for the delivery of these materials to sites. From Table 18, the average initial embodied energy consumption was 1,396 MJ/m^2 of NLA for the twenty fitout projects, ranging from 894 to 2,014 MJ/m^2.

From Table 18 and Figure 12 internal walls have the highest initial embodied energy with an average of 46%. From the table, initial embodied energy of internal wall represents a range of 199 to 1,144 MJ/m^2 with an average of 648 MJ/m^2. Project No 15 has the highest energy consumption in internal walls and this is because of the high use of internal walls to form the cellular office layout. Internal wall construction, as discussed previously, includes metal stud frames with plasterboard lining on both sides. Aluminium framed glazed partitions are also used to subdivided the spaces into cellular office areas. Aluminium, steel and glass are high energy intensity materials used in traditional office fitout. A further analysis on energy consumption of internal walls has been included in the latter part of the report.

Office furniture has the second highest initial embodied energy with an average of 30%. From the table the initial embodied energy of office furniture ranges from 297 to 601 MJ/m^2 and an average of 422 MJ/m^2. Office furniture in the study only accounts for loose furniture of workstations, office chairs and pedestals. These are common types of furniture used in office fitout. A further analysis on energy consumption of office furniture has been included in the latter part of the report.

Internal walls and office furniture are the two most important elements in office fitout. From the analysis of initial embodied energy consumption these two elements consume a combined total of 77% of the total energy. The remainder are doors and internal finishes in a combined total of 23%. Doors account for an average of 80 MJ/m^2 (6%), whilst internal finishes account for 246 MJ/m^2 (17%). Internal doors are hollow core wood doors with paint finish. Internal finishes include finishes to floor, wall and ceilings, as discussed previously.

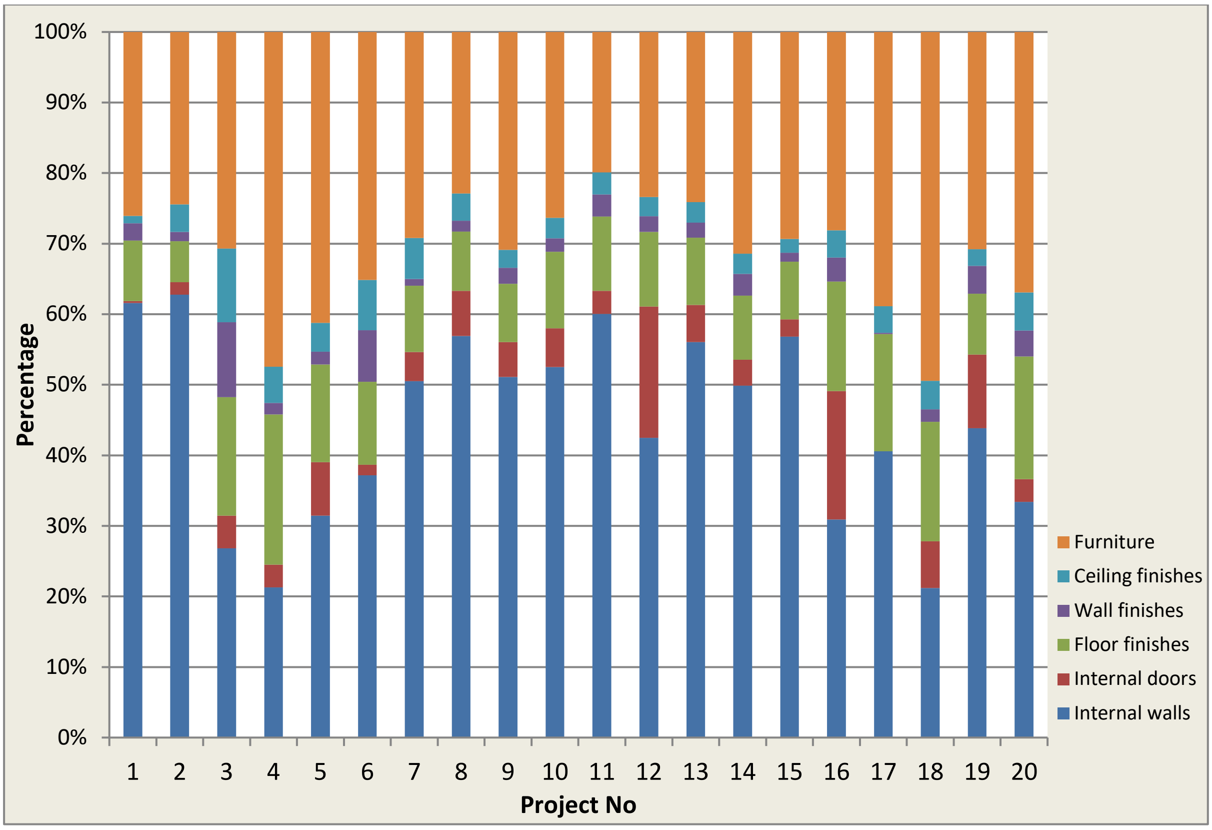

Figure 13: Percentage proportion of initial embodied energy by elements

Table 18: Summary of initial embodied energy by elements

Report ID	NLA m^2	Embodied Energy by Element							Embodied Energy per NLA by Element						
		Internal wall	Internal door	Floor finishes	Wall finishes	Ceiling finishes	Furniture	Total	Internal wall	Internal door	Floor finishes	Wall finishes	Ceiling finishes	Furniture	Total
		MJ							MJ/m^2						
Large (NLA >5,000m²)															
1	5,010	3,721,000	17,000	519,000	148,000	62,000	1,576,000	6,043,000	743	3	104	30	12	315	1,206
2	5,474	5,661,000	160,000	523,000	118,000	351,000	2,205,000	9,018,000	1,034	29	96	22	64	403	1,647
3	10,342	3,063,000	528,000	1,913,000	1,214,000	1,190,000	3,504,000	1,1412,000	296	51	185	117	115	339	1,103
Medium (NLA 1,000 – 5,000m²)															
4	1,027	204,000	31,000	204,000	16,000	49,000	455,000	959,000	199	30	199	16	48	443	934
5	1,750	641,000	154,000	282,000	37,000	83,000	840,000	2,037,000	366	88	161	21	47	480	1,164
6	2,649	1,266,000	51,000	399,000	249,000	242,000	1,197,000	3,404,000	478	19	151	94	91	452	1,285
7	3,034	2,375,000	195,000	441,000	45,000	273,000	1,374,000	4,703,000	783	64	145	15	90	453	1,550
8	3,459	2,716,000	305,000	400,000	75,000	182,000	1,093,000	4,771,000	785	88	116	22	53	316	1,379
Small (NLA <1,000m²)															
9	323	321,000	31,000	52,000	14,000	16,000	194,000	628,000	994	96	161	43	50	601	1,944
10	361	305,000	32,000	63,000	11,000	17,000	153,000	581,000	845	89	175	30	47	424	1,609
11	417	383,000	21,000	67,000	20,000	20,000	127,000	638,000	918	50	161	48	48	305	1,530
12	450	345,000	151,000	86,000	18,000	22,000	190,000	812,000	767	336	191	40	49	422	1,804
13	533	500,000	47,000	85,000	19,000	26,000	215,000	892,000	938	88	159	36	49	403	1,674
14	620	419,000	31,000	76,000	26,000	24,000	264,000	840,000	676	50	123	42	39	426	1,355
15	630	721,000	31,000	104,000	16,000	25,000	372,000	1,269,000	1,144	49	165	25	40	590	2,014
16	640	209,000	123,000	105,000	23,000	26,000	190,000	676,000	327	192	164	36	41	297	1,056
17	650	237,000		97,000	1,000	22,000	227,000	584,000	365		149	2	34	349	898
18	655	153,000	48,000	122,000	13,000	29,000	357,000	722,000	234	73	186	20	44	545	1,102
19	665	513,000	122,000	101,000	46,000	28,000	360,000	1,170,000	771	183	152	69	42	541	1,759
20	727	217,000	21,000	113,000	24,000	35,000	240,000	650,000	298	29	155	33	48	330	894
Ave.		**1,198,500**	**110,474**	**287,600**	**106,650**	**136,100**	**756,650**	**2,590,450**	**648**	**80**	**155**	**38**	**53**	**422**	**1,396**
%									**46.4**	**5.7**	**11.1**	**2.7**	**3.8**	**30.2**	**100**

Table 19 and Figure 13 present the results of GHG emissions for the twenty case studies. The GHG emissions are presented in terms of kilogram carbon dioxide equivalents ($kgCO_{2-e}$) and kilogram carbon dioxide equivalents per NLA ($kgCO_{2-e}/m^2$), by elements. The calculation includes the GHG emissions in conjunction with the extraction of raw materials, the manufacturing of these materials and the transportation required for the delivery of these materials to sites. On average the twenty case studies generate approximately 86 $kgCO_{2-e}/m^2$ per NLA, ranging from 55 to 123 $kgCO_{2-e}/m^2$.

Similar to the initial embodied energy analysis Table 19 and reveal that internal walls have the highest GHG emissions with an average of 38 $kgCO_{2-e}/m^2$, ranging from 12 to 66 $kgCO_{2-e}/m^2$. The internal walls of Project No 15 have the highest GHG emission of 66 $kgCO_{2-e}/m^2$. Aluminium, steel and glass are high GHG materials used in the construction of internal walls in these fitout projects. Internal walls are responsible for approximately 44% of the total GHG emissions in the case studies, ranging from 20 to 62%. A further analysis on emission impact of internal wall has been included in the later part of the report.

Table 19 and Figure 13 also show that office furniture has the second highest GHG emissions with an average of 35%. From the table on average office furniture emits 30 $kgCO_{2-e}/m^2$ of GHG, ranging from 21 to 42 $kgCO_{2-e}/m^2$. In a similar approach GHG emissions were only calculated for loose furniture that includes workstations, office chairs and metal pedestals. Fixed furniture has not been included in the analysis. A further analysis on emission impact of furniture has been included in the later part of the report.

Similar to the results of initial embodied energy analysis, internal walls and office furniture are also the two highest emitters of GHG in office fitout. These two elements emit a combined figure of 78% of the total GHG emissions in the case studies. Comparatively doors and internal finishes have the least impact with a combined total of 22%. Door accounts for 5 $kgCO_{2-e}/m^2$ (6%) and internal finishes account for 14 $kgCO_{2-e}/m^2$ (16%).

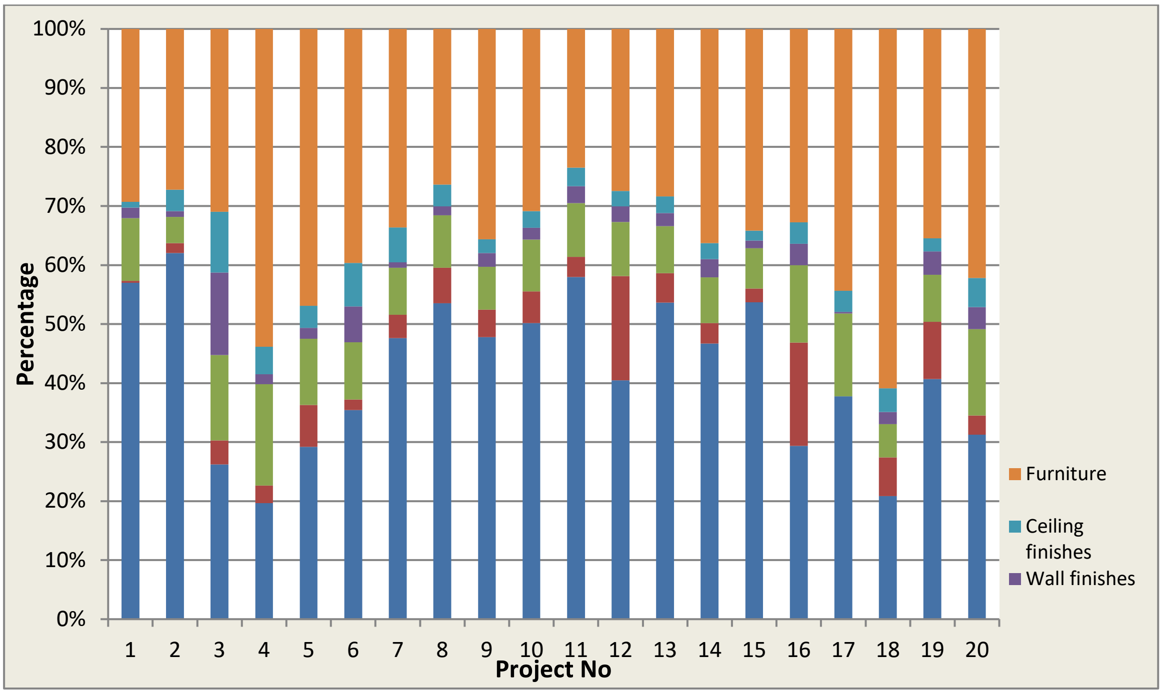

Figure 14: Percentage proportion of GHG emissions by elements

Table 19: Summary GHG emissions by elements

Project ID	NLA m²	GHG Emissions by Elements							GHG Emission per NLA by Elements						
		Internal walls	Internal doors	Floor finishes	Wall finishes	Ceiling finishes	Furniture	Total	Internal walls	Internal doors	Floor finishes	Wall finishes	Ceiling finishes	Furniture	Total
		kg CO2-e							kg CO2-e/m²						
Large (NLA >5,000m²)															
1	5,010	215,500	1,200	40,100	6,700	3,700	110,800	378,000	43.0	0.2	8.0	1.3	0.7	22.1	75.4
2	5,474	353,100	9,400	25,400	5,500	20,600	155,000	569,000	64.5	1.7	4.6	1.0	3.8	28.3	103.9
3	10,342	200,000	30,900	110,500	106,700	78,200	236,400	762,700	19.3	3.0	10.7	10.3	7.6	22.9	73.7
Medium (NLA 1,000 – 5,000m²)															
4	1,027	11,800	1,800	10,300	1,000	2,800	32,300	60,000	11.5	1.8	10.0	1.0	2.7	31.5	58.4
5	1,750	37,100	9,000	14,300	2,300	4,800	59,600	127,100	21.2	5.1	8.2	1.3	2.7	34.1	72.6
6	2,649	75,300	3,700	20,600	12,900	15,700	84,200	212,400	28.4	1.4	7.8	4.9	5.9	31.8	80.2
7	3,034	136,900	11,300	22,900	2,600	17,100	96,600	287,400	45.1	3.7	7.5	0.9	5.6	31.8	94.7
8	3,459	156,000	17,600	25,900	4,400	10,800	76,800	291,500	45.1	5.1	7.5	1.3	3.1	22.2	84.3
Small (NLA <1,000m²)															
9	323	18,500	1,800	2,800	900	900	13,800	38,700	57.3	5.6	8.7	2.8	2.8	42.7	119.8
10	361	17,700	1,900	3,100	700	1,000	10,900	35,300	49.0	5.3	8.6	1.9	2.8	30.2	97.8
11	417	22,200	1,300	3,500	1,100	1,200	9,000	38,300	53.2	3.1	8.4	2.6	2.9	21.6	91.8
12	450	19,900	8,700	4,500	1,300	1,300	13,500	49,200	44.2	19.3	10.0	2.9	2.9	30.0	109.3
13	533	28,900	2,700	4,300	1,200	1,500	15,300	53,900	54.2	5.1	8.1	2.3	2.8	28.7	101.1
14	620	24,200	1,800	4,000	1,600	1,400	18,800	51,800	39.0	2.9	6.5	2.6	2.3	30.3	83.5
15	630	41,600	1,800	5,300	1,000	1,300	26,500	77,500	66.0	2.9	8.4	1.6	2.1	42.1	123.0
16	640	12,100	7,200	5,400	1,500	1,500	13,500	41,200	18.9	11.3	8.4	2.3	2.3	21.1	64.4
17	650	13,700		5,100	100	1,300	16,100	36,300	21.1	0.0	7.8	0.2	2.0	24.8	55.8
18	655	8,900	2,800	2,400	900	1,700	26,000	42,700	13.6	4.3	3.7	1.4	2.6	39.7	65.2
19	665	29,700	7,100	5,800	2,900	1,600	25,900	73,000	44.7	10.7	8.7	4.4	2.4	38.9	109.8
20	727	12,600	1,300	5,900	1,500	2,000	17,000	40,300	17.3	1.8	8.1	2.1	2.8	23.4	55.4
Ave		**71,785**	**6,489**	**16,105**	**7,840**	**8,520**	**52,900**	**163,315**	**37.8**	**4.7**	**8.0**	**2.4**	**3.1**	**29.9**	**86.0**
%									**44.0**	**5.5**	**9.3**	**2.8**	**3.6**	**34.8**	**100**

7.3.2 The Impact of Lease Churn on Life Cycle Energy Analysis and GHG Emissions

This section presents results on the energy consumption and GHG emissions from a life cycle perspective. In this section, construction and end of life energy consumption and GHG emissions are accounted for in the life cycle analysis. The energy and GHG emissions for the construction is comparatively simple as no major or large plant and equipment are included in fitout projects. Office fitout has a short life span. The end of life energy consumption and GHG emissions occur at the end of a lease period when the tenant has decided not to renew the lease.

Table 20 summarises results of the life cycle analysis of energy consumption for the twenty projects. The table presents life cycle energy consumption into initial embodied energy (divided into fitout construction and fitout furniture), construction and end of life energy. The fitout in initial embodied energy includes internal walls, doors and finishes, whilst office furniture contains workstations, chairs and pedestals.

From the table, on average the twenty projects consume a total 2,622,920 MJ which is equivalent to approximately 1,414 MJ/m^2 of energy. The initial embodied energy from the manufacture of fitout construction and fitout furniture, consumes about 99% of the total energy, whereas construction and end of life have only a combined total of about 1%. Project No 15 is a small size tenant but consumes the highest life cycle energy, about 44% more than the average consumption. The large quantity of internal walls is believed to have contributed to the high energy consumption.

On average the three types of tenants consume a similar amount of energy and they are respectively 1,335, 1,280 and 1,490 MJ/m^2 for large, medium and small tenants. Small tenants consume about 11% and 14% more energy than large and medium tenants respectively. Average energy consumption for small tenants has a wider range, ranging from 910 to 2,037 MJ/m^2 compared with a smaller range found in large and medium tenants ranged respectively between 1,117 to 1,673 MJ/m^2 and 950 to 1,578 MJ/m^2.

The life cycle of fitout for office is short which is largely dependent on the lease period. According to the lease period study in Section 4.3 of the report, large tenants (NLA greater than 5,000m^2) are more likely to have longer leases, whilst small tenants (NLA less than 1,000m^2) are more likely to have shorter leases. Therefore using the findings from Section 4.3, the research study summarises that lease period for large, medium and small tenants are 8.9, 8 and 5 years respectively (refer to Column 3 in Table 20).

In the study it was assumed that stripout will take place at the end of each lease period. Therefore energy as required for stripout and disposal at each lease churn is considered as part of the end of life energy analysis.

Table 20 shows that when the life cycle energy consumption for office fitout is distributed across the lease churn period, the average life cycle energy consumption per year are 150, 160 and 298 MJ/m^2/year respectively for large, medium and small tenants. Large and medium tenants consume respectively 99% and 86% less energy than small tenants because small tenants churn more often at every five years. Therefore it is evident that the longer the lease period or the longer the tenant remains in the same space the lower the life cycle energy consumption for office fitout.

Table 20: Summary of life cycle energy consumption for the case studies

Project ID	NLA m^2	Lease churn period	Initial		Construction	End of Life	Total	Initial		Construction	End of Life	MJ/m^2	MJ/m^2/ year of lease churn period
			Fitout construction	Fitout furniture				Fitout construction	Fitout furniture				
		Year	MJ					%					
Large (NLA >5,000m²)													
1	5,010	8.9	4,467,000	1,576,000	14,000	24,600	6,081,600	73.5	25.9	0.2	0.4	1,214	136.39
2	5,474	8.9	6,813,000	2,205,000	45,000	94,400	9,157,400	74.4	24.1	0.5	1.0	1,673	187.97
3	10,342	8.9	7,908,000	3,504,000	46,000	90,900	11,548,900	68.5	30.3	0.4	0.8	1,117	125.47
Medium (NLA 1,000 - 5,000m²)													
4	1027	8	504,000	455,000	6,000	10,600	975,600	51.7	46.6	0.6	1.1	950	118.74
5	1750	8	1,197,000	840,000	9,000	16,600	2,062,600	58.0	40.7	0.4	0.8	1,179	147.33
6	2649	8	2,207,000	1,197,000	17,000	39,200	3,460,200	63.8	34.6	0.5	1.1	1,306	163.28
7	3034	8	3,329,000	1,374,000	27,000	57,800	4,787,800	69.5	28.7	0.6	1.2	1,578	197.26
8	3459	8	3,678,000	1,093,000	9,000	14,600	4,794,600	76.7	22.8	0.2	0.3	1,386	173.27
Small (NLA <1,000m²)													
9	323	5	434,000	194,000	4,000	5,100	637,100	68.1	30.5	0.6	0.8	1,972	394.49
10	361	5	428,000	153,000	3,000	4,600	588,600	72.7	26.0	0.5	0.8	1,630	326.09
11	417	5	511,000	127,000	5,000	5,600	648,600	78.8	19.6	0.8	0.9	1,555	311.08
12	450	5	622,000	190,000	3,000	5,600	820,600	75.8	23.2	0.4	0.7	1,824	364.71
13	533	5	677,000	215,000	4,000	6,600	902,600	75.0	23.8	0.4	0.7	1,693	338.69
14	620	5	576,000	264,000	5,000	6,100	851,100	67.7	31.0	0.6	0.7	1,373	274.55
15	630	5	897,000	372,000	6,000	8,600	1,283,600	69.9	29.0	0.5	0.7	2,037	407.49
16	640	5	486,000	190,000	4,000	6,700	686,700	70.8	27.7	0.6	1.0	1,073	214.59
17	650	5	357,000	227,000	3,000	6,600	593,600	60.1	38.2	0.5	1.1	913	182.65
18	655	5	365,000	357,000	4,000	7,100	733,100	49.8	48.7	0.5	1.0	1,119	223.85
19	665	5	810,000	360,000	5,000	7,600	1,182,600	68.5	30.4	0.4	0.6	1,778	355.67
20	727	5	410,000	240,000	4,000	7,500	661,500	62.0	36.3	0.6	1.1	910	181.98
Ave.			**1,833,800**	**756,650**	**11,150**	**21,320**	**2,622,920**	**67.8**	**30.9**	**0.5**	**0.8**	**1,414**	**241.28**

The life cycle analysis of GHG emissions has been undertaken in the same way as the life cycle energy analysis as discussed before. The life cycle analysis of GHG emissions has revealed similar results as the life cycle energy consumption. Table 21 summarises the results of GHG emissions analysis for the twenty projects. The life cycle analysis of GHG emissions consists of emissions embodied in the cradle-to-grave material manufacturing (fitout construction and fitout furniture), construction and end of life demolition and disposal.

From the table on average the twenty projects generate approximately 165,465 $kgCO_{2-e}$ or 87 $kgCO_{2-e}/m^2$ of GHG. Fitout construction and fitout furniture are responsible for respectively an average of 63 and 35% of the total GHG emissions. On the other hand a total of 98% of GHG emissions can be found from the fitout construction and fitout furniture, whereas construction and end of life generate only approximately 2%. In a similar situation Project No 15 (small tenant) produces the highest GHG emissions, about 43% more than the average emission. The large quantity of internal walls is believed to be the contributing factor for the high GHG emission in the study.

On average the three types of tenants generate similar life cycle GHG and they are 85, 79 and 91 $kgCO_{2-e}/m^2$ respectively for large, medium and small tenants. Small tenants have emitted GHG of 7% and 13% respectively more than large and medium tenants. Similar to the life cycle analysis of energy consumption, the life cycle GHG emission of small tenants has a wider range, ranging from 57 to 124 $kgCO_{2-e}/m^2$ compared with a smaller range found in large and medium tenants ranged respectively between 76 to 106 and 59 to 97 $kgCO_{2-e}/m^2$.

As discussed before, lease churn has also had a profound impact on the life cycle GHG emission analysis. In the table, life cycle GHG emissions are distributed across the lease period. As a result small tenants are found to generate much more GHG than the large and medium tenants. On average the GHG emissions per NLA per year are 9.6, 9.9 and 18.2 $kgCO_{2-e}/m^2$/year respectively for large, medium and small tenants. Large and medium tenants respectively emit approximately 90% and 84% less GHG than small tenants. Therefore the same conclusion can be drawn that the longer the lease period, the lesser the GHG emissions in office fitout.

Table 21: Summary of life cycle GHG emissions for the case studies

Project ID	NLA m^2	Lease churn period	Initial		Construction	End of Life	Total	Initial		Construction	End of Life	Kg CO_{2-e}/m_2	Kg CO_{2-e}/ m_2/year of lease churn period
			Fitout construction	Fitout furniture				Fitout construction	Fitout furniture				
		Year	Kg CO_{2-e}					%					
Large (NLA >5,000m^2)													
1	5,010	8.9	267,200	110,800	1,000	1,200	380,200	70.3	29.1	0.3	0.3	75.89	8.53
2	5,474	8.9	414,000	155,000	3,400	5,900	578,300	71.6	26.8	0.6	1.0	105.64	11.87
3	10,342	8.9	526,300	236,400	3,300	5,300	771,300	68.2	30.6	0.4	0.7	74.58	8.38
Medium (NLA 1,000 - 5,000m^2)													
4	1,027	8	27,700	32,300	500	600	61,100	45.3	52.9	0.8	1.0	59.49	7.44
5	1,750	8	67,500	59,600	700	900	128,700	52.4	46.3	0.5	0.7	73.54	9.19
6	2,649	8	128,200	84,200	1,400	2,700	216,500	59.2	38.9	0.6	1.2	81.73	10.22
7	3,034	8	190,800	96,600	1,900	3,800	293,100	65.1	33.0	0.6	1.3	96.61	12.08
8	3,459	8	214,700	76,800	800	700	293,000	73.3	26.2	0.3	0.2	84.71	10.59
Small (NLA <1,000m^2)													
9	323	5	24,900	13,800	300	300	39,300	63.4	35.1	0.8	0.8	121.67	24.33
10	361	5	24,400	10,900	400	200	35,900	68.0	30.4	1.1	0.6	99.45	19.89
11	417	5	29,300	9,000	300	400	39,000	75.1	23.1	0.8	1.0	93.53	18.71
12	450	5	35,700	13,500	400	300	49,900	71.5	27.1	0.8	0.6	110.89	22.18
13	533	5	38,600	15,300	300	400	54,600	70.7	28.0	0.5	0.7	102.44	20.49
14	620	5	33,000	18,800	400	400	52,600	62.7	35.7	0.8	0.8	84.84	16.97
15	630	5	51,000	26,500	300	500	78,300	65.1	33.8	0.4	0.6	124.29	24.86
16	640	5	27,700	13,500	500	300	42,000	66.0	32.1	1.2	0.7	65.63	13.13
17	650	5	20,200	16,100	400	400	37,100	54.4	43.4	1.1	1.1	57.08	11.42
18	655	5	16,700	26,000	300	400	43,400	38.5	59.9	0.7	0.9	66.26	13.25
19	665	5	47,100	25,900	500	400	73,900	63.7	35.0	0.7	0.5	111.13	22.23
20	727	5	23,300	17,000	300	500	41,100	56.7	41.4	0.7	1.2	56.53	11.31
Ave			**110,415**	**52,900**	**870**	**1,280**	**165,465**	**63.1**	**35.4**	**0.7**	**0.8**	**87.30**	**14.85**

7.3.3 The Impact of Intermediate Works on Fitout on Life Cycle Energy Analysis and GHG Emissions

Section 4.3 analysed results on fitout churn and yielded typical periods for small, medium and large tenants. Even so, its focus on significant fitouts did not necessarily cover relatively minor works such as isolated repainting and changes to finishes. Such issues are very hard to accurately determine therefore the analysis adopted a scenario analysis approach which assumed that approximately 20% replacement would take place every five years for large and medium tenants only (as small tenants tend to lease churn approximately every five years therefore the do not normally have to deal with such effects).

For the four elements (internal walls, floor, wall and ceiling finishes) that are likely to have a degree of intermediate work, as revealed in Table 22, there will be approximately an additional 171 MJ/m^2 and 10 $kgCO2\text{-}e/m^2$ respectively for energy consumption and GHG emissions if 20% are to be replaced within a lease period.

As indicated previously in Table 6, the total floor spaces for large and medium tenants within Sydney CBD Prime buildings equate to approximately 2,203,419m^2. If these tenants are to undertake some form of intermediate works during their tenancy period they will potentially be consuming 376,785 GJ and 22,035 $tCO_{2\text{-}e}$ respectively for energy consumption and GHG emissions for 20% retrofitting of their office spaces within a lease period. Since intermediate works during a lease period is somehow unavoidable due to a number of reasons discussed before, it may strategically be replacing energy intensity and high polluting materials with more environmentally friendly materials with a renewable nature.

Table 22: Summary of impact of fitout churn within a lease period on life cycle energy analysis and GHG emissions (for large and medium tenants only)

Fitout elements	Total energy consumption (MJ/m^2)		GHG emissions ($kgCO_{2\text{-}e}/m^2$)	
	Ave for large & medium tenants	20% fitout churn within a lease period	Ave for large & medium tenants	20% fitout churn within a lease period
Internal walls	585.5	117.1	34.8	7.0
Internal doors	46.7	-	2.8	-
Floor finishes	144.4	28.9	8.0	1.6
Wall finishes	42.0	8.4	2.7	0.5
Ceiling finishes	65.1	13.0	4.0	0.8
Furniture	400.0	-	28.1	-
Construction	5.5	1.1	0.4	0.1
End of life	11.1	2.2	0.7	0.1
Total	1,300.3	170.7	81.5	10.1

7.3.4 The Impact of Internal Walls on Life Cycle Energy Analysis and GHG Emissions

As indicated in Table 18 and Table 19 internal walls account for approximately 648 MJ/m^2 and 38 $kgCO_{2-e}/m^2$ respectively for initial embodied energy and GHG emissions from the twenty fitout projects.

The analysis of the twenty case studies also reveals that the majority of these fitout projects utilise cellular floor plan layout. Cellular office plans use internal walls to separate office spaces into cubicles with fixed partitions and doors. Traditionally, metal stud with plasterboard lining on both sides are commonly used in a cellular floor layout. Aluminium framed glazed partitions may also be used for meeting rooms and offices for senior management.

Table 23 presents the analysis of internal walls of the twenty case study projects. The last column in the table indicates the percentage of internal wall to the floor space of NLA. The higher the percentage the more internal walls are involved. The analysis indicates that the percentage of internal walls ranged from 3% to 37%. The lowest and the highest percentage of internal wall to floor space were found in small tenants. Small tenants are found to have more cellular office layout than large and medium tenants. Five out of the twenty projects require over 25% for internal partitioning and three were found in small tenants. The top three projects that required most partitioning were found in small tenants. The three small tenants were construction, recruitment and investment companies (refer to Table 16). The requirement for cellular office layout may be dictated by the nature of business. However there was no indication on the type of tenant that is linked to the use of cellular office layout in the study.

Internal partitioning offers great opportunity for reducing energy consumption and GHG emissions in office fitout. The traditional approach of internal partitioning uses steel, plasterboard, glass, aluminium and insulation to form fixed cubicle for individual office. These materials are non-renewable in nature with high energy intensity and high GHG emissions in the process of raw materials extraction and manufacturing into construction materials. Steel, plasterboard, glass and aluminium have recyclable potential but the processes of recycling these materials involves further energy input and further GHG emissions. Therefore it may be a more sustainable strategy to replace these materials with renewable materials such as wood.

Wood is a natural material that requires substantially less energy input and emits less GHG emissions that can become an important substitution of traditional materials for internal partitioning. A comparative study between the traditional and wood based design have been undertaken in Section 7.3.6 below.

Table 23: Analysis of internal wall requirements for the case study projects

Report ID	NLA (m^2)	Length of internal wall (m)	% of internal wall to NLA
Large (NLA >5,000m^2)			
1	5,010	630	12.57
2	5,474	659	12.04
3	10,342	2,816	27.23
Medium (NLA 1,000 - 5,000m^2)			
4	1,027	106	10.32
5	1,750	254	14.51
6	2,649	856	21.31
7	3,034	206	6.79
8	3,459	869	25.12
Small (NLA <1,000m^2)			
9	323	80	24.77
10	361	83	22.99
11	417	143	34.29
12	450	87	19.33
13	533	126	23.64
14	620	146	23.55
15	630	161	25.56
16	640	116	18.13
17	650	20	3.08
18	655	75	11.45
19	665	247	37.14
20	727	154	21.18

7.3.5 The Impact of Office Furniture on Life Cycle Energy Analysis and GHG Emissions

The analysis of office furniture in the study refers to loose furniture and these include workstations, chairs and pedestals. Fixed or purpose made furniture have not been included in the study as discussed above. The main materials used in the manufacturing of workstations include melamine faced chipboard, steel and aluminium. Each workstation weights approximately 34kg with a life span of 10 years. The main materials used in the manufacturing of office chairs include aluminium, steel, plastic and foam. Each chair weights approximately 22kg with a life span of 12 years. With regards to the pedestals the main materials used in the manufacturing processes include steel, concrete, and medium density fibreboard. Each pedestal weights approximately 30kg with a life span of 10 years.

Table 24 presents the life cycle analysis of energy consumption and GHG emissions of office furniture for the twenty case studies. The life cycle analysis of energy consumption and GHG emissions include initial energy input and outputs in the manufacturing of this office furniture, transportation to sites and eventual disposal to landfill at the end of lease period. In the case study each fitout project has allowed for new workstations, office chairs and pedestals in the pre-tender estimate report. From the table on average the life cycle energy consumption for the office furniture in the case studies was 755,850 MJ with an average of 424 MJ/m^2. From the table large tenants consume the highest energy but when floor space (NLA) is taken into consideration largest tenants consume much lower energy than medium and small tenants. A similar situation occurs in the GHG emissions. From the table the three types of office furniture emit an average of 53,200 $kgCO_{2-e}$ or 30 $kgCO_{2-e}/m^2$. In a similar situation large tenants emit the highest of GHG but when floor space (NLA) is included large tenants became the least.

The research on energy and GHG emissions concerning office furniture is difficult as there is no information in relation to the recycling and reuse of this furniture at the end of lease churn. However from the analysis of these twenty fitout projects all projects included new workstations, chairs and pedestals in the scheme. When none of this office furniture is reused there will incur an average of 424 MJ/m^2 and 30 $kgCO_{2-e}/m^2$ of energy and GHG respectively at the end of each lease period. As previously discussed, small tenants churn more frequently than large or medium tenants therefore the annualised energy and GHG emission for office furniture of small tenants are much higher than large and medium size tenants. Small tenants will consume approximately 126% and 63% more energy respectively than large and medium tenants per year. In a similar situation small tenants will emit approximately 125% and 66% more GHG respectively than large and medium tenants per year.

There is insufficient information/data to ascertain the extent of office furniture to be recycled and reused at the end of the lease period. If office furniture is recycled and reused at the end of the lease period there will be a saving of 106 MJ/m^2 and 212 MJ/m^2 of energy respectively for 25% and 50%. Correspondingly, there will be a saving of 8 and 15 $kgCO2\text{-}e/m^2$ of GHG if 25% and 50% respectively for the office furniture to be recycled and reused.

Table 24: Life cycle analysis of energy consumption and GHG emission of office furniture

Elements	Total energy consumption (MJ)				Total GHG emissions (kgCO2-e)			
	Average	Large	Medium	Small	Average	Large	Medium	Small
Average	755,850	2,410,000	996,000	243,000	53,200	168,200	70,200	17,300
Average per m^2 (NLA)	424	348	430	439	30.1	24.5	31.4	31.3
No reuse at the end of lease churn								
Average/m^2	424	348	430	439	30.1	24.5	31.4	31.3
Average/m^2/year	72	39	54	88	5.2	2.8	3.8	6.3
25% Reuse at the end of lease churn (i.e. 75% new office furniture)								
Average/m^2	318	261	323	330	22.6	18.4	22.8	23.5
Average/m^2/year	54	29	40	66	3.9	2.1	2.9	4.7
50% reuse at the end of lease churn (i.e. 50% new office furniture)								
Average/m^2	212	177	215	219	15.1	12.3	15.2	15.7
Average/m^2/year	36	20	27	44	2.6	1.4	1.9	3.1

7.3.6 Comparative Study between Traditional and Wood Based Design Approach

The wood based fitout design concepts presented in Section 6 were compared with the traditional design approach to fitout. As discussed in the previous sections internal walls and office furniture consume the highest energy and emit the most GHGs. However internal walls and office furniture offer an important opportunity to move away from using traditional materials to renewable and more environmentally friendly materials. This section aims to compare the impact in terms of energy consumption and GHG emissions between the traditional and wood based office fitout design approach.

A comparative study was established using a hypothetical office space with an NLA of 1,550m^2. The design of the hypothetical office space is based on an open plan layout as this is often a common layout design for most *green buildings* nowadays. Internal partitioning of individual office has only been allowed for senior management, meeting and training rooms, and storage/filing in the design. Figure 14 below shows the generic open plan layout of the design.

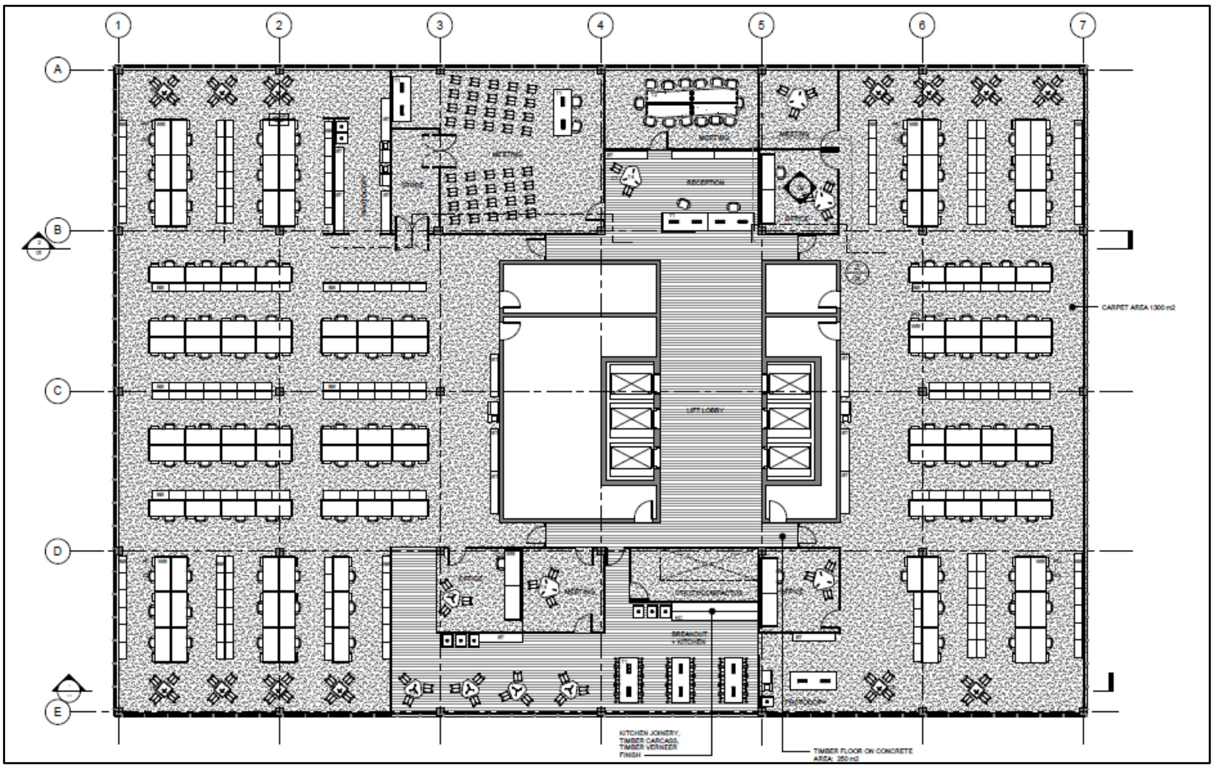

Figure 15: Generic open plan floor layout

Table 25 compares the design and material used for the two approaches. Traditionally, office fitout uses standard metal stud plasterboard partitions for general office areas and aluminium framed glazed partitions are used for offices of senior management and meeting rooms. For the wood based approach standard metal stud plasterboard partitions are replaced with 45mm thick, 1200 x 2700mm high modular wood partition panels as described in Section 6.1. The panels are similar to hollow core door construction but with thicker skins (2 x 6mm MDF skins) and thicker framing rails (33 x 55mm) and inclusive of a framed services duct running vertically down the centre of the panels. Wood frames are also used to replace glazed aluminium frames (where used in the traditional approach).

Carpet and underlay are common types of floor finishes for office fitout and they are used in both approaches for general office areas and wood flooring boards for reception and entry areas. Therefore floor finishes represent a neutral variable, common to both approaches and are subsequently not shown the analysis in order to simplify the presentation of data. Finishes to ceiling are traditionally steel suspended support system with plasterboard lining or perforated aluminium. In the wood oriented design approach 9mm plywood ceiling on a steel suspended system are used.

In the wood based approach workstations and pedestals are manufactured entirely using wood, as described previously in Part 6. The design of workstation desktops, front and side panels use the same partition panels for internal wall partitioning. In addition, these workstations moved away from a metal support chassis and instead utilised wood dowels configured in an open space frame arrangement, held together using joiners made using 3D printing technology. Wood pedestals are made from 12mm ply standard cut out using a CNC router and assembled on site.

Table 25: Summary of design details for the traditional and wood oriented approaches

Element	Traditional approach	Wood based approach
Internal walls	• Standard metal stud plasterboard and paint finish to general office area • Aluminium framed glazed partition for meeting and training rooms	• Partition panel to be 1200 x 2700mm high, 45mm thick hollow core wood, lined with 6mm MDF sheet on both sides to general office area (to be disassembled and reused) • Wood framed glazed partition for meeting and training rooms
Ceiling finishes	• Plasterboard ceiling on steel suspended support to general office areas • Perforated aluminium panel ceiling on steel suspended support to lift lobby, reception, meeting and training rooms, senior management offices	• 9mm Plywood ceiling on steel suspended support to all area
Furniture	• Standard office workstation in melamine faced chipboard, steel and aluminium • Standard office pedestal in steel, concrete and medium density fibreboard	• Workstation to be 45mm thick wood panel lined with 6mm MDF sheet on both sides with clear finish including front and side panels • Pedestal to be 12mm ply with clear finish

Table 26 and Figure 15 present the results of the comparative study that include both the initial construction and end of life stage. On a life cycle perspective the traditional design consumes approximately 1,565,300 MJ or 1,009.9 MJ/m^2, whilst the wood based design consumes 1,321,900 MJ or 852.8 MJ/m^2. The traditional approach therefore consumes approximately 16% more energy than the wood based design. In the traditional approach, ceiling finishes have the highest energy consumption followed by office furniture. In the wood based approach, ceiling finishes consume more than half of the energy followed by office furniture. However wood based ceiling panels have a long life span which require little maintenance and provide aesthetics suitable for Prime/A Grade office fitout quality, compared with plasterboard suspended ceilings in the traditional approach.

Office furniture represents a significant reduction in energy consumption. Office furniture consumes 195 MJ/m^2 and 103 MJ/m^2 respectively for traditional and wood based design. Therefore traditional office furniture consumes approximately 47% more energy than wood based office furniture. Wood based design of internal walls also provides a significant reduction in energy consumption whereby traditional represents 122 MJ/m^2 and the wood based approach 80 MJ/m^2, a reduction of approximately 35%.

With regards to GHG emissions the traditional design emits approximately 124,100 $kgCO_{2\text{-}e}$ or 80 $kgCO_{2\text{-}e}/m^2$ compared to 31,400 $kgCO_{2\text{-}e}$ or 20 $kgCO_{2\text{-}e}/m^2$ for the wood based design (refer to Table 26). Therefore, the traditional design emits approximately 75% per NLA more GHG than the wood based design. The materials used in the traditional design such as aluminium, steel and glass are highly polluting materials that emit a high content of GHG during manufacturing processes. The traditional design of internal walls using metal stud and plasterboard emits approximately 54% more GHG than the wood based partition panels. In addition, traditional workstations and pedestals also emit approximately 72% more GHG than wood based office furniture.

The end of life stage involves mainly fuel consumption of trucks delivery stripout waste to landfills or disassembled panels to recovery facilities. The energy consumption and GHG emissions at this stage represent only a small fraction of the life cycle study (Table 26). At the end of life stage the fitout for the traditional design will be demolished and transported to the landfills. The fitout design for the wood based approached are based on a modular hollow core system for partition walls, ceiling panels and workstations. Therefore they can be easily disassembled and transported to the collection centre to be reuse. The end of life energy consumption and GHG emissions for the traditional approach are both less than 1% of the whole life cycle. For the wood based design the energy consumption was also less than 1%, whilst the GHG emission was approximately 2% of the total life cycle.

Table 26: Summary of results for the comparative study

Element	Life cycle energy (MJ)									
	Traditional approach					Wood based approach				
	Initial	End of life	Total	Total/m^2	%	Initial	End of life	Total	Total/m^2	%
Internal walls	187,100	1,500	188,600	121.7	12.0	123,000	1,000	124,000	80.0	9.4
Ceiling finishes	1,071,300	4,000	1,075,300	693.7	68.7	1,031,200	6,500	1,037,700	669.5	78.5
Office furniture	296,400	5,000	301,400	194.5	19.3	158,700	1,500	160,200	103.3	12.1
Total	1,554,800	10,500	1,565,300	1,009.9	100	1,312,900	9,000	1,321,900	852.8	100
Element	Life cycle GHG emissions (kgCO_{2-e})									
	Traditional approach					Wood based approach				
	Initial	End of life	Total	Total/m^2	%	Initial	End of life	Total	Total/m^2	%
Internal walls	13,295	105	13,400	8.6	10.8	6,230	70	6,300	4.0	19.8
Ceiling finishes	91,520	280	91,800	59.2	74.0	19,245	455	19,700	12.7	62.9
Office furniture	18,550	350	18,900	12.2	15.2	5,295	105	5,400	3.5	17.3
Total	123,365	735	124,100	80.0	100	30,770	630	31,400	20.2	100

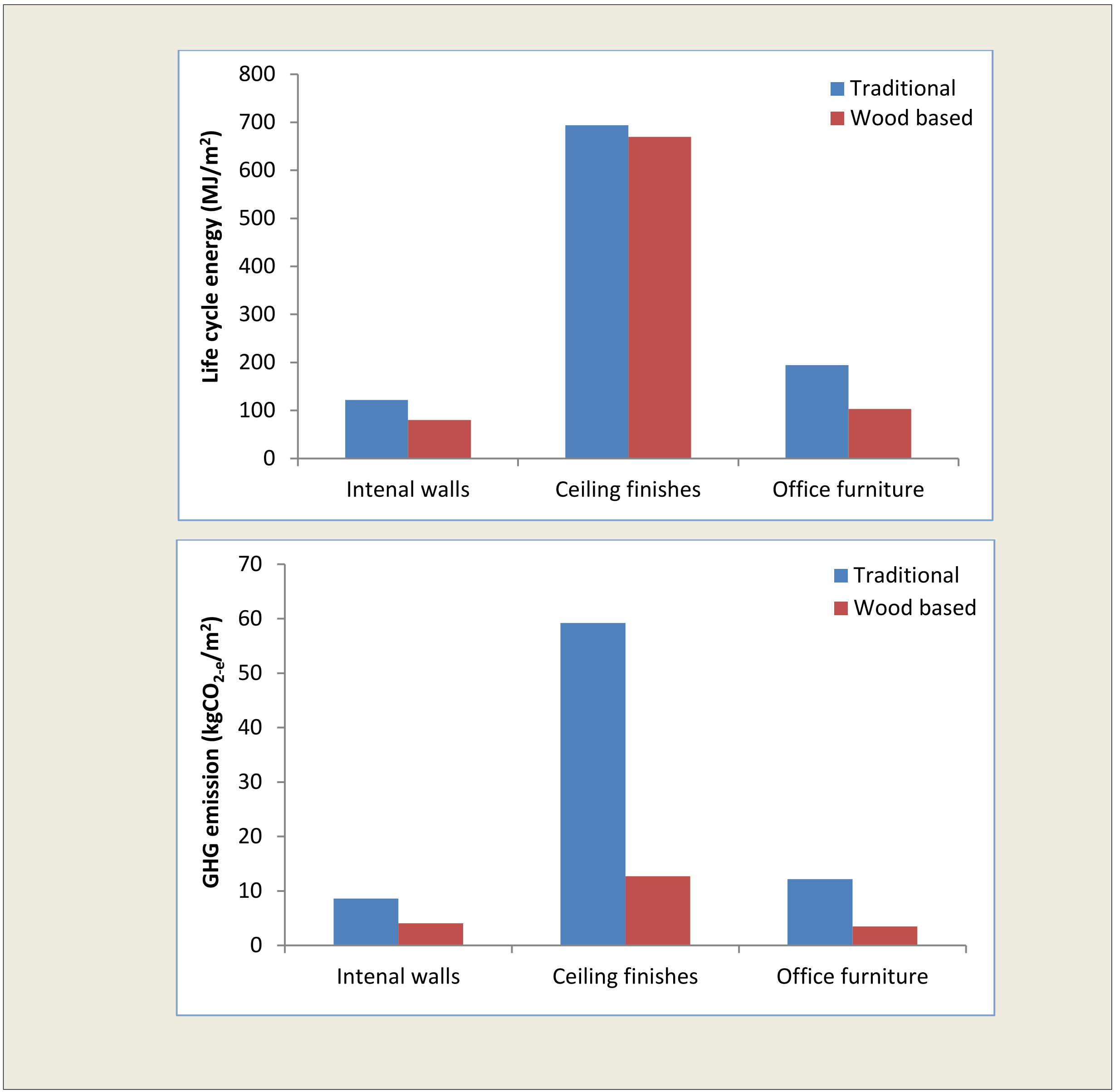

Figure 16: Comparing approach and wood base design

7.4 Life Cycle Assessment Conclusions

The life cycle analysis of energy consumption and GHG emissions arising from the office fitout was found to be significant especially given the frequency with which this occurs over the life of an office building. Fitout churn impacts significantly on the energy embodied in the construction materials and the associated GHG emissions for office fitout.

The LCA study in this project for the office fitout and stripout is the first of its kind and the research reveals that the three most important factors that have impacted life cycle energy consumption and GHG emissions are the lease churn, internal walls/partitioning (cellular versus open plan) and office furniture. Small tenants tend to lease churn approximately every five years whilst large and medium tenants 8.9 years. As such large and medium tenants consume respectively 99% and 86% less energy than small tenants from the case studies. Similarly large and medium tenants emit respectively 90% and 84% less GHG than small tenants. In addition to the impact caused by lease or fitout churn, internal walls and office furniture are two other elements that have a high impact on life cycle energy consumption and GHG emissions. Internal walls offer potential opportunity to replace the traditional metal stud plasterboard partitions with wood based partition panels. The wood based partition panel as internal wall incurs a saving of approximately 34% and 53% respectively for energy consumption and GHG emissions. The wood based office furniture has also potential savings of approximately 47% and 71% respectively for energy consumption and GHG emissions. Wood is a renewable resource and an environmentally friendly material that can potentially replace traditional materials to improve environmental performance of office fitout.

8 Overall Conclusions

A broad spanning study was undertaken into increasing wood based office fitout for sustainable life cycle benefits. The first part of the study covered the lease and fitout churn which dictate the terms and way in which office fitout occurs. It was found that lease term length for Prime buildings is a reasonably good and accurate proxy for the period between fitout churn. It was found that for these buildings, tenancy size (in terms of area leased) influences lease term length. With regard to this, it was found that small tenants (<1000m^2) have a fitout churn estimated to occur on average at 5.1 year intervals. Large tenants (>5000m^2) have a fitout churn estimated to occur on average at 8.9 year intervals.

The second part of the study quantified and qualified waste from stripout (at each fitout churn). For typical sites, approximately 63.4% goes to landfill and only 36.6% is reused and recycled. Unfortunately, most wood goes to landfill. A key part of the problem for wood is the volumetric nature of furniture which makes it expensive and impractical to handle, transport and store; it is also difficult to either reuse, convert to recycling products or utilise in resource recovery scenarios. Wood is also a relatively small quantity (in weight terms) which provides insufficient critical mass to justify dedicated reuse/recycling streams. Wood needs to be an underpinning material in fitout that concurrently refines its potential for reuse and recycling markets. It is concluded that in terms of strategic design criteria, concepts need to include:

Materiality and Configurability

- Incorporating more wood in fitouts to create sufficient critical mass for reuse and recycling practices to develop.
- Designing for reuse and recycling at the beginning of the fitout process.

- Using a relatively homogenous palette of materials.
- Using a minimal kit of parts.
- Developing multipurpose scalable components.
- Designing for reconfigurability to extend reuse options.
- Developing assemblies that allow incorporation of services (e.g. cabling).

Deconstructability

- Ensuring fast knockdown from volumetric to flat and stackable.
- Avoiding special dismantling tools.
- Ensuring compact stacking to optimise goods lift usage and efficient truck cartage.
- Ensuring wood panels and workstation tops are easily separated from the support frames beneath.
- Creating quiet deconstruction methods to allow more work during normal office hours.

Critical Handling

- Ensuring fast stripout that ensures flow from breakdown-to-lift, lift-to-truck, and truck-to-depot.

Changes in Fitout Style and Scope

- Open plan offices are becoming the norm and allow greater utilisation of a furniture based design approach.
- Broadening wood based tender packages to compress and simplify the supply chain.

The third part of the study provided a reimagined design concepts for wood based office fitout. The main focus was upon the major proportion of fitout works/costs including: partitions, workstations, ceiling tiles for suspended ceilings and furniture including shelf, storage units, pedestals and miscellaneous tables. Designs were developed that addressed the above criteria whilst still meeting the normal expectations associated with high-end office fitout. Importantly, these designs are fully detailed in a parallel document to this one, entitled “Reimagining Wood Based Office Fitout Systems – Design Criteria and Design Concepts” (Forsythe et al, 2017).

The fourth and final part of the study undertook an LCA study comparing the above wood based designs with traditional fitout construction. Here, the traditional approach was found to consume approximately 16% more energy than the wood based design. The traditional office furniture also consumed approximately 47% more energy than wood based office furniture. Wood based design of internal walls also provides a significant reduction in energy consumption whereby traditional represents 122 MJ/m^2 and the wood based approach 80 MJ/m^2, a reduction of approximately 35%.

With regards to GHG emissions, the traditional design emits approximately 75% per NLA more GHG than the wood base design. The materials used in the traditional design such as aluminium, steel, glass are highly polluting materials that emit a high content of GHG during manufacturing processes. The traditional design of internal walls using metal stud and plasterboard emits approximately 54% more GHG than the wood based partition panels. In addition traditional workstations and pedestals also emit approximately 72% more GHG than wood based office furniture.

The above findings have set an agenda for wood based office furniture design which as mentioned above, is detailed more fully for industry uptake in the parallel design guide entitled “Reimagining Wood Based Office Fitout Systems – Design Criteria and Design Concepts” (Forsythe et al, 2017).

9 References

ABS. (2006), *Australia's Environment: Issues and Trends (46130)*, Australian Bureau of Statistics, Canberra.

ABS. (2012), *Environment: Waste management (1301.0)*, Australian Bureau of Statistics, Canberra. (http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/1301.0~2012~Main%20Features~Waste%20management~277).

Ahn, C., Lee, S.H., Pena-Mora, F. & Abourizk, S. (2010), 'Toward environmentally sustainable construction processes: The US and Canada's perspective on energy consumption and GHG/GAP emission', *Sustainability*, vol. 2, pp. 354-370.

Arup, O. (2007), *An introduction to Life Cycle Energy Assessment (LCEA) of Building Developments*. Hong Kong.

Baccarini, D. & Bateup, G. (2008), 'Benefits management in office fit-out projects', *Facilities*, vol. 26, no. 7, pp. 310-320.

Ball, R. (2002), 'Re-use potential and vacant industrial premises: revisiting the regeneration issue in Stoke-on-Trent', *Journal of Property Research*, vol. 19, no. 2, pp. 93-110.

Barras, R. & Clark, P. (1996), 'Obsolescence and performance in the Central London office market', *Journal of Property Valuation and Investment*, vol. 14, no. 4, pp. 63-78.

Bayne, K & Taylor, S. (2006), *Attitudes to the use of wood as a structural material in non-residential building applications: Opportunities for growth*, Forest & Wood Products Research & Development Corporation.

Bilec, M.M., Ries, R.J. & Matthews, H.S. (2009), 'Life-cycle assessment modeling of construction processes for buildings', *Journal of Infrastructure Systems*, vol. 16, no. 3, pp. 199-205.

Bell, N. & McWhinney, S. (2000), *Wastewise construction handbook: Techniques for reducing construction waste*, National Heritage Trust, Commonwealth Department of the Environment and Heritage, Australia.

BBP. (2013), 'Better buildings partnership templates for site selection briefs', (viewed 23 July 2016, http://cdn.sydneybetterbuildings.com.au/assets/BBP-Site-Selection-Briefs-Templates.pdf), Better Buildings Partnership.

BBP. (2015), 'Case study in resource recovery from office strip out: Governor Macquarie Tower', (viewed 23 July 2016, http://www.betterbuildingspartnership.com.au/resource/4446), Better Buildings Partnership.

Brand, S. (1995), *How buildings learn: What happens after they're built*, Penguin.

Brittain, J., Jaunzens, D. & Davies, H. (2004), *Designing for flexible building services in office-based environments: understanding client needs research paper*, The Chartered Institution of Building Services Engineers, London.

Bullen, P.A. (2007), 'Adaptive reuse and sustainability of commercial buildings', *Facilities*, vol. 25, no. 1/2, pp. 20-31.

Chen, T., Burnett, J. & Chau, C. (2001), 'Analysis of embodied energy use in the residential building of Hong Kong', *Energy*, vol. 26, no. 4, pp. 323-40.

Choukry, M. (1992), 'Changeability of buildings', *Proceedings of CIB Symposium Innovations in Management, Maintenance and Modernisation of Buildings, Rotterdam*.

City of Sydney. (2007), *Floor space and employment survey (FES): Overview and results*, City of Sydney, (viewed 17 November 2014, http://www.cityofsydney.nsw.gov.au/learn/research-and-statistics/surveying-our-community/floor-space-and-employment-survey/2007-FES-overview-and-results).

City of Sydney. (2012), *Floor space and employment survey (FES) overview and summary reports*, City of Sydney (viewed 17 November 2014, http://www.cityofsydney.nsw.gov.au/learn/research-and-statistics/surveying-our-community/floor-space-and-employment-survey/2012-fes-overview-and-summary-reports).

Cole, R.J. (1998), 'Energy and greenhouse gas emissions associated with the construction of alternative structural systems', *Building and Environment*, vol. 34, pp. 335-348.

Cole, R.J. & Kernan, P.C. (1996), 'Life-cycle energy use in office buildings', *Building and Environment*, vol. 31, no. 4, pp. 307-17.

Crowther, P. (2000), 'Building deconstruction in Australia', Kibert, C.J. & Chini, A.R., Eds., *Overview of Deconstruction in Selected Countries*, CIB Report No. 252, May, pp. 18-19.

Davies, R. (2005), *Green value: Green buildings, growing assets*, Royal Institution of Chartered Surveyors, London.

Department of the Environment and Energy. (2013), *National waste stream profiles*, (viewed 23 July 2016, http://www.environment.gov.au/topics/environment-protection/nwp/reporting/national-waste-stream).

Department of the Environment and Heritage (DEH). (2006a), *ESD design guide for Australian government buildings 2nd edition*, The Department of the Environment and Heritage, Australian Greenhouse Office, Canberra.

Department of the Environment and Heritage (DEH). (2006b), *AGO factors and methods workbook*, Department of the Environment and Heritage, Australian Greenhouse Office, Canberra.

Department of Climate Change and Energy Efficiency (DCCEE). (2010), *National greenhouse accounts (NGA) factors*, Department of Climate Change and Energy Efficiency, Canberra.

Dimoudi, A. & Tompa, C. (2008), 'Energy and environmental indicators related to construction of office buildings', *Resources, Conservation and Recycling*, vol. 53, no. 1-2, pp. 86-95.

Douglas, J. (1994), 'Developments in appraising the total performance of buildings', *Structural Survey*, vol. 12, no. 6, pp. 10-5.

Douglas, J. (1996), 'Building performance and its relevance to facilities management', *Facilities*, vol. 14, no. 3/4, pp. 23-32.

Dowson, M., Poole, A., Harrison, D. & Susman, G. (2012), 'Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal', *Energy Policy*, vol. 50, pp. 294-305.

Duffy, F. (1990), 'Measuring building performance', *Facilities*, vol. 8, no. 5, pp. 17-20.

Duffy, F., Laing, A. & Crisp, V. (1993), *The responsible workplace: The redesign of work and offices*, Butterworth Architecture, Oxford.

Ekanayake, L.L. & Orfori, G. (2004), 'Building waste assessment score: design-based tool', *Building and Environment*, vol 39, Issue 7, July, pp 851-861.

Ford, S. (2014), 'Taking the rubbish out of recycling data', The GPT Group, (viewed 23 July 2016, http://www.gpt.com.au/WWW_GPT/Media/_GPT/Site-Images/Content/Blog/Files/GPT-Waste-MGMT-Paper-01-12-14.pdf)

Formoso, C.T.; Soibelman, L. de Cesare, C. & Isatto, E.L. (2002), 'Material waste in building industry: main causes and prevention', *Journal of Construction Engineering and Management, July/August*, pp. 316-325.

Forsythe, P. & Marsden P.K. (1999), 'Modelling construction waste performance – an arising procurement issue', Ogunlana, S.O. Ed., *Profitable partnering in construction procurement, CIB W92 (Procurement Systems) and CIB TG23 (Culture in Construction Joint Symposium, Spon. London*, pp. 679-688.

Forsythe, P.J. (2010), 'Office buildings – the importance of "make-good" fitout and recurring embodied energy', *Proceedings of the CIB SB10 Conference, 25-28 May, Wellington, New Zealand*.

Forsythe, P.J., Bradley, K. & Dang, T. (2017), Reimagining Wood Based Office Fitout Systems – Design Criteria and Design Concepts", WoodSolutions Australia, Melbourne.

Gerilla, G.P., Teknomo, K. & Hokao, K. (2007), 'An environmental assessment of wood and steel reinforced concrete housing construction', *Building and Environment*, vol. 42, no. 7, pp. 2778-84.

Gertsakis, J. & Lewis, H. (2003), 'Sustainability and the waste management hierarchy – A discussion paper on the waste management hierarchy and its relationship to sustainability', *EcoRecycle Victoria*, March.

Goetzl, A. & McKeever, D. (1999), 'Building codes: Obstacles or opportunity?', *Forest Products Journal* vol. 49, no. 9, pp. 12-22.

Green Building Council of Australia (GBCA). (2011), ''Premium' equals 'green' in Property Council of Australia's new guide to office building quality', (viewed 23 July 2016, https://www.gbca.org.au/news/gbca-media-releases/premium-equals-green-in-property-council-of-australias-new-guide-to-office-building-quality).

Guggemos, A.A. & Horvath, A. (2005), 'Decision support tool for environmental analysis of commercial building structures', *Construction Research Congress: Broadening perspectives*, pp. 92-97.

Hardie, M., Miller, G. & Khan, S. (2011), 'Waste minimisation in office refurbishment projects: an Australian perspective', *Open Waste Management Journal*, vol. 4, pp. 21-27.

Horne, R., Grant, T. & Verghese, K. (2009), *Life cycle assessment: principles, practice and prospects*, CSIRO Publishing, Collingwood, Vic.

Howard, N. & Sutcliffe, H. (1994), 'Precious joules', *Building*, vol. 259, no. 11, pp. 48-50.

Huberman, N. & Pearlmutter, D. (2008), 'A life-cycle energy analysis of building materials in the Negev desert', *Energy and Buildings*, vol. 40, no. 5, pp. 837-48.

Hyder Consulting. (2011), *Construction and Demolition Waste Status Report*, for Department of Sustainability, Environment, Water, Population and Communities Queensland, p. 46.

IFMA. (2002), *Research Report 23: Project Management Benchmarks*, International Facility Management Association.

IPCC. (2006), *IPCC Guidelines for National Greenhouse Gas Inventories*. Volume 1. General Guidance and Reporting, Intergovernmental Panel on Climate Change, Kanagawa.

ISO. (2006a), ISO 14040: *Environmental management – Life cycle assessment – Principles and framework,* Geneva, International Standards Organization

ISO. (2006b), ISO 14044: *Environmental management – Life cycle assessment – Requirements and guidelines*, Geneva, International Standards Organization

Junnila, S., Horvath, A. & Guggemos, A.A. (2006), 'Life-Cycle Assessment of Office Buildings in Europe and the United States', *Journal of Infrastructure Systems*, no. March 2006, p. 8.

Kelly, M.J. (2009), 'Retrofitting the existing UK building stock', *Building Research & Information*, vol. 37, no. 2, pp. 196-200.

Keystone Acoustics. (2016), 'Key Lena, Perforated Sheet, Wall Decorative Panels', (viewed 23 July 2016, http://www.keystoneacoustics.com.au/key-lena).

Kharrufa, S. (2007), 'Reduction of building waste in Baghdad Iraq', *Building and Environment*, vol 42, pp. 2053-2061.

Klopffer, W. (2006), 'The role of SETAC in the development of LCA', *International Journal of Life Cycle Analysis*, vol. 11, Issue 1, pp. 116-122.

Klopffer, W. & Grahl, B. (2014), *Life Cycle Assessment-A Guide to Best Practice*, Wiley, Germany.

Kofoworola, O.F. & Gheewala, S.H. (2009), 'Life cycle energy assessment of a typical office building in Thailand', *Energy and Buildings*, vol. 41, no. 10, pp. 1076-83.

Kohler, N. & Moffatt, S. (2003), 'Life-cycle analysis of the built environment, UNEP Industry and environment, sustainable building and construction', *UNEP*, April/September, pp. 17-21.

Langdon, D. (2005), 'Why specify recycled in office refurbishment projects', Waste & Resources Action Programme, UK, (viewed 17 November 2014, http://www.wrap.org.uk/).

Larson, C. (2008), *Design: Sustainable spaces*, Property Australia.

LaSalle, J.L. (2005), *Building refurbishment – Repositioning your asset for success*, Jones Lang LaSalle.

Lee, K., Tae, S. & Shin, S. (2009), 'Development of a life cycle assessment program for building (SUSB-LCA) in South Korea', *Renewable and Sustainable Energy Reviews*, vol. 13, pp. 1994-2004.

Lei, L., Zhifeng, L. & Fung, R. (2003), 'The Most of the Most: Study on a New LCA Method', *paper presented to the IEEE International Symposium, Boston, MA*.

Li, M. & Yang, J. (2014), 'Critical factors for waste management in office building retrofit projects in Australia', *Resources, Conservation and Recycling*, vol 93, pp. 85-98.

Li, X., Zhu, Y. & Zhang, Z. (2010), 'An LCA-based environmental impact assessment model for construction processes', *Building and Environment*, vol. 45, no. 3, pp. 766-775.

Loftness, V., Hartkopf, V., Gurtekin, B., Hua, Y., Qu, M., Snyder, M. & Gu, Y. (2001), 'Building investment design support (BIDS™)', *ABSIC Research*, vol. 2002.

Mao, C., Shen, Q., Shen, L. & Tang, L. (2013), 'Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects', *Energy and Buildings*, vol. 66, pp. 165-76.

McKeever, D.B., Adair, C & O'Connor, J. (2005), *Wood products used in the Construction of low-rise non-residential buildings in the united states in 2003*, Wood Products Council.

Mickaityte, A., Zavadskas, E.K., Kaklauskas, A. & Tupenaite, L. (2008), 'The concept model of sustainable buildings refurbishment', *International Journal of Strategic Property Management*, vol. 12, no. 1, pp. 53-68.

Miller, E., & Buys, L. (2008), 'Retrofitting commercial office buildings for sustainability: tenants' perspectives', *Journal of Property Investment & Finance*, vol. 26, no. 6, pp. 552-561.

Moe, R. (2007), 'Sustainable stewardship: Preservation's essential role in fighting climate change', (viewed 16 march 2009, http://www.preservationnation.org/sustaiable.stewardship).

Monahan, J. & Powell, J. (2011), 'An embodied carbon and energy analysis of modern methods of construction in housing: a case study using a lifecycle assessment framework', *Energy and Buildings*, vol. 43, no. 1, pp. 179-88.

NABERS (2013), 'Office of Environment and Heritage', (viewed 12 August 2013, http://www.nabers.gov.au).

Nolan, G. (1994), 'The culture of using wood as a building material in Australia', *Pacific Wood Engineering Conference*.

Nuefert, E. (1994), Architects Data, 2nd (International), English Edition, BSP Professional Books.

O'Connor, J., Kozak, R., Gaston, C. & Fell, D. (2004), 'Wood use in non-residential buildings: opportunities and barriers', *Forest Products Journal*, vol. 54 No. 3, pp. 19-28.

Open Desk. (2016a), 'Fin Lockers', (viewed 23 July 2016, https://www.opendesk.cc/fin/fin-lockers#get-it-made).

Open Desk. (2016b), 'Half Sheet Table', (viewed 23 July 2016, https://www.opendesk.cc/zero/half-sheet-table#get-it-made).

Open Desk. (2016c), 'Zero Pedestal', (viewed 23 July 2016, https://www.opendesk.cc/zero/pedestal#get-it-made).

Page, I. (2006), *Wood in Government buildings – cost and environmental impact analysis*, BRANZ.

Puettmann, M.E. & Wilson, J.B. (2005), 'Life-Cycle Analysis of Wood Products: Cradle-to-Gate LCI of Residential Wood Building Materials', *Wood and Fibre Science*, vol. 37, pp. 18-29.

Phillips, P. (2008), 'Heritage in a warming world', *proceedings Hangzhou Forum on World Heritage Conservation, June*.

Poon, C.S.; Yu, A.T.W. & Jaillon, L. (2004), 'Reducing building waste at construction sites in Hong Kong', *Construction Management and Economics*, vol 22, issue 5, June, pp. 461-470.

Property Council of Australia (PCA). (2012), 'A guide to office building quality', (viewed 20/7/2016 http://www.propertycouncil.com.au/Web/EventsServices/ResearchData/Information Products/Web/Events Services/Research Services/ItemDetail.aspx?iProductCode=0105065).

Ramesh, T., Prakash, R. & Shukla, K.K. (2010), 'Life cycle energy analysis of buildings: An overview', *Energy and Buildings*, vol. 42, no. 10, pp. 1592-600.

Rey, E. (2004), 'Office building retrofitting strategies: multicriteria approach of an architectural and technical issue', *Energy and Buildings*, vol. 36, no. 4, pp. 367-72.

RICS. (2009), *Greening make good*, Royal Institute of Chartered Surveyors, London.

Roussac, C., McGee, C. & Milne, G. (2008), *Changing the culture of commercial buildings in Australia: the role of green leases*.

Ryburg, J. (1996), *New churn rates: people, walls, and furniture in restructuring companies*, Ann Arbor, MI: Facility Performance Group.

Sartori, I. & Hestnes, A.G. (2007), 'Energy use in the life cycle of conventional and low-energy buildings: A review article', *Energy and Buildings*, vol. 39, no. 3, pp. 249-257.

SETAC. (1993) Society of Environmental Toxicology and Chemistry, 'Guidelines for life cycle assessment: a "code of practice"', *LCA "Code of Practice" Workshop*, ed. F. Consoli, Portugal.

Shah, S. (2008), *Sustainable practice for the facilities manager*, John Wiley & Sons.

Singh, S. & Bakshi, B.R. (2009), 'Eco-LCA: A tool for quantifying the role of ecological resources in LCA', paper presented to the *Sustainable Systems and Technology, Phoenix, AZ, 18-20 May 2009*.

Skoyles, E. (1976) 'Material wastage – a misuse of resources', *Building Research and Practice*, July/August, pp. 232-242.

Steiner, J. (2006), 'The art of space management: Planning flexible workspaces for people', *Journal of Facilities Management*, vol. 4, no. 1, pp. 6-22.

Stephan, A., Crawford, R.H. & de Myttenaere, K. (2012), 'Towards a comprehensive life cycle energy analysis framework for residential buildings', *Energy and Buildings*, vol. 55, pp. 592-600.

Sturgis, S. & Roberts, G. (2010), *Redefining zero: Carbon profiling as a solution to whole life carbon emission measurement in buildings*, RICS Research, London.

Su, X. & Zhang, X. (2010), 'Environmental performance optimization of window–wall ratio for different window type in hot summer and cold winter zone in China based on life cycle assessment', *Energy and Buildings*, vol. 42, no. 2, pp. 198-202.

Tam, V.W.Y. & Tam, C.M. (2006), 'A review on the viable technology for construction waste recycling', *Resources, Conservation and Recycling*, vol. 47, pp. 209-221.

The Athena Institute. (2009), 'Sustainable Materials Incentive', The Athena Institute, (viewed 13 March 2010, http://www.athenasmi.org/index.html).

Thomson, T. (1992), 'Managing change', *Facilities*, vol. 10, no. 5, pp. 19-23.

Thormark, C. (2002), 'A low energy building in a life cycle – its embodied energy, energy need for operation and recycling potential', *Building and Environment*, vol. 37, no. 4, pp. 429-435.

Treloar, G.J. (1997), 'Extracting embodied energy paths from input-output tables: Towards an input-output-based hybrid energy analysis method, Economic Systems Research, vol. 9, no. 4, pp. 374-391.

Treloar, G.J., McCoubrie, A., Love, P.E. & Iyer-Raniga, U. (1999), 'Embodied energy analysis of fixtures, fittings and furniture in office buildings', *Facilities*, vol. 17, no. 11, pp. 403-10.

Tucker, S.N. & Treloar, G.J. (1994), 'Embodied energy in the construction and refurbishment of buildings', *Proceedings of CIB International conference on Buildings and the Environment*, Garston UK, May.

Ürge-Vorsatz, D., Danny Harvey, L.D., Mirasgedis, S. & Levine, M.D. (2007), 'Mitigating CO_2 emissions from energy use in the world's buildings', *Building Research & Information*, vol. 35, no. 4, pp. 379-98.

Verbeeck, G. & Hens, H. (2010), 'Life cycle inventory of buildings: A calculation method', *Building and Environment*, vol. 45, no. 4, pp. 1037-41.

Wilkinson, S. (2011), 'Sustainable retrofit potential in lower quality office stock in the central business district', *Proceedings of the International Conference on Management and Innovation for a Sustainable Built Environment, Amsterdam, The Netherlands, Delft University of Technology*.

Wilkinson, S. (2012), 'Analysing sustainable retrofit potential in premium office buildings', *Structural Survey*, vol. 30, no. 5, pp. 398-410.

Wilkinson, S.J. & Reed, R.G. (2006), *Office buildings and the environment – The increasing importance of ESD,* pp. 22-5.

Wilkinson, S.J. & Remoy, H.T. (2011), ‘Sustainability and within use office building adaptations: a comparison of Dutch and Australian practices’, *Proceedings of the 17th Pacific Rim Real Estate Society Annual Conference, Pacific Rim Real Estate Society*.

Williams, B. (1993), ‘What a performance!’, *Property Management*, vol. 11, no. 3, pp. 190-191.

Wilmot, K., McGee, C. and Milne, G. (2014), *Market Research: Tenancy Fitout Material Procurement Attitudes and Practices*; report prepared by the Institute for Sustainable Futures, University of Technology, Sydney, for Better Buildings Partnership.

Winther, B.N. & Hestnes, A.G. (1999), ‘Solar versus green: The analysis of a Norwegian row house’, *Solar Energy*, vol. 66, no. 6, pp. 387-93.

WRAP. (2014), ‘Refurbishment guide, February 2014’, (viewed 23 July 2016, http://www.wrap.org.uk/category/subject/refurbishment).

Xing, S., Xu, Z. & Jun, G. (2008), 'Inventory analysis of LCA on steel- and concrete-construction office buildings', *Energy and Buildings*, vol. 40, no. 7, pp. 1188-1193.

Yan, H., Shen, Q., Fan, L. C., Wang, Y., & Zhang, L. (2010), ‘Greenhouse gas emissions in building construction: A case study of One Peking in Hong Kong’, *Building and Environment*, vol. 45, No. 4, pp. 949-955.

Zabalza B.I., Aranda U. A. & Scarpellini, S. (2009), ‘Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification’, *Building and Environment*, vol. 44, no. 12, pp. 2510-20.

Zhang, X., Platten, A. & Shen, L. (2011), ‘Green property development practice in China: costs and barriers’, *Building and Environment*, vol. 46, no. 11, pp. 2153-60.