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RESEARCH ARTICLE

Barriers to reusing and recycling office fit-out: an exploratory analysis of demolition processes and product features

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Abstract

Within the highly waste-generative context of Australia, waste from demolition of office fit-out significantly contributes to unsustainable landfilling. The extant literature is, however, slim on scrutiny of the situation. Therefore, this study aims to uncover office fit-out demolition processes and product features that drive high ratio of landfilling fit-out elements. The research used ten case projects and fourteen interviews to document visible and latent parameters of office fit-out waste. Waste-stream mapping and decision-tree techniques, in conjunction with basic descriptive statistics, were used to model and visualize the extent and drivers of unsustainable fit-out demolition. Further, an exemplar product features analysis was conducted to validate the identified drivers. The findings show that 78% of fit-out waste from the studied cases is landfilled. This high rate is attributed to both latent and visible factors. The main latent factor is high lease price of premium or high-quality offices which favours expeditious demolition with low consideration for reuse and recycling. Key technically visible barriers are volumetric furniture, heterogeneous fit-out assemblies, and insufficient critical mass. To move away from landfilling, production of office fit-out should be transformed for sustainable material *adequacy, product re-configurability and de-constructability, and easy handling in the use phase.*

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Keywords:

Office fit-out waste, demolition processes, product features, production for reuse/recycle.

Introduction

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 (Pink, 2010). Within this context, construction and demolition waste continues to be one of the key contributors (Pickin and Randell, 2016). Waste from office fit-out demolition, in particular, has raised concerns due to its magnitude, recurring nature, and impact on the environment (Wilkinson, 2012; Waste Management Review, 2018).

The industry broadly estimates 6.3 tonnes fit-out waste for each 100m^2 of office space in Sydney Australia (Forsythe and Wilkinson, 2015; Host, 2018). It is also known that the annual lease renewal for office buildings in Sydney's Central Business District (CBD) equates to approximately 397,000 m^2 (Forsythe and Wilkinson, 2015). Like office buildings in other metro regions, such buildings in Sydney's CBD are predominantly classified as A-grade offices in an A-to-C grading system. A-grade office buildings are characterised by high quality finishes that typically attain higher rental levels than B or C grade buildings (Property Council of Australia, 2019). Since A-grade standard necessitates complete renovation of the office fit-out for the new tenants, the annual lease renewal generates approximately 25,000 tonnes of fit-out waste per year solely from the inner district of Sydney (Host, 2018). The same issue is applicable to office buildings in other Australian capital cities and appears to be a global problem in the urban core of metropolitan areas (Junnila and Horvath 2003; Mulholland, Hartman and Plumb 2005).

This reflects the short life cycle of office fit-out compared to the building life, and thus the recurring nature of office fit-out waste. According to a recent study, the lifetime of office fit-out in tenanted A-grade office buildings is 8.5 years on average (Forsythe, 2017). In other words, fit-out elements of an office space must be demolished every 8.5 years. Severity of this waste-prone context is exacerbated by the fact that the maximum reuse and recycle rate of fit-out demolition waste is collectively in the order of 20-30% and the remaining 70-80% is sent to landfill sites (Host, 2018; Waste Management Review, 2018).

Diversion from unsustainable landfilling has been targeted by different industry associations, such as Better Buildings Partnership, the Royal Institute of Chartered Surveyors (RICS), and Green Building Council (Frics, 2009; Wilmot, McGee and Milne, 2014; Davis Langdon LLP, 2016). The targeted conversion rate, i.e. summation of reuse and recycle rates, for office fit-out waste is 80% (Host, 2018). Nevertheless, the existing industry manuals, such as "Designing Out Waste", are not adequately detailed to direct such a significant improvement (Davis Langdon LLP, 2016). On the other hand, the available literature has mainly focused on quantification of fit-out waste. Also, the literature tends to wrongly view it as an end-of-life phenomenon rather than a recurring problem during operational life of the building (Osmani, Glass and Price, 2008; Ajayi et al., 2015). Moreover, when the attempts have been made to understand the reasons behind high landfilling rates of office fit-out waste, they lack a simultaneous view into both product features and operation processes in order to identify their likely relationships (Essex, 2012; Wilkinson, 2012; Forsythe and Ahmadian Fard Fini, 2018). Leaning towards one side, i.e. by considering either product or operation process, without taking the limitations of the other side into account, has resulted in devising solutions that cannot significantly reduce the high landfilling ratios.

Therefore, this study intends to analyse the office fit-out demolition waste from both a process-driven perspective and upstream product view. The process-driven perspective investigates demolition operation during building use phase and thus, identifies associated managerial and logistics factors constraining sustainable deconstruction of office interiors. The upstream view, on the other hand, focuses on fit-out products and evaluates production features that hinder cleaner disposal of fit-out elements. The present study adopts a hybrid of quantitative and qualitative research methods by conducting ten case studies and fourteen interviews in the context of A-grade office buildings. The collected information is then presented and analysed through waste stream mapping, decision tree modelling, and basic statistics. Finally, production features of an example fit-out commodity are analysed to examine their positive or negative impacts on potential for cleaner conversion options in the event of fit-out demolition.

Literature Background

The literature asserts that the generation of waste results from interacting effects of multiple processes and factors rather than a sole process or a single cause (Kurdve et al., 2015; Parisi Kern et al., 2015; Johansson and Corvellec, 2018). Therefore, effective management of waste relies on mapping all processes and causes in a common platform.

A mapping approach is commonly adopted as an effective visualization method to simplify a multifaceted process (Kurdve et al., 2015). Through presenting the logical flow of process steps, mapping techniques assist in consistent and balanced analysis of the entire process for debottlenecking and improvement purposes. Such benefits have been recognized by scholars in studying the current state of waste management leading to the advent of Waste Flow Mapping (WFM) techniques (Shen et al., 2004; Lu, Poon and Wong, 2006; Kurdve et al., 2015). This technique is prevalent in different sectors of the production industry, specifically for auditing material management systems (De Steur et al., 2016). Example applications exist from the agriculture and food, electronic, automotive, aerospace and nuclear industries in different territories covering America (Dias et al., 2018; Treadwell, Clark and Bennett, 2018), Europe (Kurdve et al., 2015; Rybicka et al., 2015; Blanco et al., 2018), Asia (Rochman, Ashton and Wiharjo, 2017; Lockrey et al., 2018; Yagi and Kokubu, 2018), and Africa (Goriwondo, Mhlanga and Marecha, 2011; El-Sayed, Dickson and El-Naggar, 2015). The auditing applications commonly refer to the increased efficiency of material use, material cost accounting, cost effectiveness of material handling, monitoring hazardous materials, and contaminations prevention (Johansson and Corvellec, 2018; Yagi and Kokubu, 2018).

The usefulness of WFM has been acknowledged in studying construction waste and construction waste management practices at both macro and micro levels. At macro level, the mapping approach is established to investigate generation and disposal of waste across the industry through broad analysis of the main waste streams (Parisi Kern et al., 2015). In this approach, high-level waste statistics, local, regional, and national waste management plans, and best waste management practices are collectively evaluated to portray their systematic relationships. The aim is to understand what factors contribute to landfilling waste such that territory-specific guidelines for moving towards sustainability can be developed (Poon, 1997; Parisi Kern et al., 2015). A recent study on best practise of managing construction and demolition waste in the European Union can be classified under this category (Gálvez-Martos et al., 2018).

Micro level WFM places emphasis on improving waste management in individual cases, which may then facilitate extension to a wider industry sector (Kurdve et al., 2015). This can best be exemplified through a capstone research conducted by Shen et al. (2004) who adopted a free flow mapping technique to compare waste management processes across eight individual construction sites. The technique was founded on distinguishing waste source, waste processing, waste destination, and waste facilitators. The adoption of this technique led to the identification of the weaknesses and the strengths of onsite waste management practices which are attributed to the features including number of waste handling processes, availability of waste sorting-out processes, and considerations for recycling/reusing wastes; to name a few. Micro level WFM has also shaped a basis for simulating onsite waste handling processes in a single case project (Lu, Poon and Wong, 2006). The central aim is to assess the cost effectiveness of such processes under practical constraints pertaining to labour resource availability besides time and space limitations. While such a close look into onsite waste management is advantageous, the same must be applied to upstream, side stream, and downstream processes that commonly occur on construction sites.

Among diverse contributors to the minimization of waste, the upstream production stage and the design factors are best conceived as enablers of effective waste management in downstream processes (Wang, Li and Tam, 2015). In line with this, several authors have advocated design for disassembly/deconstruction and design for reuse/recycle strategies to move away from landfilling (Tingley and Davison, 2011; Akinade et al., 2017). These strategies are then translated into basic and detailed design practices. While modular construction, open plan design, and low or no use of composite materials are considered in the basic design stage, detailed design focuses on utilizing features such as detachable joints, standard structural grids, and elements free from secondary finishes (Crowther, 1999; Gorgolewski, 2008). Moreover, designers are encouraged to take the handling of building components into design considerations (Wang, Li and Tam, 2015; Won and Cheng, 2017). Nonetheless, such recommendations remain at a generic level with inadequate and rather ambiguous details on features required for a waste-preventive handling. More importantly, the design strategies tend to underline the building itself with little consideration of the viability of downstream reuse and recycle markets. This is of paramount significance in the design of office fit-out since its removal is often directly linked to lease duration (Forsythe, 2017), thus making it a short life construction proposition. There is subsequently an increased need to consider downstream reuses of the fit-out to prolong its useful life.

Given the potential regularity of this fit-out-to-stripout cycle, it is apparent that the extant literature is under-developed in viewing it as an operational life problem. Instead, the literature tends to wrongly view it as an end-of-life phenomenon (Osmani, Glass and Price, 2008; Ajayi et al., 2015). This gap, however, has not received the attention it deserves. The context of office building fit-out/stripout, therefore, demands a more detailed study particularly when it is known that 1) higher targets are being progressively set for waste reduction (e.g. zero waste) (Downes, 2017), thus, no single area of waste generation should be overlooked; and 2) fit-out demolition represents a recurring waste that can cumulatively build up a significant quantity of waste over the building life cycle (Forsythe, 2017).

Buildings fit-out contains materials and components that have high potential for recovery. Nonetheless, the current reuse and recycle rate is on average 27% of the total stripout waste (Li and Yang, 2014). An opinion survey of stripout contractors and salvagers undertaken by the Institute of Sustainable Futures identified four factors influencing rate of recovery, namely time, cost, transport distances, and contamination (Wilmot, McGee and Milne, 2014).

This study highlighted a strong tendency towards the quickest demolition option which is concurrently justified by low demand for the salvaged commodities (Essex, 2012). Although these findings are valuable, research into fit-out waste must be expanded beyond opinion surveys to real world cases and technical aspects of office fit-out. Tangibility and technicality of real-world scenarios will facilitate a shift in paradigm from landfilling-dominant mindset to reusing and recycling approaches. A prerequisite for this shift is to gain a holistic insight into both the demolition processes and sustainability constraints of office fit-out commodities.

Research Methodology

Figure 1 shows methods and techniques used in studying office fit-out demolition waste. As seen, the study used a hybrid research method, consisting of case studies and interviews, in conjunction with visual and quantitative data analysis techniques. These steps and their findings were then validated by reviewing features of an example office fit-out product.

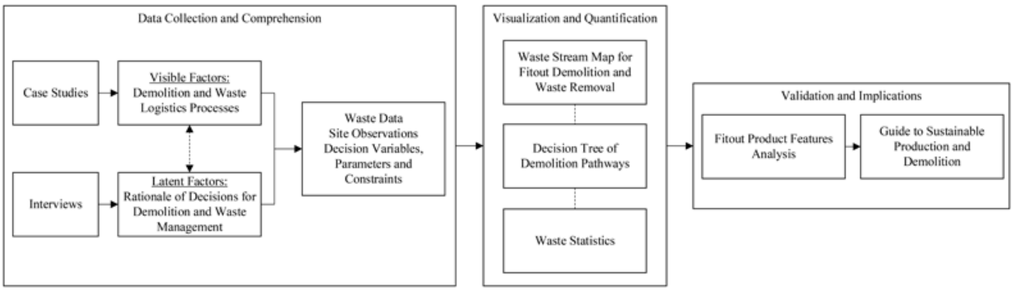


Figure 1 Methods and Techniques Used to Study and Validate Sustainability Barriers of Office Fit-out Wast

The case study stage focused on ten separate projects of the two largest fit-out demolition companies operating in the Sydney CBD. The scope of case projects was office stripout in high rise A-grade buildings (20 stories or taller). Such buildings were purposely chosen because they have been found to contain higher fit-out churn than other forms of office buildings (Wilkinson, 2012). This stage involved site observations and acquisition of waste data from the case projects. Site observations specifically aimed at recording processes of demolition operation and logistics of waste removal. Waste data, on the other hand, were obtained from weighbridge documentations of the case projects. To ensure the collected data are adequately representative of the fit-out demolition industry, the statistics and operation workflow of the two large demolishers were qualified by eight demolition contractors during the interview stage.

The interview stage intended to uncover rationales behind demolition methods and waste logistics observed during the case study stage. Therefore, semi-structured interviews were undertaken with fourteen stakeholders of office fit-out, including eight demolition contractors and six large property owners/managers. Each interview lasted approximately 60 minutes and utilised semi open questions about typical stripout and logistics processes and qualification of the materials that went to landfill, reuse, and recycling. The tenants of office buildings were not interviewed as they are not usually involved in any stage of the demolition process.

The data and information collected through case studies and interviews were analysed using four techniques. First, value stream mapping technique was employed to contextualize the processes and logistics of office fit-out demolition through both graphical and data representations. In addition, data from each interview was analysed according to the methods recommended by Boyatzis (1998). It is used to process raw qualitative data into categories of thematic meaning. This is similar to content analysis but importantly the focus is on categorising theme frequency rather than word frequency. Themes are patterns that make sense of seemingly unrelated data (Boyatzis 1998). The findings of interviews were used to both complement and confirm the observed site operations and demolition logistics.

Third, dynamics of fit-out demolition were also visualized through a decision tree. The tree was developed by classifying the fit-out demolition dataset into a hierarchy of subsets. Each subset was formed based on a variable that can predict the decision to reuse, recycle, or landfill the fit-out objects. The predictor variables include product features (shape, material, configuration, and condition) and economic factors (i.e. quantity, labour cost, and logistics). The features are ranked and positioned in the hierarchy in accordance with their importance in creating different decision outcomes. A variable is positioned higher in the tree if it has a higher entropy in determining the demolition destinations with largely different coefficients. For instance, shape is a predictor variable that classifies the fit-out items into non-volumetric and volumetric with 71.9% weight of the latter category ending in landfill sites. The classification continued until reaching one of the reuse, recycle, or landfill decisions. It should be noted that 56.3% of the paths were built based on the results of interviews and thus, are not supported by quantitative data. Therefore, the model is usable predominantly for qualitative assessments and visualization of the decision-making process in office fit-out demolition.

Finally, waste statistics from the ten case studies were summarized initially as total tonnage per each case, and then as tonnage per waste types, tonnage per waste streams and percentage of waste streams across all the cases. The fit-out wastes were decomposed into their constituting materials with a view to identify their likely associations with unsustainable disposal.

The above steps provided an informative basis for feature analysis of fit-out products. Therefore, production features of an existing fit-out element were examined to determine the validity of the findings and the extent to which the current state of fit-out production and demolition fosters a clean lifecycle. Finally, the implications of this research for different parties in the lifecycle of office fit-out are presented.

Results and Discussion

The interviewees insisted that the building owner and demolition contractor are the main actors who determine the extent of reduced waste to landfill, while the tenant has the least interest to influence their decision. The interviews also found that the contractors are primarily driven by the client's brief. If this brief mainly focused on cost, they are inclined towards choosing the easiest and the most cost-effective method which often results in the majority of the fit-out items going to landfill. The landfill ratio is perceived in the range of 65-80% on most of the jobs performed by the contactors.

To decrease the proportion, responsibility tends to reside with the building owner. This manifests in the way they setup the original leasing agreement (with tenant) where stipulations can be made about stripout requirements, including minimum percentages for reuse and recycling at the end of lease. Nevertheless, commercial arrangements negotiated at the end of the lease, may still see the actual management and physical execution of this work assigned to building owner. In other words, even though it is the tenants contractual obligation to "make good" (i.e. stripout their fit-out and return the area to original condition), it is also common for the tenant to eventually negotiate a financially based "walk away" arrangement with the building owner, who then take responsibility for executing the work on their behalf. Consequently, the leadership in such instances ultimately falls back with the building owner as the stipulation of reuse and recycling is no longer linked to the leasing agreement, but rather the building owner's own internal commitment to reuse and recycling.

Figure 2 shows the operational stages involved in managing the office stripout process. The interviews found that the management of this stage is assigned to the demolition contractor with neither involvement from the tenant nor intervention or supervision of the building owner. The process consists of nine stages across onsite, on-road, and offsite locations. The onsite sub-processes start in the office area being stripped out; continue on the waste marshalling area on that floor level; then waste materials are transported via the goods lifts; and end at the loading bay of the office building. The on-road stage involves dispatching the stripout materials by trucks to one or more of four different destinations. These may include an interim station for temporary storage of the materials when necessary, which can then be sent to recycling facilities, landfill sites, or salvage warehouses depending on the type and status of the waste.

ONSITE DEMOLITION PROCESS

Stage 1: Strip-out Area

In operational terms, barriers to adopting reuse and recycling approaches involve volumetric furniture, labour factors, and space constraints as affirmed by the interviewed contractors. Strip-out is a labour intensive process and subsequently a key issue is the cost of labour time. This is particularly paramount when volumetric items must be managed. A typical example is a workstation which can best present the operational situation during the demolition process. It is a bulky item that is difficult to avoid damage to during removal, thus reducing its reuse value. Such items are also slow and inefficient to handle in moving to the marshalling area for removal via goods lift. Under common designs, workstations are not easy to disassemble into recyclable material groups. Thus, an economic option is to knock it down where the metal base may be saved for recycling, but the rest, which commonly involves Medium Density Fibreboard (MDF) with laminate finishes, simply becomes part of mixed waste, as such materials are hard to recycle. Thus, labour costs and space savings are achievable since the mixed waste is directly placed into the wheeled bins. The bins are of a standard capacity of $1m^3$ which lends itself to easy move and manoeuvre.

If the demolition of such items is noisy, the process must be undertaken out of the office hours to ensure the residents of neighbouring offices are not affected. The speed of knocked-down demolition (i.e. generation of mixed waste) is approximately 85 tonnes/day, compared to demolition for recycling and reuse at 30 tonnes/day and 5-8 tonnes/day, respectively. Nevertheless, the cost-saving from the higher speed mixed-waste approach may be partly reversed by an extra cost of overtime labour rates that the contractor must incur due to the out-of-office-hours' work arrangement.

The interviewed contractors asserted that reuse and recycling must at least be cost neutral relative to landfill costs if they are to decide on a reuse/recycling demolition method. Nonetheless, the lost time on reuse/recycling methods is equivalent to the loss of rental revenue from the office building owners' point of view. Where the building owners tend to transfer this risk to the contractor through the liquidated damage clauses within the demolition contract, it is deemed as a cost factor which favours landfilling.

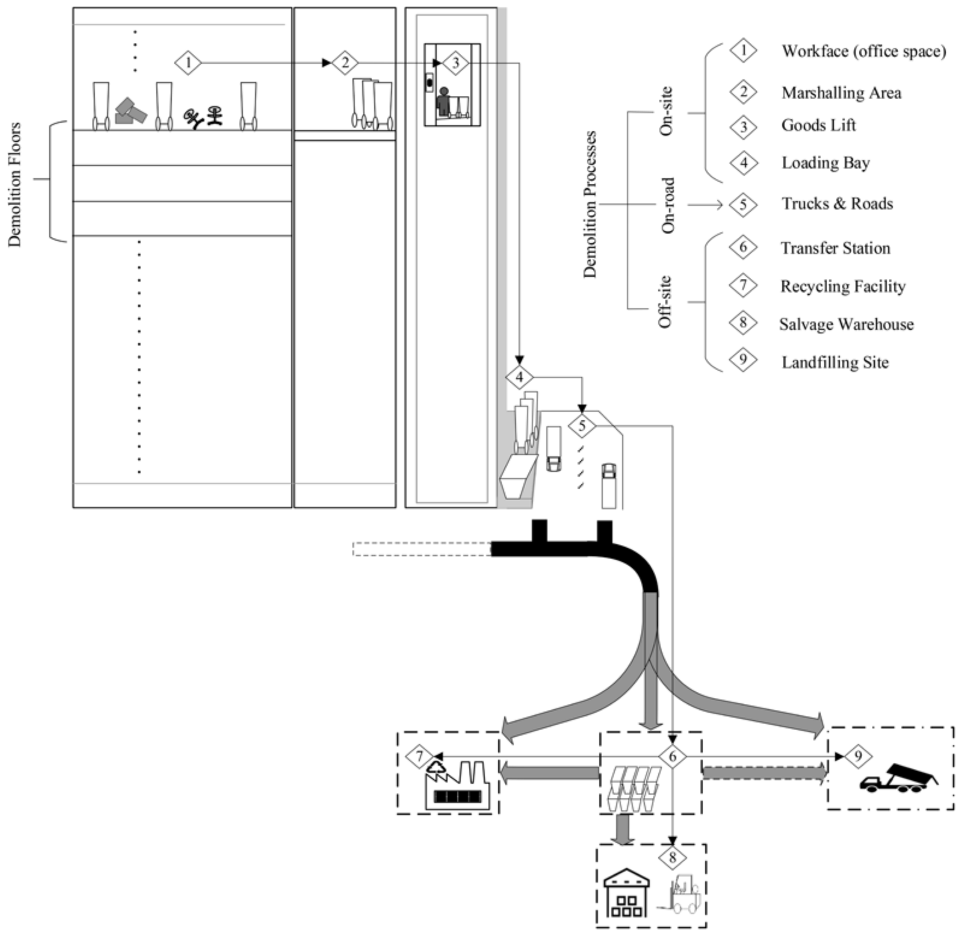


Figure 2 Fit-out Waste Stream Map in A-Grade Office Buildings

Stage 2: Marshalling Area

The demolished materials are then transported to the marshalling area near the goods lift(s). This is a shared area that other residents can utilize and hence, should not be fully occupied particularly during working hours. This suggests two limiting factors: one pertaining to space and the other relating to timing.

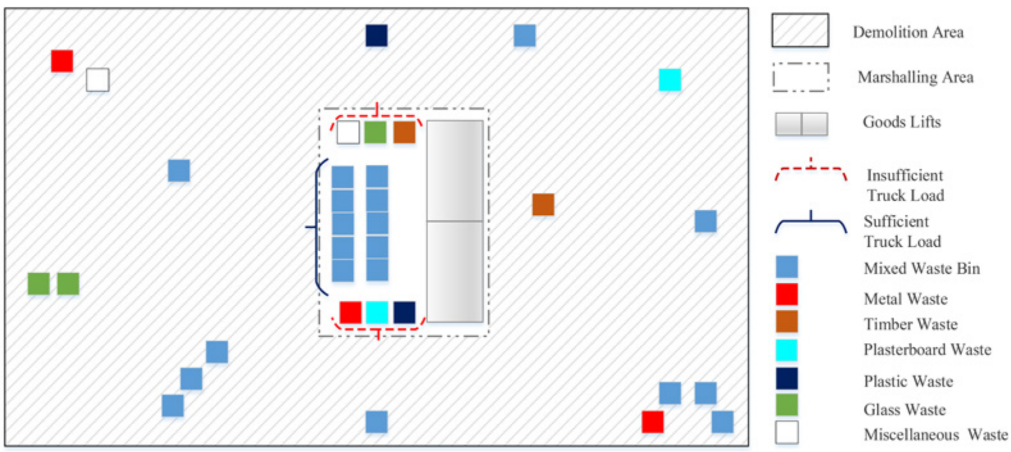


Figure 3 An indicative layout of an office building floor during fit-out demolition

The space constrains the amount of stripout waste that can be queued in front of the lift. It represents another reason behind impracticality of moving large volumetric units for reuse elsewhere. Conversely, this limited marshalling area tends to favour wheelable bins where materials can be densely loaded or packed with waste. Whilst this can then manifest as a single stream of mixed waste bins, preferable is streams of recyclable material bins. The interviews revealed that this latter option will be economically achievable if the collective bins in a stream are sufficient to fill a truck for cost effective road transport. Otherwise, cost efficiency will demand that such materials be relegated to mixed waste.

Figure 3 depicts an office building floor layout portraying office area, marshalling area, and goods lift during demolition of fit-out elements. As seen, the wheeled bins belonging to different types of waste can only be lifted down when a full truck load of a certain waste type is collected in the marshalling area. However, a full truck load of recyclable and reusable items usually requires a long waiting time in the marshalling area and hence, a line of such wastes awaiting removal obstructs others' movement into and out of the lifts. To minimize interference with business of neighbouring offices, the demolition contractor may be required to resort to out-of-office hours work arrangements. While this assists in avoiding time clashes with normal business hours, it is associated with two consequences; overtime labour rates and no time overlap with reuse/recycle centres. The latter one prevents just-in-time dispatching of wastes to those centres and necessitates intermediate links for temporary storage of materials.

Stage 3: Goods Lift

The goods lift is central to the efficiency of moving stripout materials from the working floor to the loading bay. This requires an unimpeded access to the lifts which tends to become possible during non-working hours. Another contributor to efficiency is full utilization of the lift capacity at each lift cycle. The interviews attested that a hindrance to a fully laden lift is carrying volumetric assemblies that cannot be disassembled and hence, results in carrying "air" and insufficient mass. Also, the size of the lift, inclusive of the lift door and the lift room, is a barrier to reusing such items as careless handling devalues them. It is also important to consider the speed of lift to ensure workflow at the loading bay is not interrupted and allows direct dispatching of waste materials.

Stage 4: Loading Bay

The space limitation is a more sever issue in the loading bay area than the upstream locations which reflects the fact that all the building tenants, not just the residents of one floor level, must have unrestricted access to the area. Therefore, a single party cannot occupy the loading bay in the basement level for an extended period. This imposes a limit on both the number of reusable furniture and the number of wheeled bins that can be placed in this location, as given in Appendix 1. Therefore, when sufficient waste from a given stream is attained to load a truck, the entire line of bins or furniture items should be sent down and removed from the building immediately. This favours handling and dispatching waste at the loading bay out of office hours when there is less competition for the area. In a limited number of cases, a temporary skip bin may be permitted in the car park that can later be picked up by the trucks.

ON-ROAD PROCESS

Stage 5: Trucks

Like the lifts, a fully laden truck is vital to efficiency and cost effectiveness of the entire demolition process. Thus, the truck capacity dictates the maximum quantity of waste (number of bins) from a certain stream that can be sent down at once. The full utilization of trucks, however, disfavours carrying awkward assemblies that in addition, are typically time-consuming to load. Moreover, trucks have a limited arrival and departure time over the working hours. A remedy suggested by the interviewees is an after-hours logistics arrangement that enables extended access to loading deck. Such an arrangement has its own pros and cons in terms of travel parameters. While a shorter travel time is expected during the off-peak hours, the demolition contractor must pay extra fees to removalists. The latter cost tends to be smaller than the benefit from fast shuttle between the waste destinations and the office building.

OFFSITE PROCESSES

Stage 6: Transfer Stations

A transfer station is an interim spot where stripout wastes may be temporarily stored for later dispatch to a final destination. Two aspects of such stations are non-stop working hours and inner-city location which both contribute to the efficiency of the entire work. The nearby position allows fast travel back to the site and hence assists uninterrupted demolition and logistics of wastes, considering the onsite space limitations. It was found during interviews that the non-stop working arrangement particularly facilitates the logistics of reusable and recyclable waste streams that can be held until recyclers and salvagers are open the following day. Moreover, when these streams do not have sufficient mass, they are collected in the transit depot until satisfying the economy of scale. A cost factor is tipping cost that is also taken into consideration when the decision on the demolition approach is made.

Stage 7: Recycling facilities

Stripout contractors acknowledged in the interviews that metals, glass, and to a lesser degree ceramic and plasterboard are materials that may have recycling value. Their decision to recycling is driven by a cost-benefit analysis accounting for separation costs, transport fees, and recycling benefits which are then compared with landfill costs. Two factors may impact the economics of recycling: i) a sufficient quantity of recyclables, referred to as "critical mass", should exist to justify separating and sending waste to a recycling depot. While this quantity may vary from one material to another, a mass in the order of approximately ten tonnes is generally perceived by the demolishers as critical to substantiate recycling, ii) recyclers generally accept deliveries in office working hours. Bearing in mind that the demolition process is mainly done during non-office hours, this necessitates temporary storage of materials in an interim yard which must be then taken to the recycling facilities during office hours. Accordingly, a double handling cost is added to the cartage of recyclables.

Stage 8: Salvage Warehouse

All the aforementioned circumstances for recycling are similarly applicable to reusable fit-out items. Besides, there are other costs associated with reselling of salvaged materials including storage costs, administration charges, and marketing and sales costs. Also, special care is required in handling reusable assemblies to avoid any damage that can devalue them. Apart from subsequent inefficiencies in the processes, a damaged item, for instance office furniture, is hard to find a market for, when newly manufactured ones exist with competitive prices and perhaps better functionality. Such themes tend to disadvantage the reuse pathway and prioritize landfilling or recycling. A potential remedy adopted occasionally by some of the projects studied is to directly sell or donating items, such as workstations, from demolition site to non-profit organizations and charities.

Figure 4 Views from office fit-out demolition: a) open plan view after demolition b) demolished elements

Stage 9: Landfilling site

When recycling or reusing does not return sufficient savings, the dominant stream will be mixed waste that goes to landfill sites. There is no quantity limit on admitting waste types except for hazardous materials, e.g. asbestos, that must be sent and buried in certain sites. Also, working hours of landfill sites are normally extended which allows coordination with the non-office-hour pattern of onsite demolition processes. Under landfilling scenario, a drawback is long haul from the office building in CBD to the landfill sites commonly located in suburban or regional zones. Such trips are associated with driver cost, fuel cost, road time, traffic time, and tip time which impact on the cost effectiveness and the efficiency of the entire stripout process. In this case, a nearby transfer station brings efficiency through facilitating fast shuttle back to the demolition site.

Table 2 Case studies and their waste statistics a) waste summaries per case floor area b) waste composition

a)

Case number	Total floor area (m^2)	Quantity of waste generated (tonnes)
1	1550	149.38
2	6130	469.27
3	1330	32.08
4	1340	35.90
5	1180	43.14
6	24875	1955.19
7	2290	100.44
8	1150	44.8
9	1470	44.92
10	1260	64.37
Total	42575	2939.49

b)

Type of waste	Reuse (tonnes)	Recycle (tonnes)	Landfill (tonnes)
Hard-fill (concrete, brick, Wall/floor tile)	7.42	180.21	280.09
Glass	-	9.59	-
Timber	-	1.76	-
Plasterboard	10.66	22.78	-
Mixed waste (Non-putrescible)	-	-	1946.07
Metal	8.46	381.84	27.54
Insulation	-	1.64	-
Electrical waste	-	0.20	-
Carpet	-	-	11.07
Asbestos	-	-	19.88
Workstations/Furniture	28.50	-	9.20
Percent total	1.62 %	20.35%	78.03%

SITE OBSERVATIONS

Figure 4 indicates interior views from an office building case in Sydney CBD, visited during this study. The typical open plan design of an office building after demolition and the wheeled bins carrying the demolished elements are respectively shown in part a and part b of Figure 4. As seen, lease churn is significantly waste generative which extends to demolition of basic building elements such as lighting fixtures and floor carpet.

A more negative aspect of this waste-prone practice is exposed when the statistics prove that the demolished materials are largely landfilled. The waste summaries of the ten observed projects indicate that from 2939.49 tonnes total waste generated, 78.03% goes to landfill sites, as shown in Table 2. This percentage validates the range stated for landfilling by the interviewed stripout contractors. However, the reused part of stripout waste is as tiny as 1.62%, reflecting perhaps both little market potential for reuse and inefficiencies associated with logistics of this stream. Nevertheless, a considerably higher reuse ratio of 41% was observed in Case 9 (see Table 2.a) which shows the possibility of moving further in this direction in the other cases. Three factors contributed to a higher reuse rate in this project. First, like the other two low-waste projects, this project had excluded the entire ceilings and part of the walls and bathrooms from the scope of demolition. Second, the demand for reuse had been readily identified and organized in a public school concurrent with the demolition operation. A third factor was the nearly-clean condition of furniture which facilitated donation to the public school.

The recycle stream has a relatively higher share, reaching 20.35% in the office stripout waste. This suggests that recycling currently presents a more economically feasible pathway than reusing for fit-out demolition.

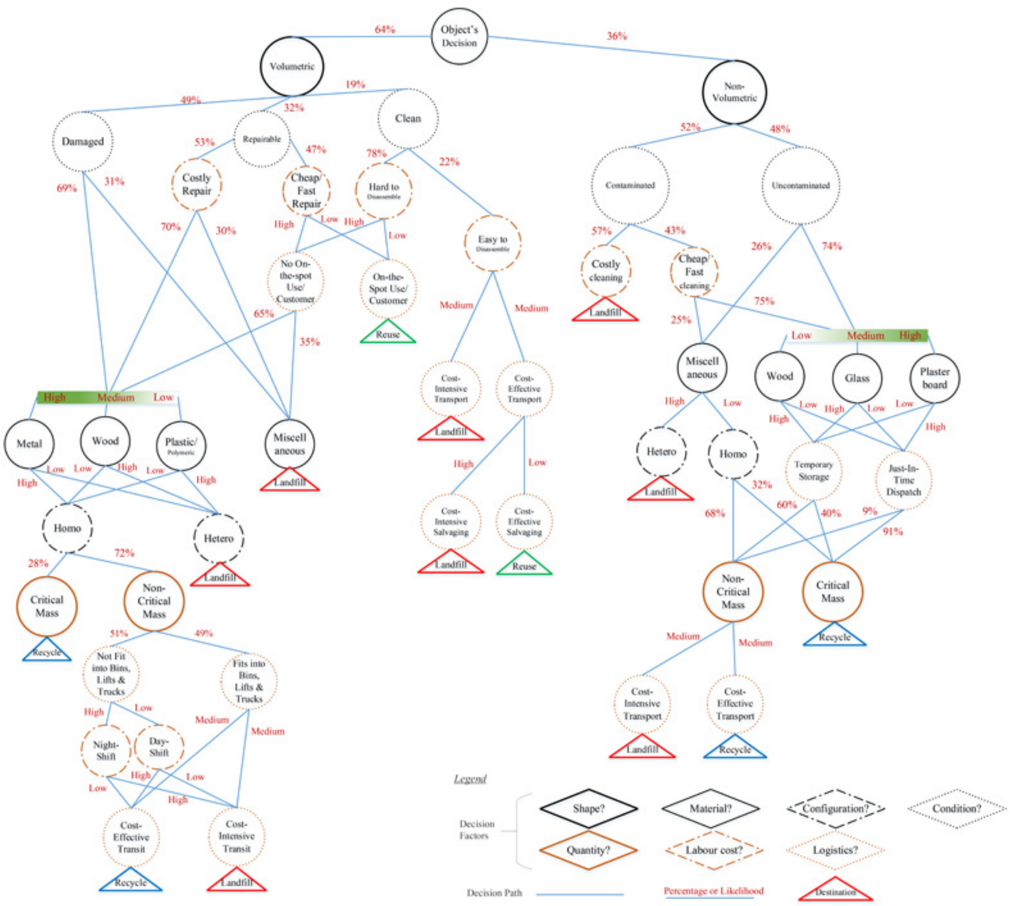


Figure 5 Dynamics of decision making on demolition of fit-out elements

Figure 5 demonstrates decision paths for demolition of fit-out elements in the case projects. A linguistic or numeric value shown on each arrow corresponds to the likelihood of that pathway for demolition wastes. Seven decision factors contributing to the selection of demolition methods for fit-out elements are shape, condition, labour cost, material, configuration, quantity, and logistics. The first decoupling point is attributed to shape of objects whereby more than 60% are volumetric items. Under this pathway, an object's condition is classified into damaged, repairable, and clean. A volumetric furniture may be reused if it is clean or quickly repairable and has an on-the-spot customer. Otherwise, it must be easy to disassemble and economical to transport and salvage to promote reuse. As shown, a recycling pathway for volumetric elements becomes possible when several conditions are satisfied. These include materials with high recycling value (i.e. metal, wood, and plastics) which are homogenous in configuration, and have enough. If the latter condition is not met, recycling income should overweigh fees incurred for movement and temporary storage besides costs of onsite sorting and labour rates.

Figure 5 also separates pathways of demolishing non-volumetric items which constitute less than 40% of fit-out elements within the case projects. Under this classification, it is notable that reuse is not usually an option. On the contrary, recycling became a feasible choice subject to certain circumstances. First, the item should be uncontaminated or cheap to remove its contamination. In addition, plasterboard, glass, and wooden panels are usually worthwhile to recycle particularly if sufficient mass is available. When minimum quantities set by recyclers are not available through a single project, the demolition contractors must assess profitability of collecting recyclables from multiple sites considering costs associated with temporary storage and transportation. Other materials, if not heterogeneous in their design, predominantly reside in the category of insufficient mass and thus, the decision to recycle them relies mainly on possibility of low-cost transport.

Table 2.b gives the waste composition generated in the case studies. As seen, the "mixed waste" has the record quantity of 1946.07 tonnes. This waste category contains different types of materials and fit-out components, including those commonly perceived to have recycling or reusing value. For instance, timber materials and workstations are spontaneously knocked down and placed into the mixed waste bin and thus, are all sent to the landfill sites. The interviews found that this is not an unexpected demolition approach under the context of office buildings in which the highest priority is given to economy. Concurrently, there are waste quantities separately recorded for workstations/furniture category both under landfill and reuse streams. These equate to 37.7 tonnes and indicate the initial attempts made by the contractors to consider such items for reuse. However, 9.2 out of 37.7 tonnes were landfilled. The interviewees attributed this issue to the inability to find a market due to either being not fit for reuse or not economically attractive in competition with brand new furniture.

Validations and Recommendations

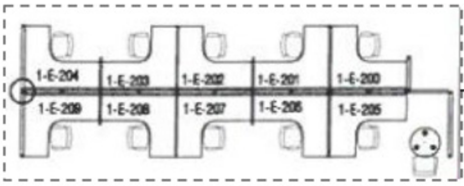
An example floor fit-out layout and one workstation within this layout were used to assess validity of the above findings. As shown in Figure 6, a section of the floor layout (in the middle depicted by a blue box) was analysed to identify reusable and recyclable items. As seen in the tabulated results, potential for reuse and recycling are sought in certain types of materials and elements.

Waste Stream	*Material*	*Item/Element*	*Percentage (%)*
Reuse	Plasterboard, metal	Wall panels, cabinets	6
Recycle	Metal, ceramic, glass	Plumbing fixtures/fittings, mirror/glass partitions, tiles	34
Landfill	Polymeric materials, Composite timber, Medium density fibreboard (MDF)	Carpet, MDF tables, toilets, cable trays, lightings	60

Figure 6 A quantitative analysis of reusability and recyclability of office fit-out elements

Here, composite materials of fit-out products that cannot be easily separated into homogenous material groups, and materials that lack sufficient quantity, typically go to landfill despite their inherent reuse/recycle potential. Figure 7 further elaborates on the issue by examining production features of a workstation and their likely impact on reusability and recyclability. This workstation is made of composite MDF, polymeric (laminate) surfaces and metal chassis.

Except for the scratch-resistant laminate surfaces that are a positive feature for reuse, the remaining materials do not independently affect reusability. However, the customized dimensions and non-identical panels may lower adaptability to other uses in a different location and hence, hinder reusability. Simultaneously, existence of non-screwed joints combined with low re-configurability means that this workstation cannot be easily and quickly disassembled into parts and hence, must be transported as a volumetric item. This costly handling in conjunction with its non-competitive value in the second-hand market diminishes its potential for reuse. On the other hand, its composite materials do not contain recycling value except for the metal chassis. The metal chassis must be sawed and separated into relatively identical pieces for economic removal. This is, however, constrained by two process factors: noise level limitation and inadequate quantity (critical mass) of metal. Difficulties in managing the noise level and reaching critical mass legitimize quick breakdown into mixed waste which is ultimately landfilled. Further, there exists no end-of-life return program to encourage recycling.



Production		Impact on potential for	
Feature	Description	Reuse	Recycle
Material	1. MDF 2. Polymer 3. Metal (chassis)	O	-
Dimensions	1.4m×2m×1.8m	-	-
Components	Non-identical panels	-	-
Surfaces	Laminate	+*	O
Joints/Connections	screwed and no screwed (Fixed)	-	-
Re-configurability	Low	-	-
Second-hand market or salvage value	Low	-	NA
End-of-life return program	No	NA	-

*If laminate is durable.

O: Neutral, +: Positive, -: Negative; NA: Not Applicable

Figure 7 Production features of a workstation and their impact on reusability and recyclability

Redesign philosophy for increased reuse and recycling rates, must fit in with the above conditions to enable sustainable deconstruction. The redesign criteria include increasing critical mass of sustainable materials, simple and quiet site demolition and separation (through screw joints and nut/bolt connections), flat components or compressed handling of items, and homogenous materials as distinct from composite materials that are hard to recycle. There is a significant need to design and produce systems that have minimum different components, but maximum simple and readily available parts made from one or two sustainable materials instead of multiple materials.

To achieve the high targets set for diversion from landfilling, the changes in design philosophy must also be accompanied by reforms in managing the supply chain of office fit-out. There is a need to redefine the roles that different parties play. The tenants, as the main users, have little or no practical involvement in the end of life stage of office fit-out. If the office occupiers can be rated on their performance in fit-out waste management, like the green ratings assigned to the assets and objects, they may demonstrate a stronger commitment and involvement in greener demolition of the fit-out. Similar strategies can be adopted to assess the sustainability performance of the building owner and the demolisher. These may require extending the currently facility-dominant sustainability rating systems as well as adjustments in the lease contracts. The reform should also place significance on integrating and engaging the end-of-life players, i.e. the landfill sites, recyclers, and second-hand users. The landfill sites can play a verifying role in reporting the fit-out waste. The recyclers can be further engaged in preplanning stage to maximize the recyclable items and perhaps to flexibly provide access to their depot. Similarly, the salvagers and charities can proactively be engaged to find potential reuse for the office furniture.

Conclusions

The processes and logistics of office fit-out demolition were investigated through site observations, interviews, and data modelling and analysis. Further, fit-out commodities were analysed to examine their production features that may hinder sustainable demolition.

Current practices of office stripout are found to be shaped mostly by economic decisions arising from the stripout process, cartage and drop off demolition waste. The high lease price of A-grade offices in CBD's multistorey buildings triggers a landfill-prone approach in demolishing fit-out elements since it is perceived as the most expeditious and cost effective option in the given market circumstances. In addition, fit-out elements were found to be typically produced for single use with features that limit, if not discourage, sustainable demolition. These are evidenced by small proportion of 1.62% and 20.35% respectively for reuse and recycle, in 2939.49 tonnes fit-out waste generated from the ten case studies.

Key fit-out product features that cause unclean demolition include volumetric configuration, inconsistent and heterogeneous composition of materials, rigid and non-restorable joints, and non-resistive surfaces and skins. Such features limit possibility of dismantling, separating, and sorting fit-out componentry and thus result in insufficient material streams. Therefore, reuse and recycle potentials are not technically and economically feasible in majority of the cases.

To cope with the green office interiors requirements, changes are necessary in design and production features of office fit-out elements. Using a relatively homogenous palette of materials to create sufficient critical mass that justifies recycling, developing scalable components that facilitate multipurpose use/reuse, ensuring fast knockdown from volumetric to flat and stackable packages, using screw or bolted joints that allow quiet deconstruction methods are the most required alternations in production attributes of office fit-out. The changes in design philosophy must be accompanied with reforms in managing the supply chain of office fit-out and the roles different parties play across the lifecycle of office fit-out.

Further investigations are needed to translate these attributes into practice. The scope of future studies should, therefore, be extended to involve office building tenants, designers, manufacturers, landfill sites, recyclers, and salvagers, each of whom must play role in realization of high reuse and recycle ratios.

The scope of this research is limited to high-rise office buildings located in inner city areas. Therefore, the findings may be generalizable to the same class of buildings in other capital and metropolitan cities that encounter similar circumstances, in terms of office buildings stakeholders, fit out demolition parties, and vertical and horizontal logistics of wastes.

Appendix 1 Parameters and constraints associated with office strip-out stages

Stage No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Constraints	*Office*	*Marshalling Area*	*Goods Lifts*	*Loading Bay*	*Trucks Arrival/Departure (Loading Deck)*	*Transfer Stations*	*Recycling Facilities*	*Salvage Warehouses*	*Landfill Sites*
Actors	Demolition contractor, Property owner, Tenants (Client)	Demolition contractor; Building residents	Demolition contractor; Building residents	Demolition contractor Building residents	Demolition contractor, Logistics partner	Demolition contractor, logistics partner,	Logistics partner; Recycler company	Demolition contractor, Salvager	Demolition contractor, Landfill Site Operator, Government
Materials restriction	Volumetric furniture and work stations	Volumetric furniture and work stations	Between 1000 and 1500 kg	Volumetric and bulky items	NA	Hazardous materials	Composite materials, critical mass	Impacted functionality, contaminated components/material, critical mass, Value of core materials compared to new materials	Hazardous materials/ contaminated materials
Cost factor	Labour cost (productivity cost) Sorting out Cost, Overtime labour rates	Labour cost	High pay rates for out of hours (or overtime) work	High pay rates for out of normal hours	Loading and logistics crew cost, fuel cost,	High tipping cost	NA	Cleaning and repair cost, cost of storage, administration and marketing	Landfill fee
Time	Office hours= non-noisy works, Out of office hours= noisy works	Office hours= Towards end of office hours	Outside normal office hours	Outside normal office hours (2-3 hours before opening time)	Traffic time	NA	(Extended) Office hours	Office hours	Tip time
Speed	Mixed waste= kg/day Reuse waste= kg/day Recycle Waste= kg/day		1-2 minutes waiting time plus 50-300 vertical meters/ minute	3-5 minutes/ 10 meters distance (from lift)	Inner city streets speed	20-40 minutes per truck (including waiting time)	-	Sufficient turnover	Long haul trips/ road time
Space	Floor area (Variable)	1-3 rows for up to 15 bins (each $1m^3$)	Door's width= 80-120 cm Height= 230-270cm Volume = 3-8 bins (7-23 people)	1-3 rows for up to 15 bins (each $1m^3$)	Up to 3 trucks in queue (loading bay)	-	-	Limited Storage Area	-
Labour	Day shift: 6 labours Night shift: 3-4 labours	3 labours	1-2 labours	Loading crew (1-2 labours)	Loading crew (1-2 labours), truck driver	1 Truck driver, lift truck operator and/or flagman	1 Truck driver	1 Truck driver	1 Truck driver

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