Residential construction and demolition waste in Perth, Western Australia: Cost benefit analysis of best practices.

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DECLARATION

This thesis is submitted to the School of Engineering and Information Technology, Murdoch University, as partial fulfilment of the requirements of ENG470 Engineering Honours Thesis and for the degree of Bachelor of Engineering Honours (BE(Hons)) in Environmental Engineering.

I, Casey Felmingham, hereby declare that the work presented herein has been completed in accordance with Murdoch University policy on plagiarism, is my own work unless otherwise referenced.

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ABSTRACT

In Perth, Western Australia the construction and demolition (C&D) industry contributes 50% of all waste generated. The recovery rate in WA for C&D waste is currently only 38% which is very poor compared to European countries as they are exceeding 80%. This project aimed to assess C&D waste generation in Perth to determine how waste recovery could be improved. Waste from three construction sites and two demolition sites was collected and collated to determine waste generation and composition and to identify areas for improvement. Also landfill sites, skip bin operators, and resource recovery facilities were surveyed on the cost of waste disposal to determine the most cost effective option. This study showed that the residential construction industry would generate approximately 881,000 tonnes of waste during 2015 using the predicted housing figures from HIA and UDIA. Also it shows that there is great variation with the generation of demolition waste due to the different site characteristics, which was shown by the two demolition sites of different sizes both generating nearly 300 tonnes of waste. Resource recovery was found to be the most cost effective option out of landfill, skip bins and resource recovery. The waste streams produced highlight that the main area of concern is rubble materials, concrete, sand, dirt, and broken bricks and tiles. Therefore better waste management of these wastes and possible recycling into waste derived materials is recommended. The findings from this study indicate that large scale changes are needed within the industry to increase resource recovery rates in WA, such as legislation change, more education, and the possible introduction of subsidy programs.

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INTRODUCTION

Globally, construction and demolition (C&D) waste contributes a significant amount of waste to landfill. C&D waste includes a mixture of inert and non-inert materials arising from a range of activities, including excavation, civil and building construction, roadwork, site clearance, demolition and building renovation (Yuan *et al.* 2011). It is estimated globally that C&D waste contributes between 10-50% of all waste going to landfill per annum and Australia is not immune to this trend (Esin & Cosgun 2007; Sáez *et al.* 2012). The waste going to landfill can have serious detrimental effects to the environment, such as leaching which causes the land to become contaminated (Waste Authority 2012). There is growing pressure for C&D companies to reduce costs, improve the sustainability of the industry and try to improve the quality of the environment. As a result the C&D industries in a range of countries are trying to recover 70% and upwards of all C&D waste produced from the industry, a figure set by their respective governments (Esin & Cosgun 2007; Sáez *et al.* 2012). Recovery rates of some countries overseas far exceed 70%, for example Ireland, Germany and the Netherlands recover 80%, 86% and 89% of their C&D waste respectively (DSEWPaC 2011). To achieve these goals countries have implemented different kinds of auditing and management strategies, these strategies incorporate the 3R's (reduce, reuse and recycle) wherever possible (MoECC 2008). When these recovery rates of C&D waste are compared to those of Australian states it is clear that there is room for improvement with Australia's recovery rates varying from 0.2-81% (DSEWPaC 2011).

In 2010/11 Australia produced 48 million tonnes of waste with the C&D industry contributing 18 million tonnes or 37.5% of all waste (DSEWPaC 2014). This is significance for Australia. Western Australia (WA) has been identified as the biggest producer of waste Australia wide, of which C&D waste is a major contributor (HIA 2007a). The recovery rate of C&D waste has gradually improved over time and in 2012/13 approximately 40% of waste was recovered. However, the most recent report for 2013/14 indicated that waste recovery had gone backwards (38%) and was the same as 2010/11 (ASK 2015), indicating that the C&D waste recovery system in WA is flawed (Esin & Cosgun 2007). Closer to home the Department of Sustainability, Environment, Water, Population and Communities in 2012 published a report that defines management classification systems, policies and identified the lack of consistency across Australia, which is restricting the opportunity for resource recovery activities within the industry (DSEWPaC 2014). C&D waste can be reduced by following the recommended waste hierarchy which is used to reduce the amount of waste created on the construction or demolition site (Waste Authority 2013).

In 2007 the Housing Industry Association (HIA) estimated that the average residential building site in WA was producing approximately 14.3 tonnes of waste, with a large portion ending up in landfill (HIA 2007a). It is normal practice for C&D sites in WA to combine all wastes into mixed loads for disposal at inert (Class I) landfill sites; this limits the potential for resource recovery (DoE 2006). Numerous issues surrounding generation, collection and treatment of building waste within WA were identified by the Department of Environment (DoE) with the key factors including low cost of disposal to landfill and an industry culture of mixed loads (DoE 2006). Another factor contributing to the high levels of waste generation is state legislation relating to residential C&D waste management in WA, including collection, disposal, recovery, and recycling. The legislation is not designed to reduce waste and it mainly relates to nuisances caused by C&D waste and its removal from site, associated health impacts, site maintenance and safety issues, therefore not including best practices for waste management which would improve environmental health (DEC 2009; Waste Authority 2013). Finally, reliable transparent data on waste generation from the residential C&D sector is lacking, making informed decision-making difficult for all stakeholders. These combined factors have resulted in poor waste recovery in WA, which needs to be addressed for waste recovery systems to be improved.

Significant research into waste recovery has been conducted around the world and a range of methods have been used to measure and analyse the amount of waste produced per site, as well as different management plans being implemented (MoECC 2010). However, there is not a consistent way of auditing and managing construction waste anywhere. Due to this there are large gaps in the literature, which make it difficult to compare studies. Therefore, more research into auditing and management strategies is required, which can help create a consistent and efficient way of auditing and managing C&D waste.

The aim of this thesis is to assess residential C&D waste production by builders and demolishers in Perth and to identify the main waste streams associated with this process. For this study double brick houses will be the main focus as they represent the most common type of home being built in Perth. Material flows, modelling and quantities of waste products generated at these sites will be used to highlight the need to implement the waste hierarchy (avoid, reduce, reuse and recycle) into recovery of C&D waste on and off site. Further to this, this study aims to undertake a simple cost analysis of sending C&D waste to landfill and resource recovery facilities. There is also a need to identify the gaps where other recycling services can help reduce the overall waste input to landfill. Finally this thesis will assess existing constraints such as legislation and costs, and new opportunities and programs for residential C&D waste resource recovery options will be identified in WA to help aid in waste reduction to landfill from the C&D sector.

LITERATURE REVIEW

Australia produced 48 million tonnes of waste in 2013 with the C&D industry producing 18 million tonnes, which equates to 37.5% of all waste (DSEWPaC 2014). Although this is a huge issue Australia wide, WA has been identified as the biggest producer of C&D waste in the country. In the Perth metropolitan area, over 50% of waste can be attributed to the C&D industry, which is a 20% increase on what has been recorded in the past (HIA 2007a). It has been estimated by HIA (2007) that the amount of waste going to landfill in Western Australia is in the vicinity of 1.5 million tonnes per annum, of which approximately half is C&D waste (HIA 2006). Table 1 shows the breakdown of C&D waste being sent to landfill and the percentages being recovered across all the states and territories (ASK 2015; DSEWPaC 2011).

Table 1: C&D landfill and recovery rates across states and territories of Australia.

State/Territory	Tonnes to landfill	Landfill rate (%)	Tonnes recovered	Recovery rate (%)
New South Wales	1,845,183	27.5	4,871,868	72.5
Queensland	2,182,674	63.3	1,265,820	36.7
Victoria	1,717,938	47.4	1,906,230	52.6
South Australia	430,795	23.5	1,402,756	76.5
Tasmania	57,739	84.8	10,334	15.2
Northern Territory	194,890	99.8	449	0.2
Australian Capital Territory	40,405	18.8	174,712	81.2
Western Australia	N/A	62.0	N/A	38.0

The report by ASK (2015) details the most recent figures for C&D waste in WA, and these numbers suggest that the C&D industry has taken a backslide. The results from the 2012-13 financial year periods indicate that 40% of waste was being recovered and in the 2013-14 financial year period C&D recovery rates backslid by 2% to 38% (ASK 2015). This is the same recovery rate of the 2011-12 financial year period. It is clear that there is room for improvement in the C&D industry for waste recovery, therefore more research, auditing, and management is needed.

C&D Projects

The Urban Development Industry Australia (UDIA) (2014) state of land report suggests that the number of lots of land produced for sale has increased since 2008, but the average lot size has started to decline with the median lot size being 419m^2 in the 2012/13 period (UDIA 2014). The housing forecast produced by HIA (2015) suggests that there will be a large decrease in houses being built, from 24,010 thousand in 2014 down to 20,350 thousand in 2015. The long term forecast predicts a continued decline over the next few years as the Perth population starts to stagnate (HIA 2015). If these predicted trends are to occur then demolition works will also be expected to slow as the need for more housing is reduced. This decline would also affect the amount of waste being produced from C&D works, but this decline in waste doesn't reduce the need for resource recovery to be improved.

Legislation/Regulation

The National waste policy "less waste, more resources" was endorsed by the Australian waste minister in 2009. This policy aims to avoid the generation of waste, reduce the amount of waste for disposal, manage waste as a resource and ensure that waste treatment, disposal, recovery and re-use are undertaken in a safe, scientific and environmentally-sound manner (DSEWPaC 2012). Strategy 11 states that all state governments should continue to encourage best practice waste management and resource recovery for C&D projects in all states and territories (DSEWPaC 2012). The Australian government does not directly legislate management of C&D waste; therefore the management of environmental issues, including all waste revenues is the responsibility of Australian state and territory governments. Due to waste management being left to state and territory regulations the approach commonly adopted by governments is one that involves stakeholder to be engaged and multi-party agreements (DSEWPaC 2012). Table 2 illustrates the state legislation that directly impacts the C&D industry.

Table 2: Legislation/Policy/Standards set by the State Government (WA) (DSEWPaC 2011; DER 2015).

Legislation/Policy/Standards	Relevance to C&D waste
Environmental Protection Act 1986	Makes policies and regulations for WA's waste management. • Site clearing relating to dust & noise that impacts health. • Transporting materials to/from site and stockpiling of wastes/recycled products on site. Ensure dust due to wind movement across unsealed areas and material movements. • Poor site maintenance practices relating to pests, vermin and weeds that impact on local flora & fauna. • Prevention of illegal dumping and issuing fines. • Uncontrolled or poorly managed site run-off.
Environmental Protection Regulation 1987	Provides detail for the functioning of the Environmental Protection Act 1986. The regulation deals with prescribing the sorts of activities should be permitted as well as licensing and fees for applicable activities.
Environmental Protection Regulation (Controlled Waste) 2004	Sets out a licensing and tracking system for transportation and disposal of waste such as asbestos and making it an offence not to comply.
Waste Avoidance and Resource Recovery Act 2007	The key responsibilities of this Act are: • The development of long term waste management strategy for WA. • To improve waste services. • To avoid waste generation. • To set targets for resource recovery.
Waste Avoidance and Resource Recovery Levy Act 2007	This Act prescribes the levy that is payable in respect to waste received at disposal premises. The levy revenue is used to fund waste management initiatives.
Waste Avoidance and Resource Recovery Levy Regulations 2008 Waste Avoidance and Resource Levy Regulations Administration Policy 2009	Outlines the levy requirements for the disposal of waste to landfill. This policy relates to the WARR Act 2007, WARR Reg. 2008 and WARR Levy Reg. 2008 and provides a summary of the procedures and requirements for the assessment and calculation of the landfill levy on all waste received by licensed landfills in WA.
Draft Waste Strategy for Western Australia 2010	Recommends government agencies and government owned agencies to take 50% of the current C&D waste stream for use as raw material. Strategies and targets set: • By 2016 C&D waste recovery rate of 50%
Extended Producer Responsibility Policy Statement	To ensure implementation of extended producer responsibility programs to problem wastes (C&D waste) as priority for product stewardship schemes.
Main Roads Western Australia Specification 501 – Pavements	Allows the use of recycled concrete road base materials as a sub-base or base course in road construction.
Main Roads Western Australia Specification 201 – Quality	Implementing a third party certified management system or plan, for example an AS/NZS ISO system.

Systems	
Reducing Construction and Demolition Waste going to Landfill in WA – Draft discussion paper Nov 2010	To replace a proportion of virgin material used in road base products with recycled materials.

Local governments also have their own legislations that should relate to the WARR Act (2007), but only a few have any regulation/legislation for C&D waste. Local governments are primarily concerned with noise control and health concerns from dust and waste, which all tend to fall under the Local Laws Health Act 1911 and /or the Local Government Act 1995. Most that have these are similar to Table 3 which shows the health local government laws for the City of Bayswater, Town of Cambridge and City of Wanneroo. A full list of local government law that refers to C&D waste can be found in Appendix A.

Table 3: Local laws for C&D in the City of Bayswater, Town of Cambridge, and City of Wanneroo (City of Bayswater 2015; City of Wanneroo 2015; Town of Cambridge 2015).

Legislation/Regulation	**Relevance to C&D waste:**
City of Bayswater Health Act 1911 WA amended to suit local government: Health Local Laws 2001 (Part 4.15 Removal of rubbish from building sites)	(1) During all periods of construction on any building site – a) The builder shall provide and maintain on the site a rubbish disposal bin of sufficient capacity to enable all waste generated on site to be effectively disposed of. b) The builder shall keep the site free of rubbish and offensive material, whether temporary or otherwise. c) The builder shall maintain the street verge immediately adjacent to the site free of rubbish and offensive matter, whether temporary or otherwise. d) The builder shall on completion of construction immediately clear the site and the street verge adjacent there to of all rubbish and offensive matter and shall remove there from all or any rubbish disposal bins there on by the builder. (2) In this section the word "rubbish" shall include stones, bricks, lime, timber, iron, tiles, bags, plastics and any broken, disused or discarded matter whatsoever.
Town of Cambridge Health Act 1911 WA amended to suit local government: Health Local Laws 2001 (Part 5.13 Construction site refuse)	On every building construction site the builder shall – a) Ensure that an appropriate refuse receptacle is provided on site for the storage of building rubbish on any premises in which building or construction work is being carried out. b) Ensure that all rubbish from the site is placed in the receptacle as directed by an authorised person, any building surveyor of the local government or

	an environmental health officer. c) Ensure the receptacle is maintained on the site for the duration of the construction work. d) Ensure the receptacle does not overflow e) Ensure that any refuse in the receptacle cannot be blown out by wind.
City of Wanneroo Health Act 1911 WA amended to suit local government: Health Local Laws 2001 (Part 12.3 Litter control on building sites)	12.3 Litter control on building sites (1) No person, owner or occupier shall allow or commence or continue the construction of any building works on any land, unless one of the following measures is implemented to prevent building litter or rubbish of any kind whatsoever from being blown from the construction site - a) Provide a receptacle of a capacity not less than $4m^3$ fitted with a lid on site for the disposal of all rubbish. b) Provide an equivalent wire enclosure on site with a lid for the disposal of all rubbish. (2) All rubbish which is capable of being wind-blown and other offensive matter on the construction site is to be placed and kept in the receptacle. (3) The lid is to be kept secure on the receptacle at all times.

Economics

Currently the large majority of C&D waste in Perth goes to landfill, representing a significant loss of resources (HIA 2007a). As a result the landfill levy fees in WA have been raised in an effort to deter C&D waste being sent directly to landfill (Table 4), it appears that further factors need to put into practice that would further encourage minimisation of waste to landfill.

Table 4: Landfill levy rates (Waste Authority 2015).

Period	Putrescible rate per tonne	Approx. Inert rate per tonne	Inert rate per m^3
1st Jan 2015-30th Jun 2016	$55	$40	$60
1st Jul 2016-30th Jun 2017	$60	$50	$75
1st Jul 2017-30th Jun 2018	$65	$60	$90
1st Jul 2018-30th Jun 2019	$70	$70	$105
1st Jul 2019 onwards	$70	$70	$105

Contractors are most likely to take on more recycling measures once the cost of landfilling exceeds the cost of bringing the waste to the recycling facilities (Duran *et al.* 2006). Therefore, a comparison of waste disposal and recycling methods that are being used is crucial for making economic decisions surrounding C&D waste (Johnston & Mincks 1993). There are a variety of economic benefits from recycling waste as it can provide the opportunity for selling specific waste streams and the removal of waste at little to no cost (Begum *et al.* 2006). Although there are a variety of issues surrounding this due to different perspectives on the topic, as few contractors actually spend time considering the environment and the concept of recycling building materials. This is due to contractors ranking time as their top priority, therefore project completion in the shortest time is the goal rather than the condition of the environment (Begum *et al.* 2006). Markets for these recycled materials are limited as C&D waste is comprised of a variety of different wastes, which requires time to separate out into single acceptable waste streams at some facilities and is therefore considered a low project priority (Duran *et al.* 2006; Teo & Loosemore 2001). Those that do take the environment into consideration will notice a higher productivity rate, with increased safety and a savings in time from producing less waste to dispose of which ultimately saves them money (Begum *et al.* 2006). There are a couple of market based instruments such as policy like the *"polluter pays principle"* used in the Ireland, which means polluters within the industry will be fined for their actions (Duran *et al.* 2006). The use of taxes and government subsidies is seen by many economists as a positive way to encourage change. By increasing landfill taxes the industry is more likely to change from landfill as an option to resource recovery which can result in useful products (Duran *et al.* 2006). Also the use of subsidies does not just involve programs to help decrease landfilling, but to also encourage the use of waste derived materials (Duran *et al.* 2006). Within the industry there are self-regulators which can encourage the industry to adopt best practices through programs, management plans, and auditing methods that could be great if they were subsidised. Overall, there is limited information on the costs of recycling C&D waste, particularly in Australia.

Self-regulators

In the industry there are a number of self regulators which encourage the industry to adopt best practices such as the Master Builders Association WA, which has the Green Living Program. The Green Living Program is a national training program that provides builders with the appropriate information to build sustainably (MBA 2015). Builders gain an education in project planning, passive solar efficient design, onsite management, framing and structure, water and energy conservation, interior fit-out and business strategy (MBA 2015). The Green Living Program can benefit participants by allowing access to builders who deliver high quality sustainability solutions as well as gaining personal and financial rewards for pursuing the sustainable option (MBA 2015). Also Master Builders Association WA have the "Smart Waste Guide" which can help builders with the use of a management plan as well as a current list of service providers in the Perth and South-West areas of WA (MBA 2015).

The Green Star Program by the Green Building Council Australia (GBCA) is "achieving high environmental ratings reduces exposure to commercial risk and asset obsolescence by ensuring that assets are 'future-ready'" (GBCA 2015). On average Green Star – as built certified buildings recycle 96% of all C&D waste generated during construction and demolition. Furthermore, on average Green Star certified buildings send 54% less C&D waste to landfill than standard practice buildings (GBCA 2013).

One Planet Living is another self regulator within the industry which abides by 10 principles to guide local government, and businesses to address the key sustainability issues surrounding everyday living (One Planet Living 2015). The 10 key principles are zero carbon, zero waste, sustainable transport, sustainable materials, sustainable food, sustainable water, land use and wildlife, culture and community, equity and local economy, and health and happiness (One Planet Living 2015). Therefore for a C&D project the main principle focused on would be zero waste which requires a clear waste management plan. This plan would require a reduction in all waste generated including recyclables, as this principle is aiming to approach zero waste to landfill by 2020 (Landcorp 2015).

EnviroDevelopment is another self regulator within the industry that abides by six key principles which are ecosystems, waste, energy, materials, water and community. Two of these key principle leafs apply to the C&D industry and they are waste and materials. The objective of the waste leaf is to reduce waste being sent to landfill and to use current resources more efficiently. Their objective is to use environmentally responsible materials such as waste derived materials (EnviroDevelopment 2015).

The HIA has also developed a self regulator for builders and designers, which aims to promote sustainable house construction, which is achieved through the GreenSmart accreditation program. The key areas focused on by the GreenSmart accreditation are improving energy efficiency, reducing water usage, resource efficiency and finally reducing waste which is the main focus in the C&D industry (HIA 2015). For these self regulations to apply to builders and designers there needs to be some kind of auditing and/or waste management plan in place to determine if the standards have been met for accreditation to be given out.

Product stewardship is also an important factor to consider for waste derived products. The new Department of Environmental Regulations (DER) for waste derived materials aims' to regulate the use of waste-derived materials such as fill materials, fuel and compost. It includes the end-of-waste criteria on which DER will base its regulatory decision-making (DER 2014).

Waste Hierarchy

The waste hierarchy in Figure 1 was adopted in the WARR Act (2007) and is applied by the Waste Authority WA in its decision making processes. The hierarchy takes into account the total environmental impacts of different management options and ranks them in order of their general environmental desirability, from waste avoidance being the most preferred option through to the least preferred being disposal, which in WA has historically been to landfill.

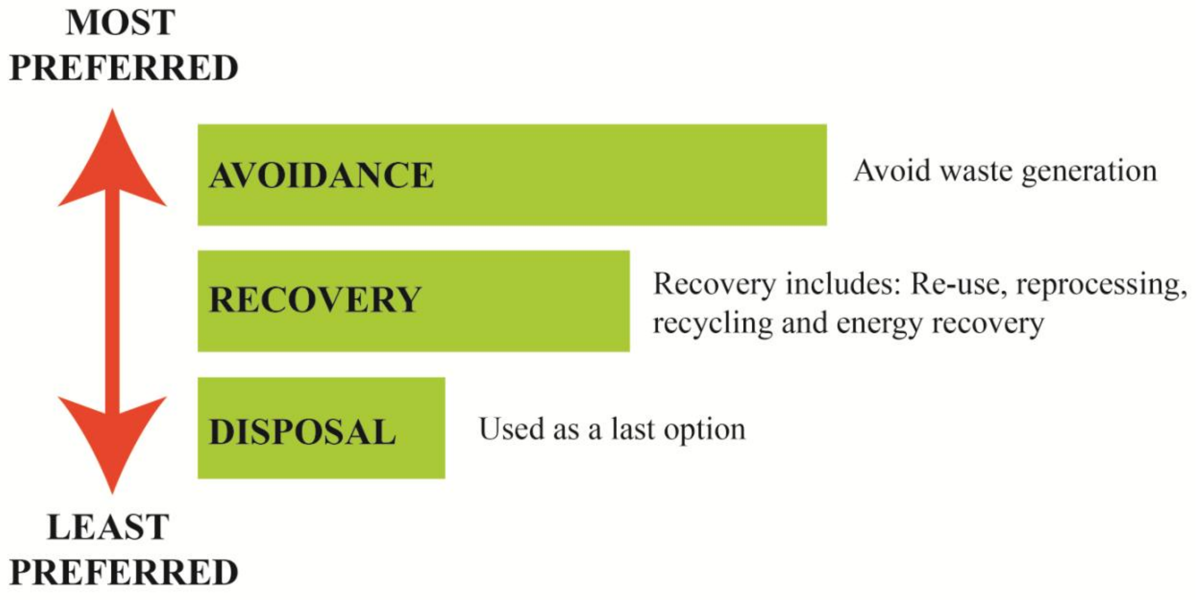

Figure 1: Principles of the waste hierarchy adopted by WARR**.**

The avoidance option at the top of the hierarchy aims to avoid or minimise waste generation thus minimising overall environmental impacts. This could include improving efficiency of production processes or substituting raw materials with recycled materials or less environmentally damaging materials. Resource recovery options refer to actions that recover all or some of the materials that would otherwise be disposed. Disposal refers to the discharge of waste to the environment e.g. landfill, thus it recovers the least value from waste materials and offers the lowest environmental benefit (Waste Authority 2015).

Auditing Methods

Waste auditing is a very important part of the process of reducing the amount of waste sent to landfill, as it can identify the waste streams which need the most improvement on C&D sites. Different units of measurement are being used around the globe as no standard method has been identified (Li *et al.* 2013). Li *et al.* (2013) assessed a range of different auditing methodologies including manual waste sorting on site, comparing waste measured to supplier's invoices and also interviews/surveys to get an estimate of the waste generated by area and by weight. Li *et al.* (2013) also offers a model for quantifying waste generation per gross floor area, based on mass balance principle for building construction in China. Wang *et al.* (2004) developed an economic analysis tool to track the waste at different stages to see if resource recovery was an economically viable. The stages for this tool were generation, separation/processing, recycling and disposal. The waste is estimated by a model generated on the materials used and they can vary depending on location and build type, to get the volume and tonnage of waste produced throughout the stages (Wang *et al.* 2004). Begum *et al.* (2006) audited the waste in an economic way using a benefit cost analysis system to define the total costs involved in the construction of a non-residential building in Bangi, Selangor. Also total benefits were calculated taking into account all the advantages of recycling construction waste, such as savings on transport costs and selling off used materials (e.g. scrape metals; Begum *et al.* 2006). Gangolells *et al.* (2014) conducted a comprehensive survey on C&D waste to determine whether or not builders and other parties involved would take on the 3R's wherever possible, and how their behaviour matches the results.

Waste audit design requires a methodical approach to be efficient. The Waste Audit Users Manual by CCME (1996) provides a comprehensive and detailed guide to waste audit procedures in general. More recently Talis Consultants Pty Ltd. prepared a comprehensive resource kit for the City of Fremantle for use in a pilot trial for waste audits. The Talis Consultants Pty Ltd. (2014) report dealt with C&D waste at two properties that were being renovated. These properties were audited in Fremantle to determine a waste generation breakdown from the sites. A simple data collection sheet was used to record all data found from the two sites and a resource kit was put together of all recycling facilities in the Fremantle area to aid in recycling this C&D waste (Talis 2014). There was a waste audit conducted in Canada that required the materials to not only be measured but also note the composition of the waste and how the waste gets produced during the C&D process, including management decisions and policies involved (MoECC 2010). The auditing process involves many steps which are as follows:

1. Step one which is assembling the basic information about the build and also assessing existing waste reduction and disposal activities,
2. Step two is identifying waste streams as well as noting how they are collected and stored,
3. Step three is identifying recycled content of these building materials; and
4. Step four is completing a waste audit report which requires the reviewed information, assumptions made throughout the audit, waste samples examined and the material weights and/or volumes calculated (MoECC 2010).

A compositional study of C&D waste streams in New South Wales was undertaken in 2007 with the report released by Department of Environment and Climate Change (DECC). It characterised the composition of C&D waste (HIA 2007a). It identified different waste stream quantities and provides a model for similar audits. However, the level of audit detail can depend on the size and complexity of a project. This is important to the audit process to ensure enough information is collected to effectively implement waste reduction management plans (MoECC 2008). Design and preparation of a waste audit on a changing work site also becomes an issue. Construction sites often present an environment that is continually changing and have large quantities of materials moving through limited spaces. Therefore most projects will find it difficult to obtain a representative sample of waste from a limited audit and results from one project may not be representative (REBRI 1999). The method used to obtain these results follows simple steps which are as follows;

1. Step one identify the waste streams,
2. Step two estimate the quantity of waste,
3. Step three plan the audit for the waste streams being audited,
4. Step four onsite data recording; and
5. Step five data analysis to identify the composition of wastes and overall quantities (REBRI 1999).

Quantifying and analysing the data collected from a waste audit is crucial for the implementation of a successful waste recovery system. The various shapes and size of waste collected from various sites needs to be identified so the following formulas can be used; Volume = Length x Width x Height to identify the waste pile size and if the pile is a pyramid shape, one third of that value will be used (Wu *et al.* 2014). Values such as these are used to identify waste ratios and percentages as done by Sáez *et al.* (2014). Sáez *et al.* (2014) shows how to calculate ratios of residential construction waste around Spain. Several formulas have been used to identify kg of waste/m^2 and m^3 of waste/m^2 and also show ratios from other residential construction sites around the globe to compare their waste efficiency. This helps identify gaps that they have missed to make waste recovery more successful. Mercader-Moyano and Ramirez-de-Arellano-Agudo (2013) supply several mathematical models that can be used to help quantify the data collected from a waste audit and also identifies the waste produced per m^2 on a construction and demolition site just as in Sáez *et al.* (2014). Once these quantities have been identified it is easier to set management plans to meet the waste streams that appear to be the most detrimental to the environment.

Waste Management Plans

As C&D waste generates such a large volume of waste in WA the introduction of waste management plans has the potential to reduce waste going to landfill. Abdelhamid (2014) illustrates a successful decision making matrix that has been implemented in Egypt which includes a cost break down allowing identification of the most efficient way to deal with the generation of construction and demolition waste. Yuan (2013a) conducted a strengths, weaknesses, opportunities and threats (SWOT) analysis to determine how to deal with construction waste and where improvements need to be made to reduce waste generation. The elements found during this SWOT analysis are crucial when implementing successful C&D waste management plans (Yuan 2013a). Hong Kong has been implementing construction waste management plans since the 1980's so their waste reductions have really started to show (Yuan 2013a). Yuan (2013b) suggests that the key factors affecting C&D waste management plans are encompassing design changes, consideration of C&D waste reduction in design, investment in

C&D waste management, C&D waste management regulations, site space for performing waste management, adoption of low-waste construction technologies, impacts of waste reduction cost, and waste management culture within an organisation. In Canada waste reduction plans get put into place depending upon the data found during the auditing process. These plans are designed around the 3R's principlesand encompass each principle within the project (MoECC 2010). These waste reduction plans are broken down into a few steps;

1. Step one being review of information gathered during an audit,
2. Step two identifying areas of greatest waste reduction,
3. Step three assessing waste reduction priorities,
4. Step four determining why waste is generated,
5. Step five identifying opportunities to implement the 3R's,
6. Step six assessing the impact of material purchasing on waste reduction; and
7. Step seven completing an achievable waste reduction work plan (MoECC 2010).

In 2007 the HIA brought out the Draft code of practice for C&D waste management to aid in trying to reduce the amount of C&D waste and the impact it is having on the environment by providing steps and a checklist to be used within the industry (HIA 2007b). This code of practice has been developed to offer a step by step approach to implement C&D waste management for all projects and should be used in conjunction with the HIA's GreenSmart Program (HIA 2007b). The aim of this code of practice is to comply with policy, legislation and regulations on waste management, to minimise the cost of building materials by reducing waste in the C&D industry, to prevent illegal dumping, control waste disposal, conserve natural resources, reduce environmental harm by minimising the use of raw material and waste to landfill (HIA 2007b). The steps to follow entail a detailed description of the project, a waste prevention plan for during the design stage, during the estimate and purchasing stages and during the construction stage. Following this a proposal for minimisation/reuse/recycling, estimated cost of waste management, demolition plan, roles and responsibilities for C&D waste, training system for C&D waste, record keeping procedures and waste auditing protocols can be tailored to the project (HIA 2007b).

Illegal Dumping

There are a wide range of issues that come up during C&D works such as illegal dumping. It is estimated that approximately 50% of all illegal dumping within C&D in the Perth metropolitan area, is from other companies and contractors within the C&D industry (Waste Authority 2015). Builders dump waste on other builders sites, which makes up the majority of illegal dumping on construction sites, as well as random rubbish such as whitegoods as seen by Felmingham *et al.* (2015). Other issue have been found that could help reduce illegal dumping, and possibly reduce the amount waste going to landfill, such as number identifying systems for bins and trucks that truck C&D waste, mandatory self auditing with a reporting system to the government, and also lack of environmental awareness (Ofori 2000).

METHODS

Background

Identifying the costs of managing any type of waste and how to reduce them involves a structured and methodical process. The waste audit was designed to be able to demonstrate the amount of waste that could potentially be reduced during construction and demolition of double brick residences in WA. Therefore waste was measured in both mass and volume. The audit addressed all non-hazardous waste generated at the sites, whether intended for reuse, recycling or disposal. Waste from all regular activities in the operation of the site was considered in the course of the audit. Any waste generated from activities not associated with the construction process was not included, but was noted.

Prior to sampling an initial site visit was undertaken with the builder/demolition team to assess what was going to take place and help formulate the scope of the audit. This step provided valuable insight into the proposed projects and helped the development of the sampling strategies. This step also helped define the timeline for the sampling process. The following methods are split into two categories, construction and demolition,

Construction

The construction audit was broken down into three stages: Stage 1 demolition to plate height, Stage 2 plate height to lock up, and Stage 3 lock up to hand over. The sampling methodology used was applicable to all three stages of construction and consists of a site description, identified waste streams and the waste auditing process.

Site Descriptions

Stage 1: Demolition to plate height

3 Stanmore Court, Lynwood, has a total lot area of 830 m^2 where two units were under construction. The first unit at the front of the block is composed of three bedrooms (including a master bedroom), two bathrooms, a garage, a porch and an alfresco area with a total floor plan

area of 220.64 m^2. The second unit, located to the rear of the lot, has three bedrooms, two bathrooms, a garage, a porch and an alfresco but is slightly smaller than unit 1 with a total building area of 208.75 m^2.

Stage 2: Plate height to lock up

4 Walton St, Bayswater is a standard double brick home, with a concrete slab, timber roof frame and a tin roof. It has three bedrooms, two bathrooms, a two car garage, a porch and a pergola over an area of 199.52 m^2 on a block of 335 m^2. The block is considered small for a residential construction site. There was no formal waste collection system on site, such as a cage or skip bin, therefore there was only a commingled pile of waste located at the front of the house.

Stage 3: Lock up to hand over

35 Moulden Ave, Yokine is two standard double brick units, with a timber roof frame and a tin roof. Both units have three bedrooms, two bathrooms, a two car garage with storage, a porch and alfresco area, which covers an area of 227.50 m^2 and 197.02 m^2 for unit 1 and 2 respectively. The block is of moderate size, with adequate space for a skip bin. However, a skip bin was not present at all times and piles of comingled waste were placed near the back unit for the majority of the sampling period.

Waste Streams

The typical waste streams for all three stages included:

- **Roof Timber** – off cuts from beams and roof and ceiling members. Majority being H2 hazard level (biological hazard: termites and borers) treated pine and laminated veneer lumber (LVLs).
- **Roof Hardware** – nail plates, nails, screws, gutter straps facia and gutter.
- **Mixed Rubble** – mixed and separated inert waste such as concrete, concreting mesh render screeding, sand, ceramic floor tiles, broken bricks, pavers, sands (excludes earth works).
- **Bricks** – Complete unused bricks.
- **Pavers** – Complete unused pavers.
- **Electrical** – leftover cable wire.
- **Roof sheeting** – colorbond roof sheeting and corrugated clear polycarbonate roof sheets.
- **Cardboard** – packaging materials e.g. boxes.
- **Ceiling plasterboard & cornice** – plasterboard sheeting and cornice.
- **Paint** – used paint tins.
- **Plastics** – packaging & drink bottles. Identifiable by codes:
    - PET (1) – soft drink bottles;
    - HDPE (2) – milk bottles;
    - PVC (3) – cling wrap;
    - LDPE (4) – plastic bags;
    - PP (5) – microwavable take-away containers, ice cream containers;

- Polystyrene (6) – foam trays and packaging; coffee cup lids, yoghurt containers; and
- Other (7) – all other plastics.

- **Rubbish** – mix of putrescibles and inert waste (e.g. beer bottles, take away wrappers).
- **Water** – water use throughout stage 2 and 3.
- **Green waste** – organic waste from site including garden waste, food scraps

Hazardous wastes such as asbestos were not included for the audit as they were not generated during the construction process. If hazardous materials were detected onsite e.g. asbestos fencing, the site manager was informed so that it could be segregated for appropriate disposal.

Auditing

Site auditing was undertaken during each visit, which occurred at least once a week until the completion of that stage of construction. During the auditing process comingled piles of waste were sorted into separate waste streams and measured as a volume, area or weight, as applicable. The following waste streams were measured as follows:

- Timber waste was sorted into groups depending on their length, width and depth. The depth, width and lengths were then measured in mm. Offcuts small enough to fit in flexible storage tubs were classed as small and they were bulked together and weighed. The larger lengths of wood were measured (length, width and depth), one length was weighed which was used as a measurement for the remaining pieces. This was done for each wood size class. Observations regarding the condition of the wood were made and these included wood type, hazard treatment, evidence of contamination and if placed in waste pile or set aside for reuse.

- Off cuts of fibre cement sheeting were sorted into size categories. Where large enough they were measured by length, width and depth and weighed. Any small off cuts were put into the flexible storage tubs and weighed. A full flexible storage tub (40 litres) was weighed and this was used for future weight conversions, particularly when there were very large quantities of small offcuts.

- Building rubble such as waste sand, blocks of concrete, brick rubble and render was often intermixed and hard to audit. Rubble that could be manually moved or put into flexible storage tubs was weighed. Where the waste piles were large and had fused together it was measured in cubic metres using a tape measure and its composition was recorded. Full unused bricks were counted separately as they can be reused elsewhere.

- Roof sheeting off cuts were often large and cut on certain angles. To estimate the amount of waste whole sheets were reconstructed using the offcuts to provide a measure of waste in m^2. All small offcuts were put into flexible storage tubs and weighed.

- Metal wastes came in a variety of forms and were separated into individual groups for measurement. Metal fascia and guttering was laid in lengths and measured in m^2, and was then weighed. The other common metal wastes were brick ties and copper wire and tubing, which were weighed in flexible storage tubs.

- Plasterboard offcuts were separated and due to their bulkiness each off cut was measured separately by obtaining length and width in meters. Cornice pieces were measured in lengths and samples weighed for conversion using the flexible storage tubs.

- Cardboard waste, glass and general rubbish waste were separated into individual piles, put into flexible storage tubs and weighed.

- Plastics such as drink bottles or packaging were sorted into flexible storage tubs and weighed. Brick straps at most sites were separated into large plastic bags (for later recycling) and were weighed. Were bags were not available they were measured in the flexible storage tub. PVC piping was separated into their different sizes and the running length and diameter measured. The pipes were then weighed separately for the different size classes and types. The codes for all plastic types were recorded and any barriers to recycling such as contamination were noted.

- Rubbish accumulated on site, being a mix of putrescibles and inert wastes were put into flexible storage tubs and weighed.

Demolition

The demolition audits were conducted on 2 different sites of different size, one being a double story and other only being a single story. Both properties were double brick older style homes to try to keep data continuity.

Site Descriptions

11 Brown St, Dalkieth

11 Brown St, Dalkieth was a large double brick two story home with a timber roof frame and a tile cover roof. It had twelve rooms, five bedrooms, two bathrooms, one extra toilet, with a large alfresco area out the back of the house. Also a large shed with storage out the back corner of the block. This was quite a large block therefore Capital were able to source separate some materials

onsite into the following categories; recovered materials to be sent back to Capital, green waste, and timber and general waste.

1 Prowse St, Beaconsfield

1 Prowse St, Beaconsfield was an average double brick single story home with a timber roof frame and a tin roof. It had 3 bedrooms, 2 bathrooms, a large family room, a garage and a large garden with high density vegetation. The block was large in size so there was some room for source separation of materials onsite, into the following categories; green waste, timber, scrap metal, rubble, contaminated rubble, and limestone.

Waste Streams

Typical waste streams encountered during the demolition phase include:

- **Green waste/vegetation**: organic waste from site including garden waste
- **Scrap metal**: slightly or non-contaminated metal materials.
- **Timber**: slightly or non-contaminated timber materials.
- **Rubble**: concrete, bricks, tiles, pavers and minimal sand and dirt.
- **Contaminated Rubble**: rubble that contains non-recyclables for that waste stream such as timber and metal.
- **Limestone**: limestone bricks, pavers and rubble
- **Mixed loads**: timber, metal, concrete, green waste, bath tubs, air conditioner units, tiles.

Hazardous wastes such as asbestos were not included for the audit as they were not generated during the construction process. If hazardous materials were detected onsite e.g. asbestos fencing, the site manager was informed so that it can be segregated for appropriate disposal.

Auditing

The demolition process took approximately a week for each house and daily auditing was undertaken. Due to the large quantities of waste generated during demolition, waste was measured by the truckload and cubic metres. Waste was audited from the following waste streams separated by the excavator. From here all stock piles where measured in m^3 at the end of the demolition process with the help of the demolisher, through the observations and recorded information on truckloads of waste streams taken from site. The composition of these truckloads is also recorded so that they can be separated out later by waste stream in each truckload. Also other measurements, observations and any contamination or barriers to recycling were recorded on materials data sheet.

Data analysis

Construction and demolition analysis

The data collected from site visits was collated, manipulated and transformed in Excel into graphs and tables to illustrate composition and waste generated by weight. Excel was also used to generate material flow diagrams for all sites audited. Waste authority and sustainability Victoria waste conversion tables were used for demolition waste weight conversion, as well as waste weight conversion for some volumes at construction sites.

Cost analysis

Data was collected from phone calls to the following types of facilities:

- Landfill sites
- Resource recovery facilities
- Skip bin companies
- Bobcat and truck providers

Several bobcat and truck providers were called to get and average cost for a site clean for a $20m^3$ truck load. This price was then diveded by 20 to give an average price per cubic meter. A number of landfill sites, resource recovery facilities and skip bins companies were called to get quotes for waste disposal fees. Skip bin companies include pick up, drop off bins and disposal costs, therefore the average price per cubic meter was generated by dividing the size of the bin. The price quotes from the landfill sites and resource recovery facilities were given by cost per cubic metre, so a conversion factor of $2.83m^3$ per tonne (Waste Authority 2015) was used if quoted by the tonne. Once this data was collected and collated in Excel, the mean, median, standard deviation and range was calculated for each of the options. Once the mean price was determined the waste generation from the sites surveyed were used to determine cost of waste disposal for these projects.

RESULTS

Construction

Stage 1: demolition to plate height.

The collection of construction waste from 3 Stanmore Court, Lynwood shows that the total amount of waste produced from stage 1, demolition to plate height, was 68.85 tonnes and the amount of known ordered material was 184.97 tonnes (Figure 2). The floor plan of the two units, had a total area of 429.39 m^2, therefore the amount of waste produced was 0.43 tonnes per square metre.

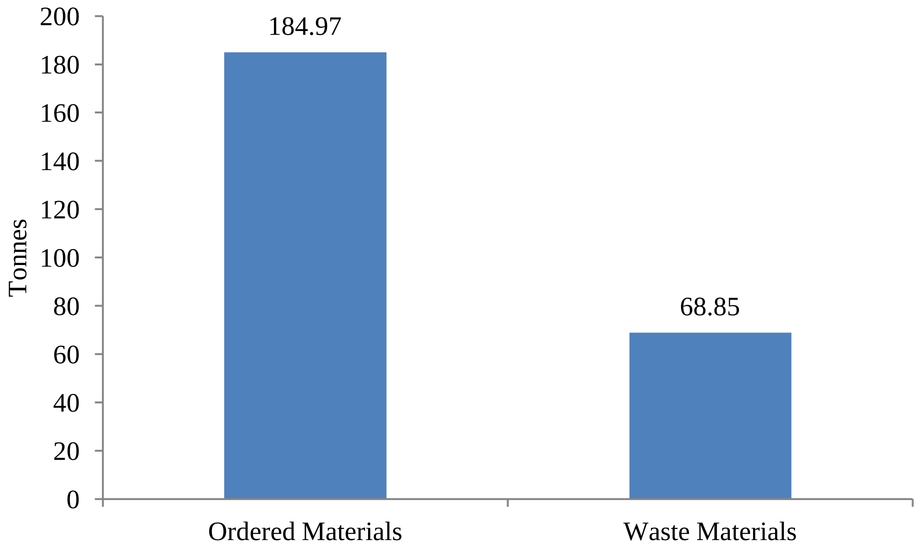

Figure 2: A comparison of the ordered materials with waste materials in tonnes for stage 1 at 3 Stanmore Crt, Lynwood.

Figure 3 illustrates the amount of waste produced if the sand (can include dirt and green waste) from earthworks is removed which was 49.50 tonnes. A large proportion of the remaining waste once the earthworks material is removed was cement from the slab pours at each unit, which equated to 16.43 tonnes. The remaining waste stream equalled 2.92 tonnes and included all other materials used throughout this stage.

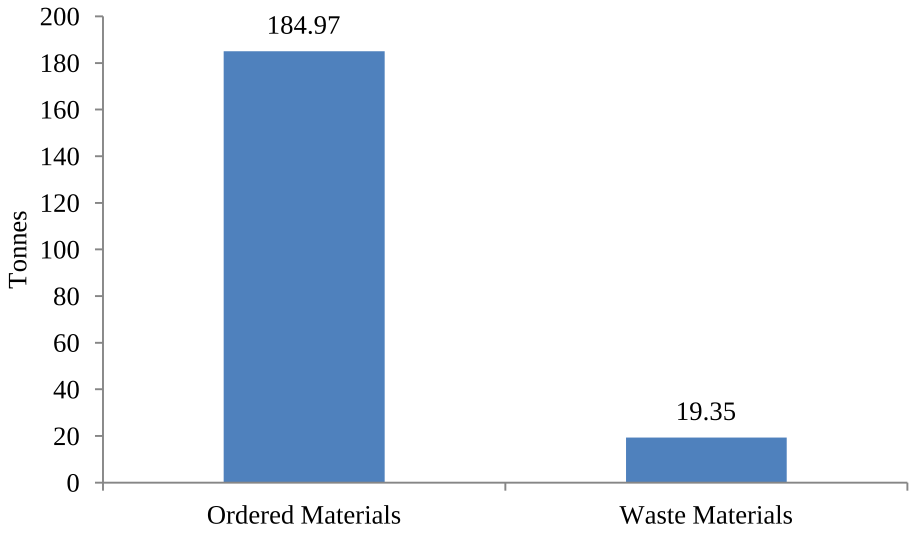

Figure 3: A comparison of the ordered materials with waste materials in tonnes for stage 1 at 3 Stanmore Crt, Lynwood excluding waste from earthworks.

The composition of waste by weight produced from stage 1 is broken down into percentages (Figure 4). The main components of waste produced throughout this stage were sand from earthworks (71.90%), concrete (23.86%) and bricks (3.31%). Figure 4 also quantifies the compositions of the remaining 0.93% of waste which is as follows: green waste, fibre cement, plastic, cardboard, metal, electrical waste, timber, glass and cement bags.

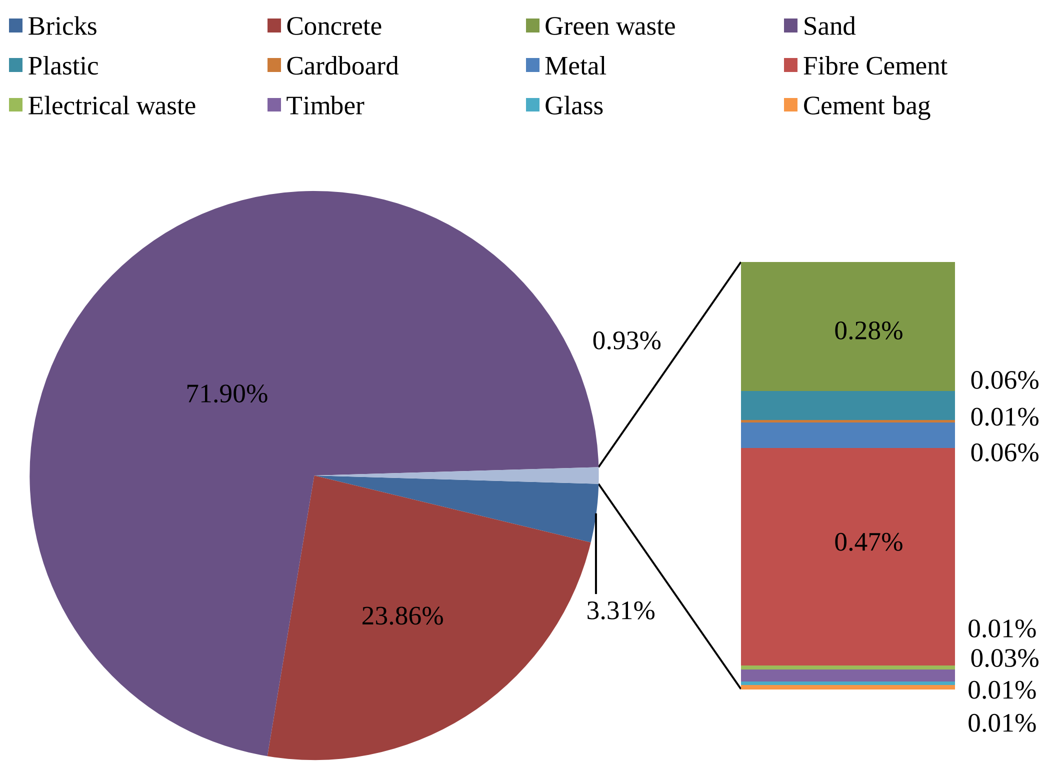

Figure 4: A breakdown of the waste streams as a percentage at stage 1 at 3 Stanmore Crt, Lynwood.

Figure 5 shows the composition of waste produced by weight from this stage as a percentage excluding the waste from earthworks. The waste streams with the earthworks waste removed are green waste (1.01%), fibre cement (1.69%), plastic (0.22%), cardboard (0.02%), metal (0.20%), electrical waste(0.03%), timber (0.09%), glass (0.03%) and cement bags (0.03%) (Figure 5).

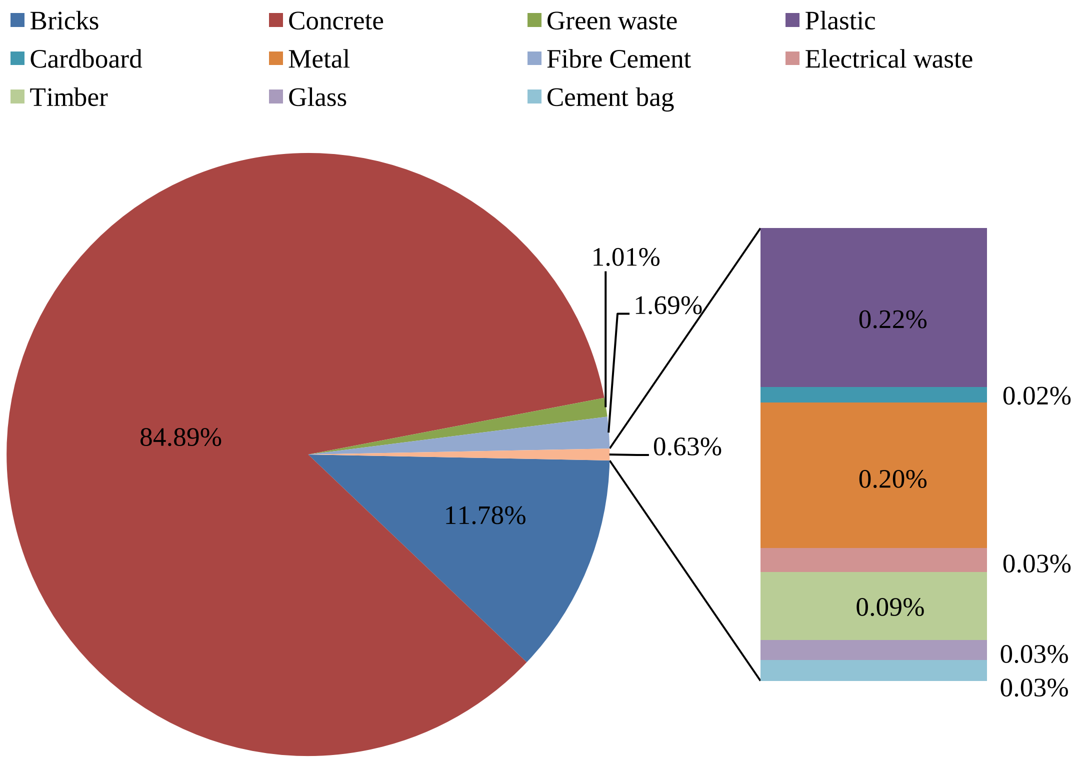

Figure 5: A breakdown of the waste streams as a percentage at stage 1 at 3 Stanmore Crt, Lynwood excluding waste from earthworks.

A breakdown of the waste streams from stage 1 is identified in Figure 6 which shows that 3.31% (2.280 tonnes) of waste produced was reused on site at a later date or on another construction site (Figure 6). It has been identified that the C&D resource recovery facility rate is 80% (Instant Waste Management 2015), therefore, 53.255 tonnes (77.35%) is assumed to have been recovered at the facility and 13.314 tonnes (19.34%) of all waste is sent to landfill (Figure 6).

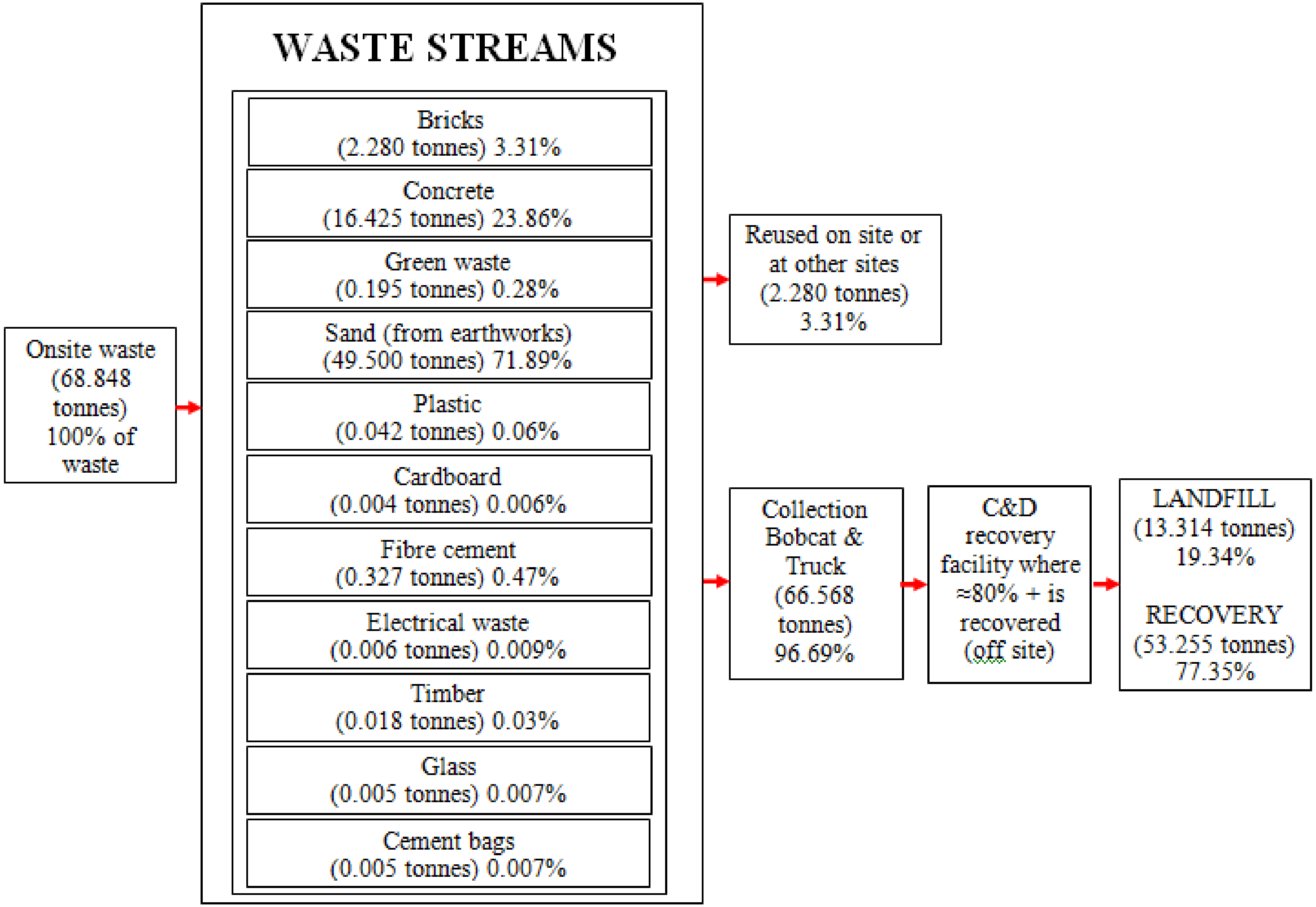

Figure 6: Mass flow diagram of waste produced at 3 Stanmore Crt, Lynwood (assumed 80% recovery rate at C&D recovery facility).

Figure 7 compares the amount of concrete used as a percentage by weight (80.50%) compared to amount wasted (19.50%). It also highlights the amount of waste that is assumed to be recovered at a C&D resource recovery facility, which is as 15.60 % leaving only 3.9% going to landfill (Figure 7).

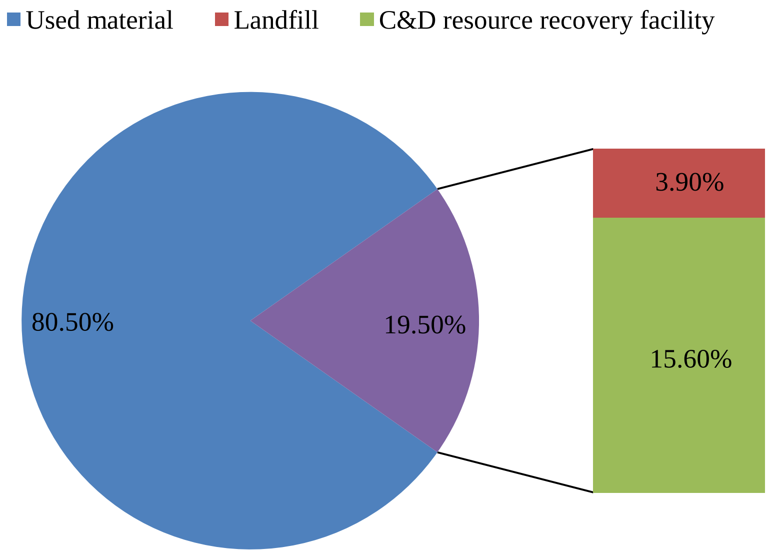

Figure 7: Used ordered concrete versus materials wasted and what is done with the waste quantities from stage 1.

Figure 8 shows that 97% of all bricks ordered have been used on sites, and the remaining 3% of bricks will go to later use on site at 3 Stanmore Crt, Lynwood, or to another site.

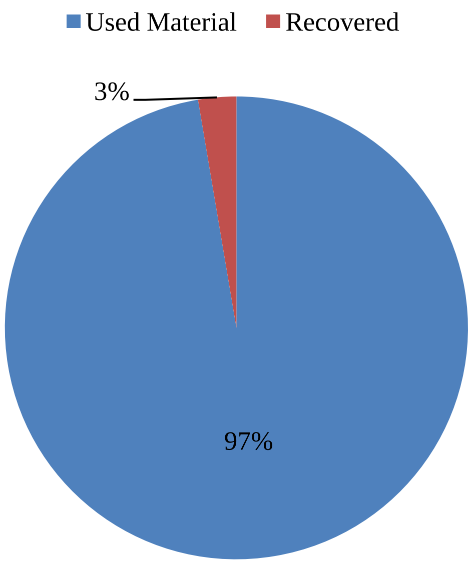

Figure 8: Used ordered bricks versus waste materials and what is done with it from stage 1.

Figure 9 compares the amount of cement bags ordered and used for brick laying on site (99.98%) and the amount that was considered waste (0.02%).

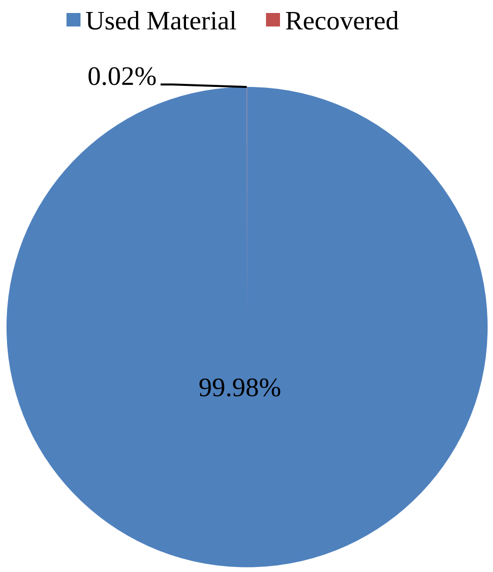

Figure 9: Breakdown of cement bags ordered and used versus cement bags wasted from stage 1.

Stage 2: plate height to lock up.

The collection of construction waste from 4 Walton St, Bayswater shows that the total amount of waste produced from stage 2, plate height to lock up, was 19.86 tonnes and the amount of known ordered material was 78.02 tonnes (Figure 10). The floor plan included a garage and pergola, for stage 2 which measured 199.52 m^2, therefore the amount of waste produced was 0.10 tonnes per square metre.

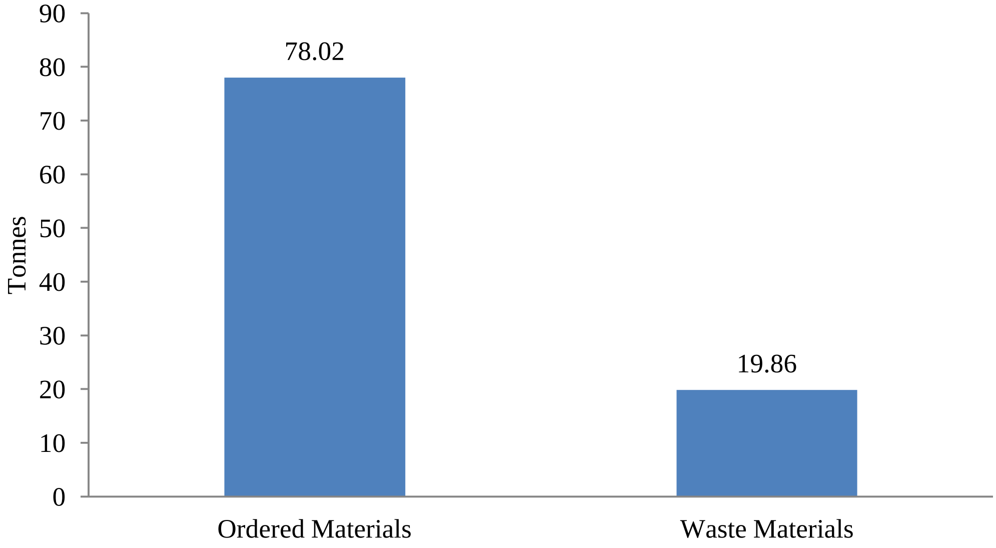

Figure 10: A comparison of the ordered materials with waste materials in tonnes for stage 2 at 4 Walton St, Bayswater.

The composition of waste by weight produced from stage 2 is illustrated as a percentage as shown in Figure 11. The main components of the waste produced for stage 2 were cement, sand and rubble (86.78%) and bricks (8.20%) (Figure 11). Figure 11 also quantifies the composition of the small waste streams identified during this study; those streams were ceiling plasterboard and cornice, roof timber, roof sheets, roof hardware, plastic, rubbish, electrical waste and cardboard, which equated to approximately 5% of all waste.

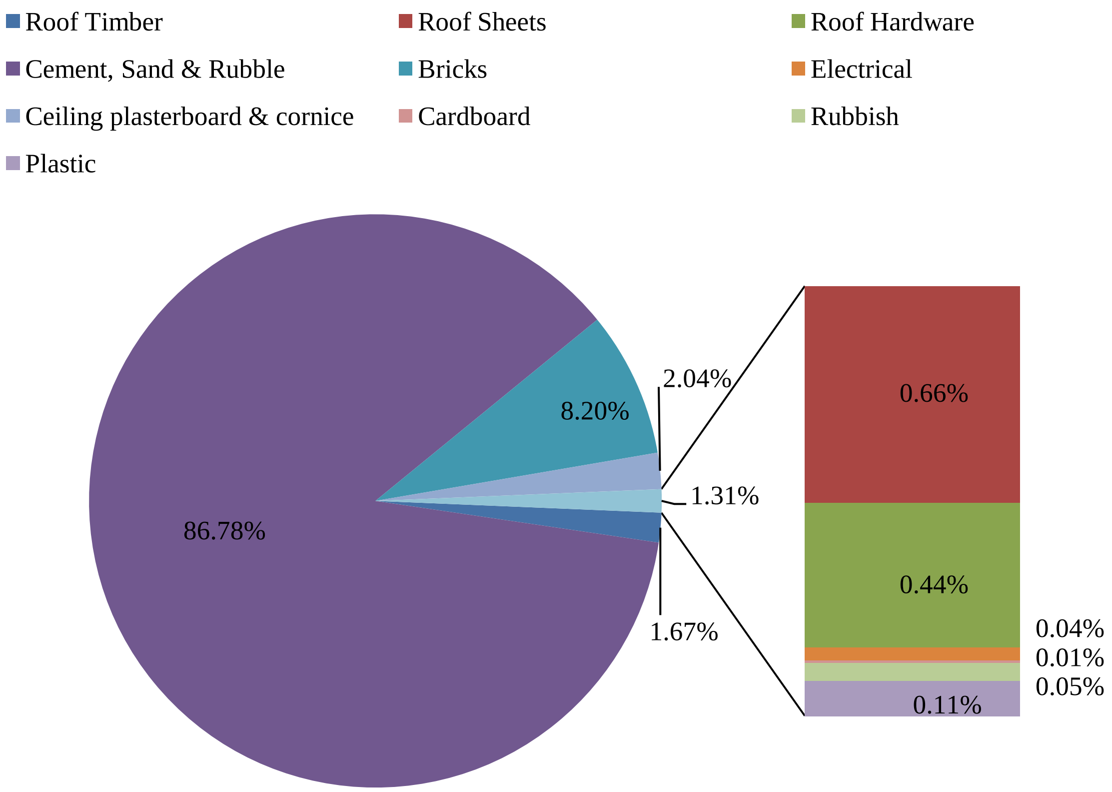

Figure 11: A breakdown of the waste streams as a percentage at stage 2 at 4 Walton St, Bayswater.

A breakdown of the waste streams from stage 2 is identified in Figure 12, which shows that 10.02% (1.99 tonnes) of the waste produced was reused on site at a later date or on other construction sites. It has been identified that the C&D resource recovery facility rate is 80%, therefore 14.30 tonnes which is 71.98% of all waste has been assumed to be recovered and 3.57 tonnes which is 18.00% of all waste was sent to landfill (Figure 12).

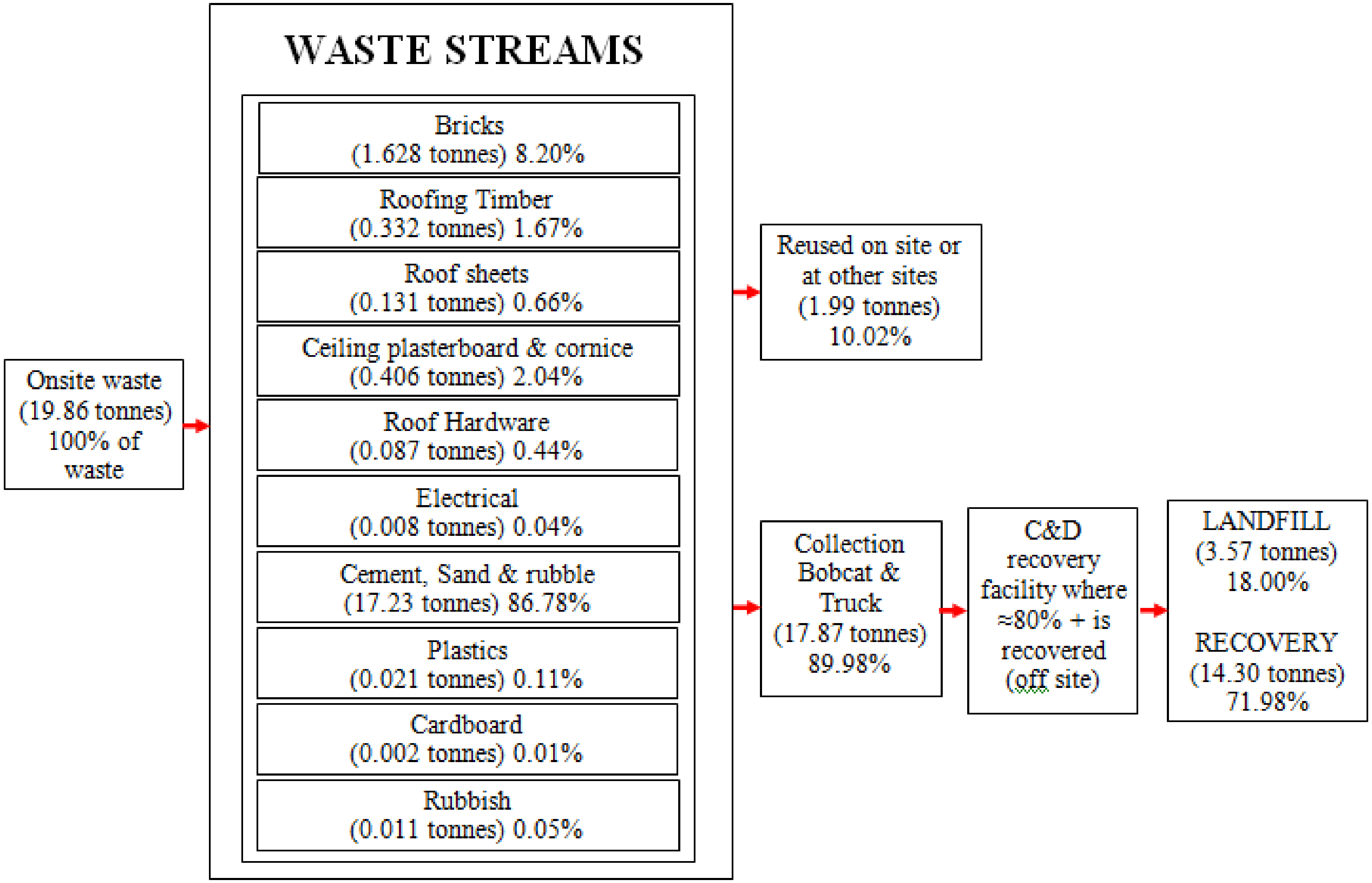

Figure 12: Mass flow diagram of waste produced at 4 Walton St, Bayswater (assumed 80% recovery rate at C&D recovery facility).

Figure 13 shows that 86.14% by weight of the ordered roof timber was used and the remaining 13.86% was discarded. Out of that 14.00%, 8.82% was reused on site or put aside for use on other construction sites. The remaining 5.04% was sent to the C&D waste recovery facility where 80% of that is assumed to be recovered.

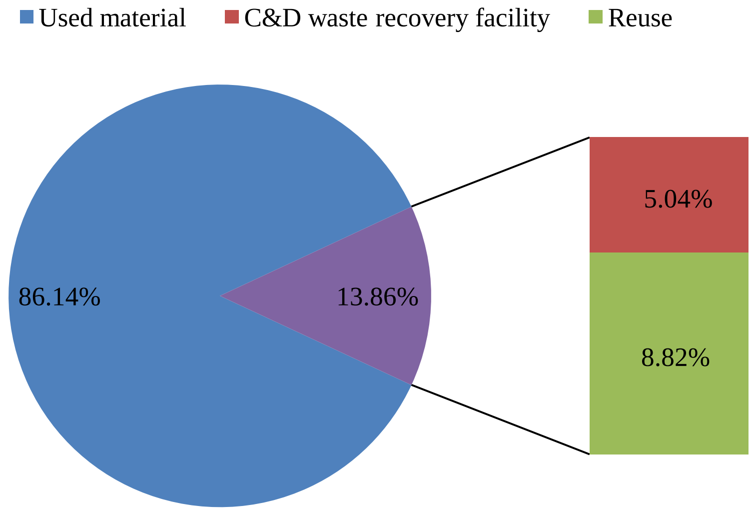

Figure 13: Used ordered roof timber versus waste materials and what is done with it from stage 2.

Figure 14 shows that by weight 73.69% of all plasterboard and cornice was used during construction and that 26.31% was discarded. Of the 26.31%, 9.74% was earmarked to be reused on site or another construction site, with the remaining 16.57% going to a C&D waste recovery facility (Figure 14).

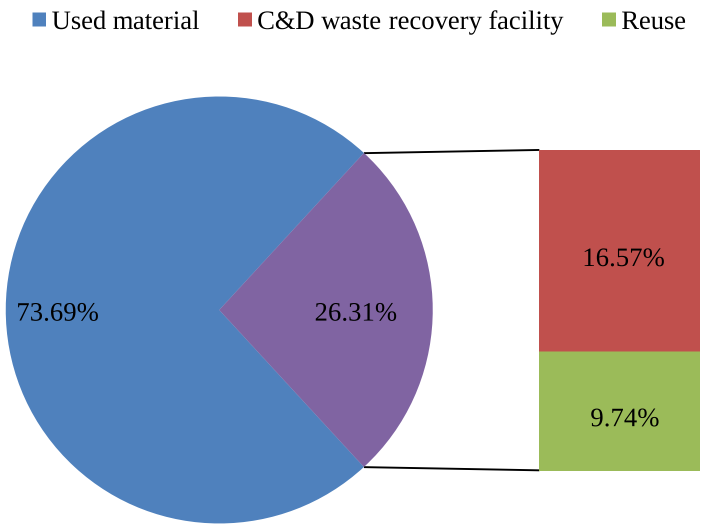

Figure 14: Used ordered ceiling plaster and cornice versus waste materials and what is done with waste quantities from stage 2.

It is shown in Figure 15 that 88.72% by weight of all ordered roof sheets were used and 11% was wasted. Figure 15 also illustrates that out of the remaining11%, 4.00% was able to reused elsewhere and 7.28% was sent to a C&D waste recovery facility.

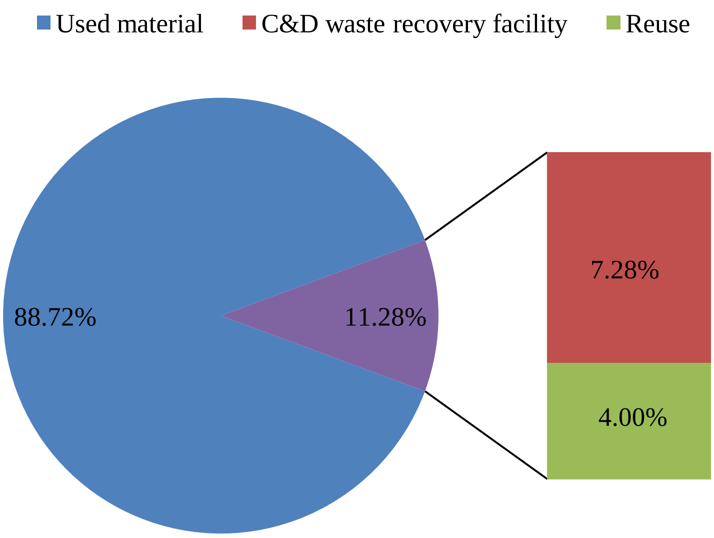

Figure 15: A breakdown of waste streams from roofing and what happens to the waste from stage 2.

Figure 16 compares the amount of cement, sand and rubble that was used, assumed recovered or sent to landfill. The assumed recovery rate at the C&D recovery facility is 80%, of which 38.84% was used material, 48.93% was recovered material and 12.23% was sent to landfill (Figure 16).

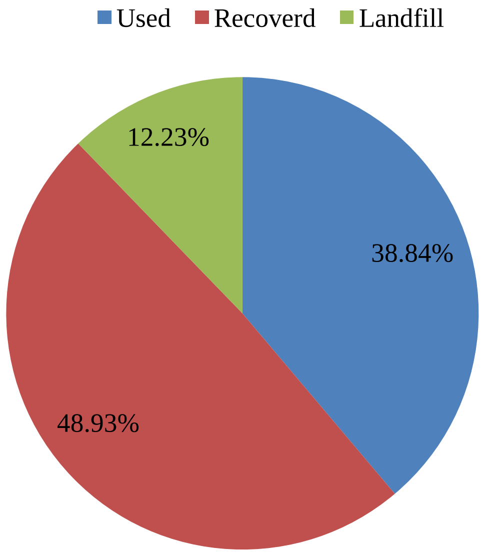

Figure 16: A breakdown of what happens to the ordered cement, sand and render from stage 2 (assumed 80% recovery rate at C&D recovery facility).

Figure 17 shows that 96.36% of all bricks ordered were used on site, and the remaining 3.64% of full bricks were reused on site at 4 Walton St, Bayswater.

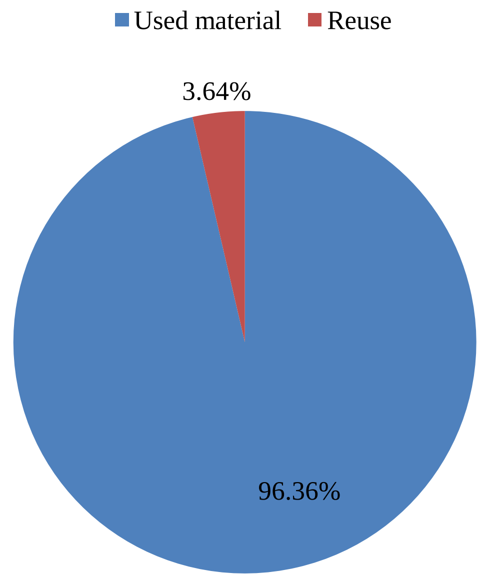

Figure 17: Used ordered bricks versus waste materials and what is done with it from stage 2.

Stage 3: lock up to hand over.

The collection of construction waste from 35 Moulden Ave, Yokine illustrates that the total amount of waste produced from stage 3, lock up to hand over, was 24.97 tonnes and he amount of known ordered material was 16.42 tonnes (Figure 18). The floor plan of the two units 424.52m^2 , therefore the amount of waste produced was 0.06 tonnes per square metre. This Figure 18 includes the road base material that was brought in to improve site access.

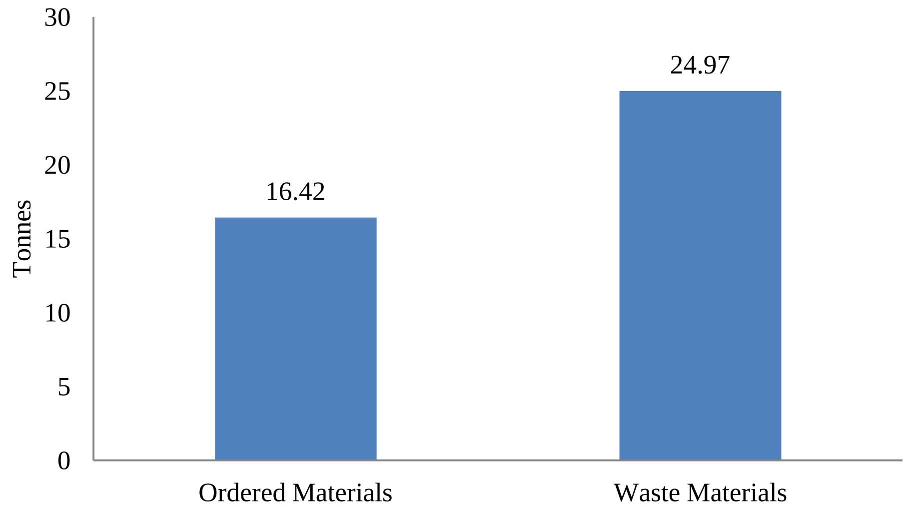

Figure 18: A comparison of the ordered materials with waste materials in tonnes for stage3 at 35 Moulden Ave, Yokine.

Figure 19 shows the amount of waste produced excluding the road base brought into to improve access which is approximately 10m^3 (15 tonnes). The remaining waste with the road base removed is 9.97 tonnes (Figure 19).

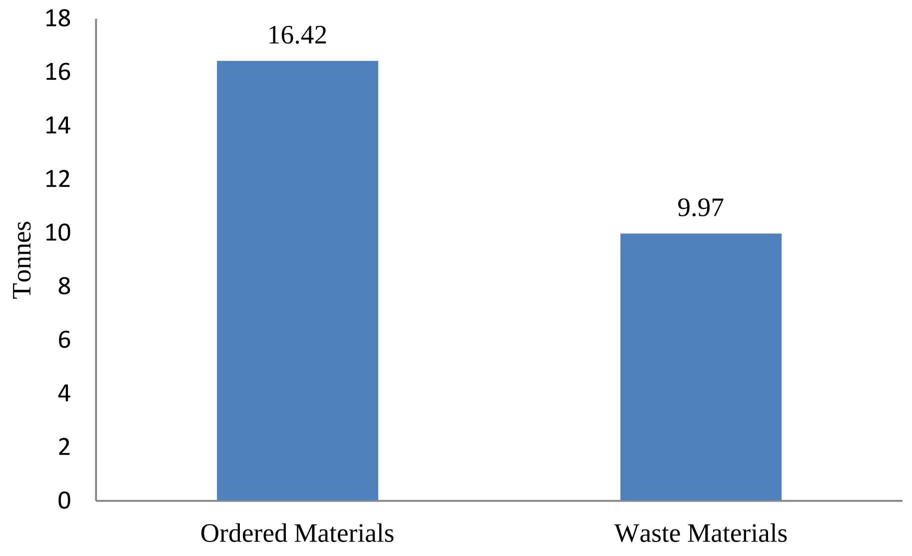

Figure 19: A comparison of the ordered materials with waste materials in tonnes for stage 3 at 3 Moulden Ave, Yokine excluding road base waste.

The composition of waste by weight produced from stage 3 is broken down into percentages (Figure 20). The main components of waste produced throughout this stage were road base (60.06%), sand (12.01%), full bricks (7.81%), concrete (5.50%), and pavers (4.08%). Figure 20 also quantifies the composition of the remaining materials.

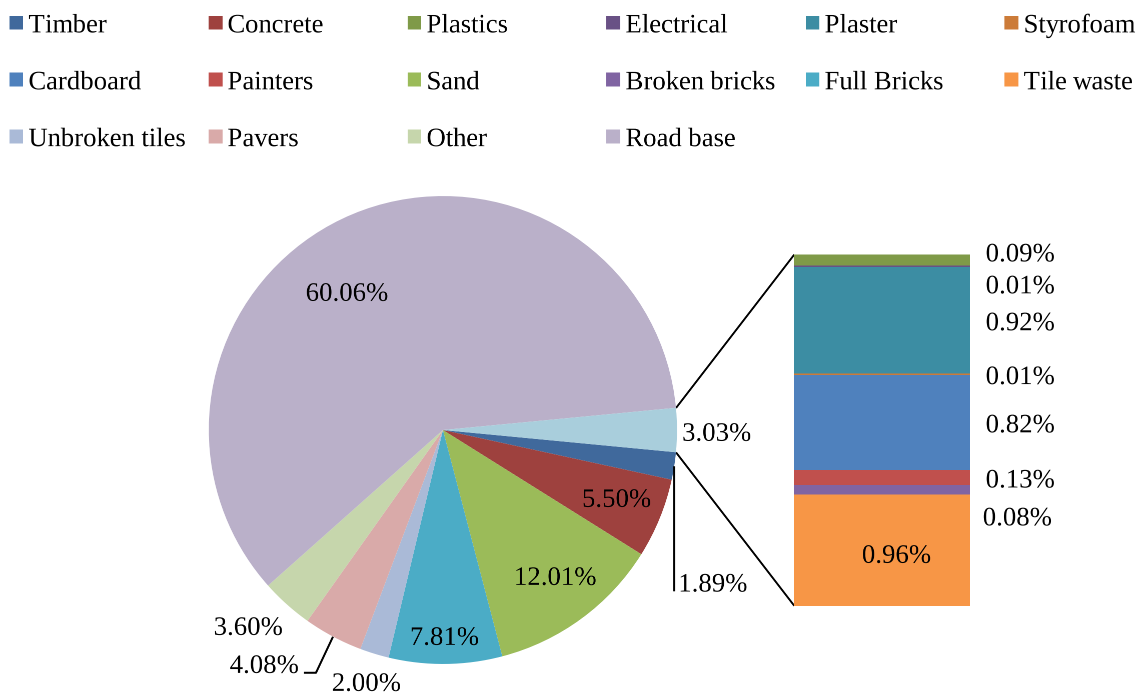

Figure 20: A breakdown of the waste streams as a percentage at stage 3 at 35 Moulden Ave, Yokine including road base waste.

Figure 21 shows the composition of waste produced by weight from this stage as a percentage excluding the road base waste. The waste streams with the road base waste removed are sand (30.08%), full bricks (19.56%), concrete (13.77%), pavers (10.23%), other (9.02%), unbroken tiles (5.02%) (Figure 21).

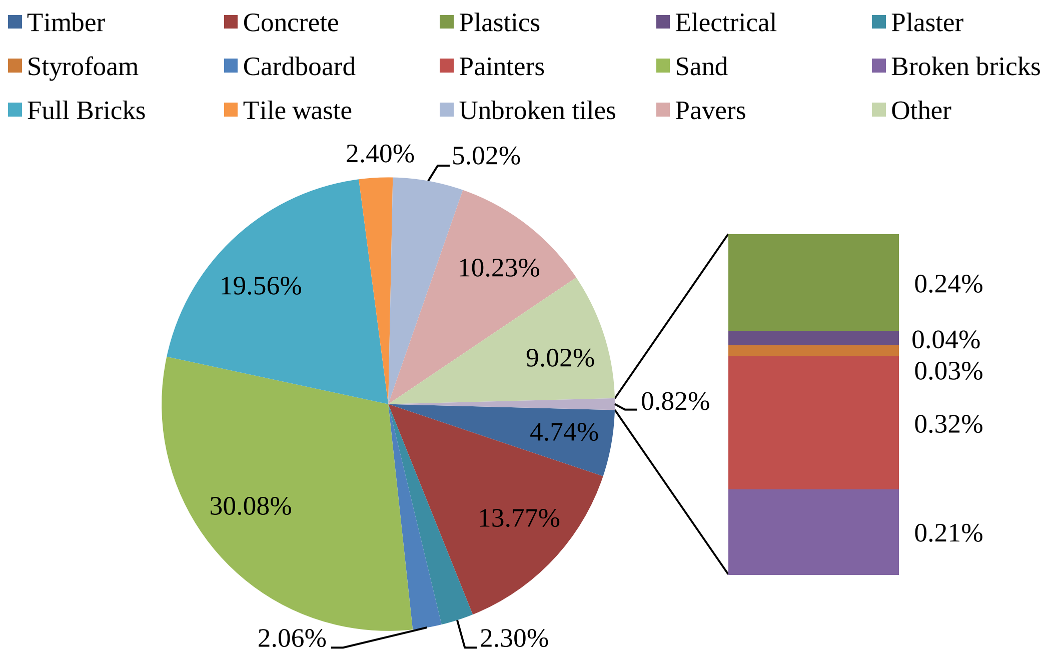

Figure 21: A breakdown of the waste streams as a percentage at stage 3 at 35 Moulden Ave, Yokine excluding road base waste.

Figure 22 illustrates a breakdown of the waste streams from stage 3, which shows that 13.90% (3.472 tonnes) of waste was recovered. Also it shows that 68.88% (17.202 tonnes) of all waste materials were recovered before the remaining 17.22% (4.301 tonnes) was sent to landfill (Figure 22).

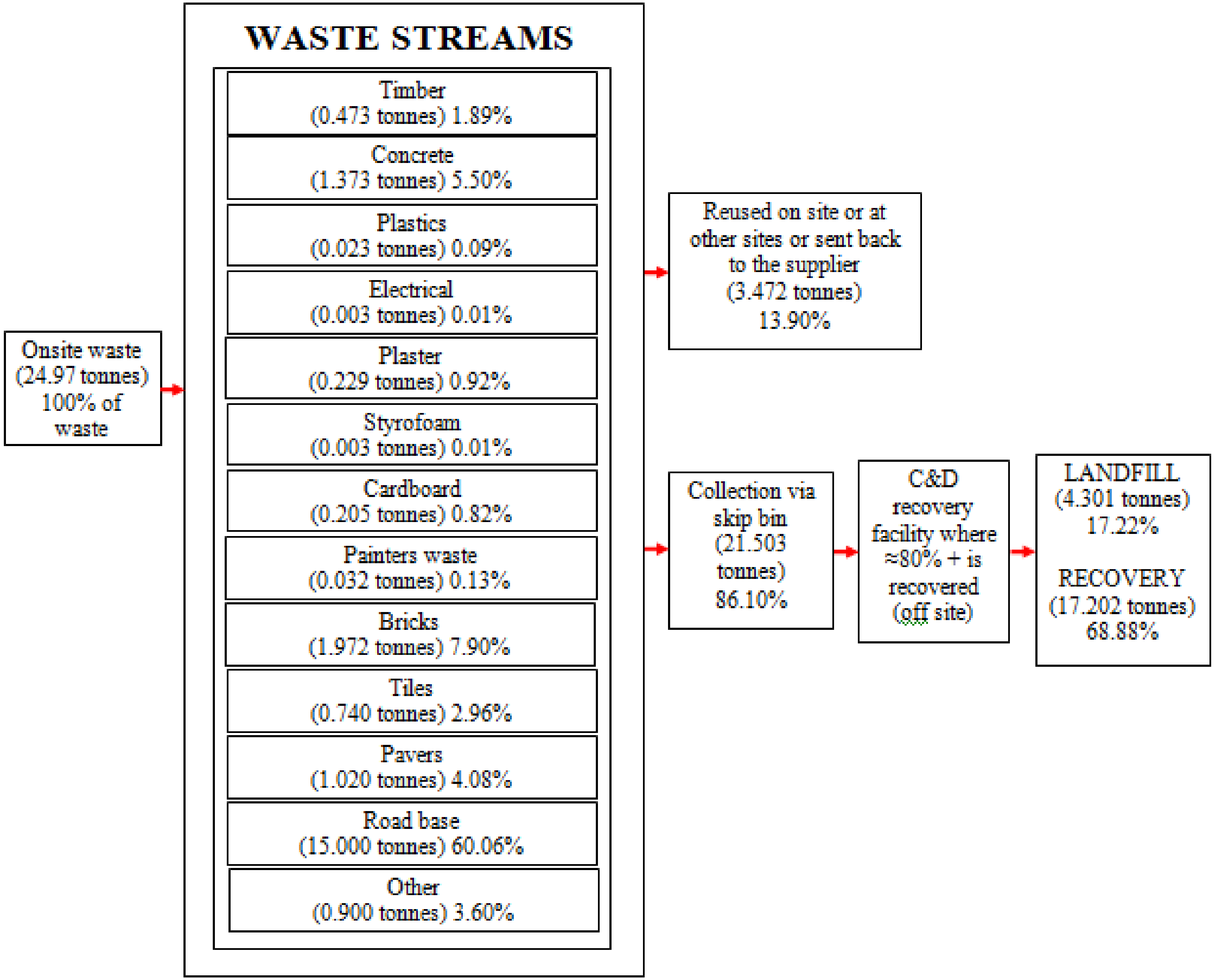

Figure 22: Mass flow diagram of waste produced at 35 Moulden Ave, Yokine (assumed 80% recovery rate at C&D recovery facility).

The amount of tiles used that were ordered for this stage was 78.09%, and the remaining 21.91% was considered waste (Figure 23). 14.82% of the 21.91% was excess tiles that were sent back to the supplier or keep by the owners in case of future breakages, the last 7.09% was broken tiles that went to a resource recovery facility (Figure 23).

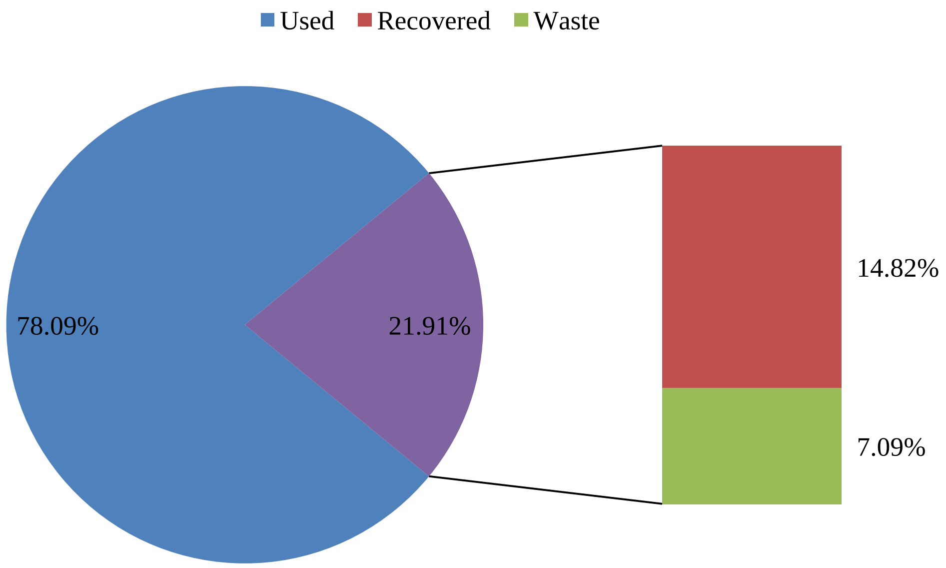

Figure 23: Used ordered tiles versus materials wasted and what is done with the waste quantities from stage 3.

Figure 24 shows that 91.05% of all pavers ordered for this site were used, and the remaining 8.95% of pavers was sent back to the supplier to be reused.

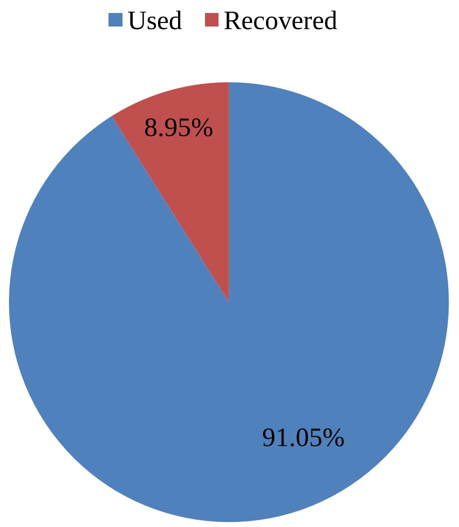

Figure 24: Used ordered pavers versus materials wasted and what is done with the waste quantities from stage 3.

Overall construction

Overall results from all three stages of construction indicates the average waste produced per square meter is 0.21 tonnes **per** square meter (Table 5).

Table 5: Average amount of waste produced per square meter of house being built.

Waste Material	Stage 1	Stage 2	Stage 3	Total
Tonnes	17.21	19.86	6.24	43.31
House sizes m²	214.70	188.52	212.26	615.475
Tonnes per m²	0.08	0.10	0.03	0.21

Figure 25 shows the overall known materials entering a three bedroom, two bathroom home and the known amount of waste materials generated being 178.71 tonnes and 43.31 tonnes respectively. This illustrates that 24.23% of all known materials ordered are considered as waste generated (Figure 25).

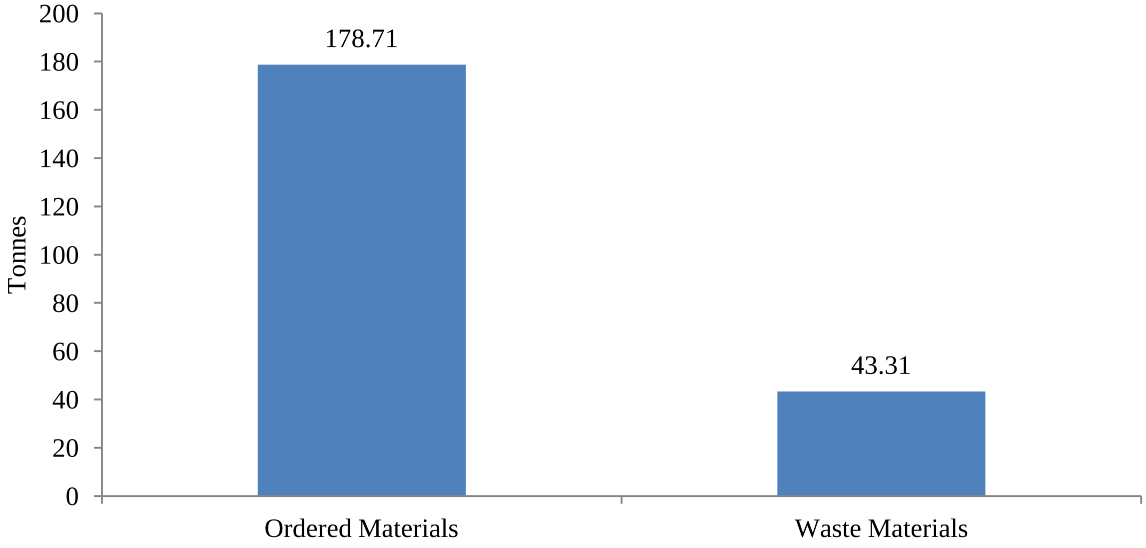

Figure 25: Average amount of waste materials produced for a 3 bedroom, 2 bathroom double brick house and know amount of materials ordered.

The percentage waste composition graph (Figure 26) illustrates the breakdown of waste generated during the construction of a three bedroom, two bathroom double brick home in WA. Sand was the largest waste stream generated at 30.40%, followed closely by concrete at 30.25%., and the next largest was road base 20.23% (Figure 26). The next largest waste stream was bricks making up 5.06% and the remaining waste streams made up only 4.06% (Figure 26).

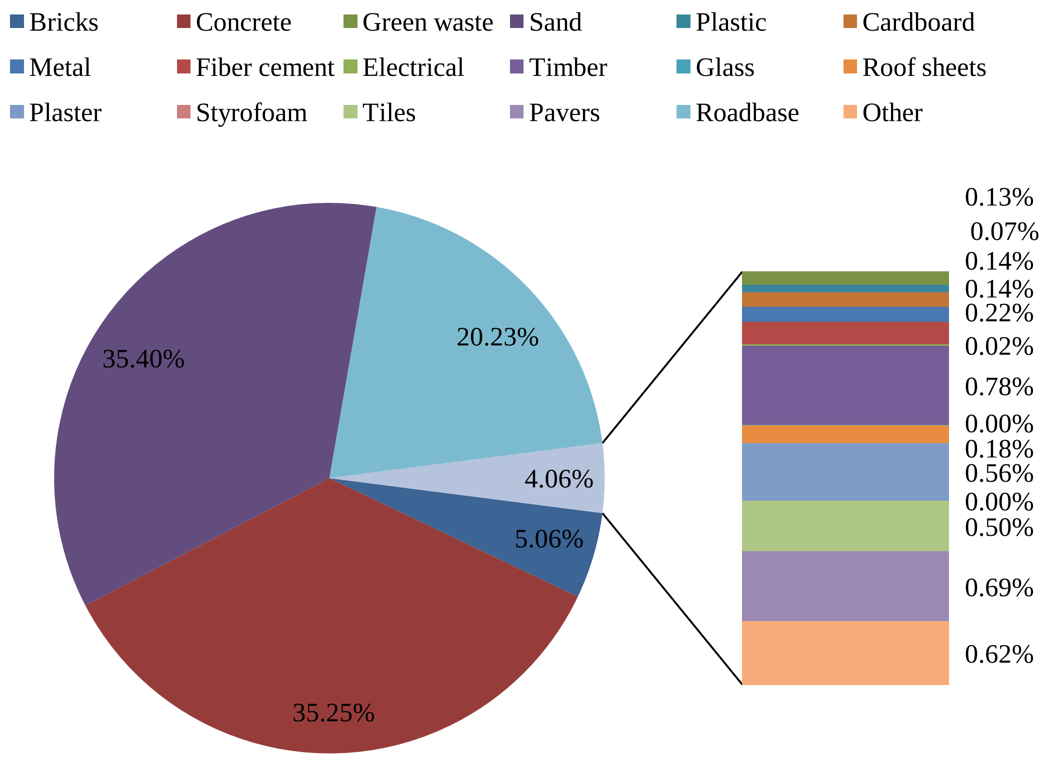

Figure 26: Composition of waste materials from the construction of a 3 bedroom, 2 bathroom double brick house.

From the data obtained in the C&D project section in the literature review we can determine the expected yearly amount of waste generated assuming all houses are of the same type, 3 bedroom, two bathroom double brick homes. Therefore if 20,350 houses are expected to be built in 2015 (HIA 2015; UDIA 2014), therefore, the expected waste generation is 881,358.5 tonnes from residential construction.

Demolition

11 Brown St, Dalkieth

The collection of demolition waste from 11 Brown St, Dalkieth depicts the amount of waste generated from demolition of this site (Figure 27). 269.5 tonnes of waste went directly to C&D recycling to be turned into recycled aggregate concrete, 7.95 tonnes of green waste went to mulch, 10.8 tonnes went to Henderson resource recovery facility to be sorted, and 4.95 tonnes went to landfill (Figure 27).

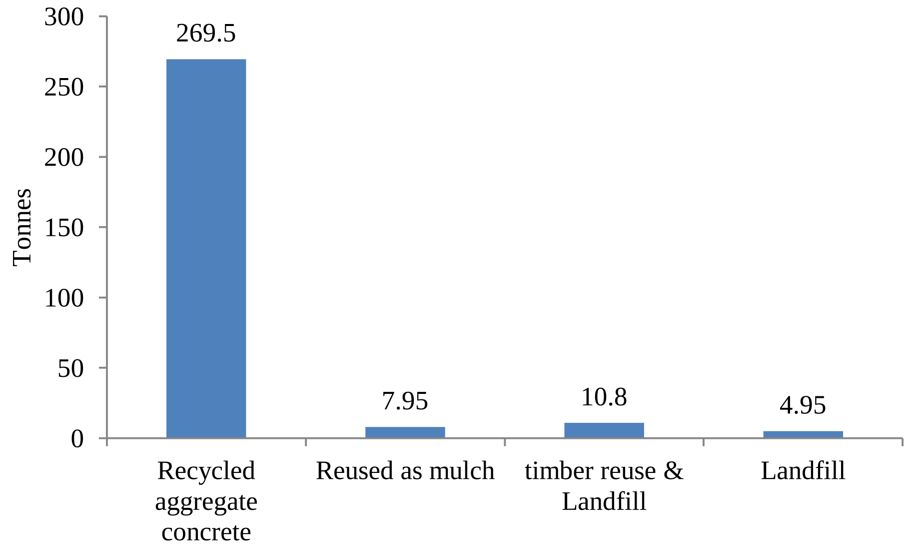

Figure 27: Waste streams by weight for 11 Brown St, Dalkieth.

Figure 28 compares the waste stream quantities as a percentage by weight, which indicates that approximately 94.63% of waste was recycled, and 1.69% was sent to landfill.

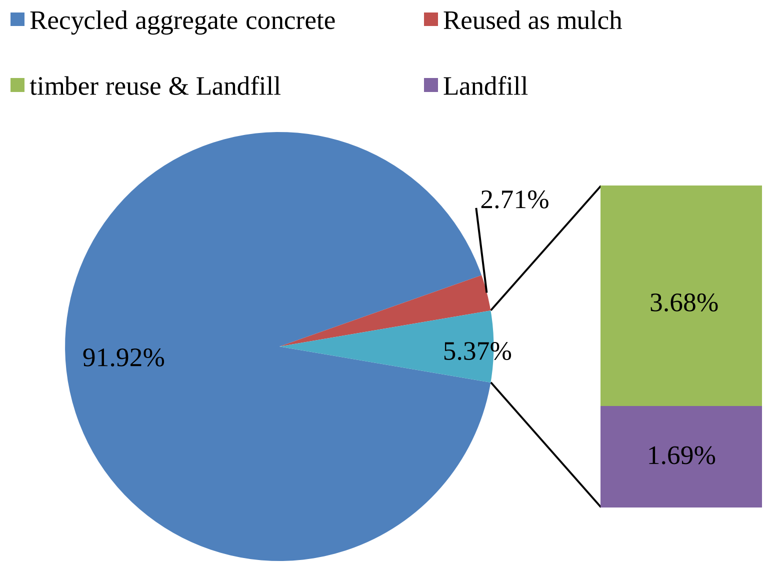

Figure 28: Waste stream composition as a percentage by weight at 11 Brown St, Dalkieth.

Figure 29 compares the total amount of waste by weight that was recoverable (286.09 tonnes) and the total amount of waste by weight being sent to landfill (7.11 tonnes). These results indicate that 97.56% of the waste generated was taken away to be recycled.

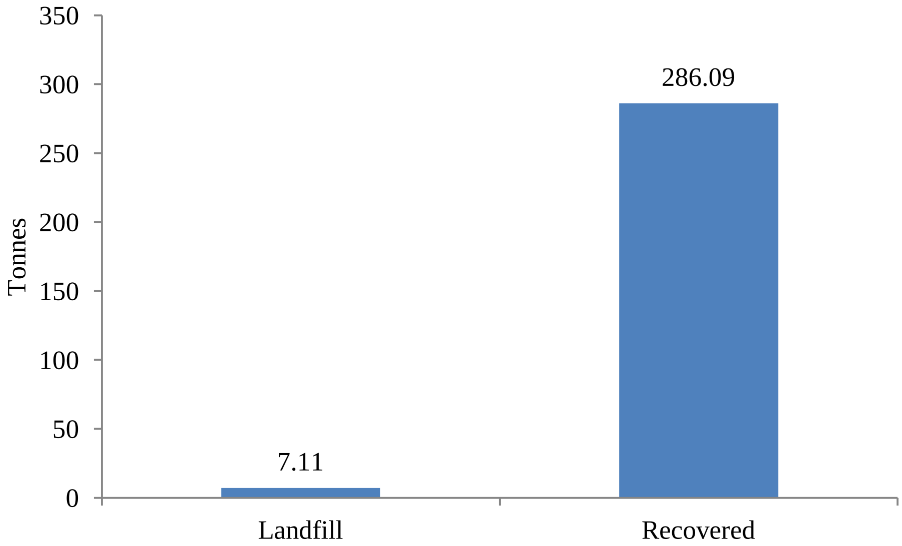

Figure 29: All waste recovered versus waste sent to landfill at 11 Brown St, Dalkieth.

A breakdown of the waste stream generated from the demolition of 11 Brown St, Dalkieth is shown in Figure 30. The breakdown shows that 2.71% (7.95 tonnes) of all waste by weight was green waste, which was reused as mulch, 91.92% (269.50 tonnes) was recovered by the demolisher for the use as recycled aggregate concrete. Also 2.94% (8.64 tonnes) of timber has been assumed recycled and 2.42% (7.11 tonnes) was sent to landfill (Figure 30).

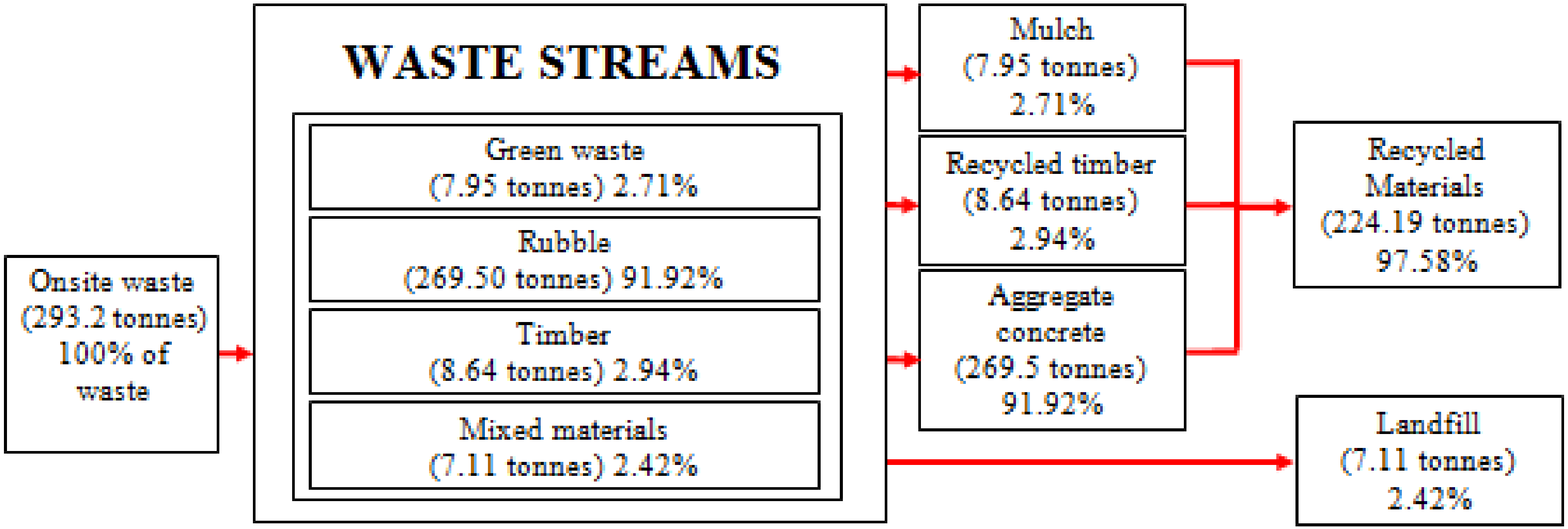

Figure 30: Mass flow diagram of waste produced at 11 Brown St, Dalkieth.

1 Prowse St, Beaconsfield

The collection of demolition waste from 1 Prowse St, Beaconsfield shows the amount of waste and the types of waste generated from this demolition (Figure 31). 199.89 tonnes of waste went directly to C&D recycling to be turned into recycled aggregate concrete, 6.30 tonnes of green waste went to mulch, and 13.50 tonnes of recycled metal went to SIMS metals for recycling (Figure 31). It also shows the amount of timber waste which was recycled (4.50 tonnes) and the amount of waste sent to landfill (63 tonnes; Figure 31).

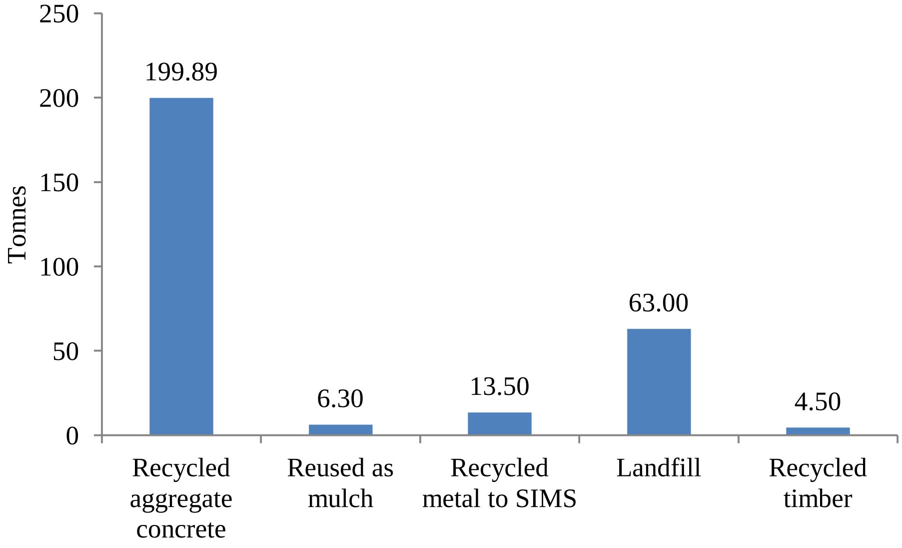

Figure 31: Waste streams by weight for 1 Prowse St, Beaconsfield.

Figure 32 illustrates the waste stream quantities as a percentage by weight indicating that at 78.06% of waste is recycled, and 21.94% is sent to landfill. Of this recycled material 69.6% is recycled aggregate concrete and the remaining 8.46% split into three groups (Figure 32).

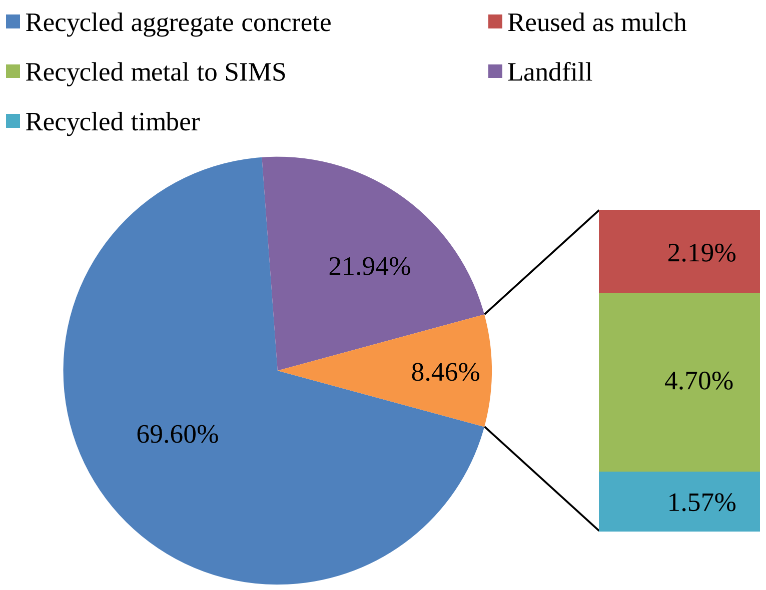

Figure 32: Waste stream composition as a percentage by weight at 1 Prowse St, Beaconsfield.

Figure 33 shows the total amount of waste by weight that was recovered (224.19 tonnes) was nearly four times greater than the total amount that was sent to landfill (63 tonnes).

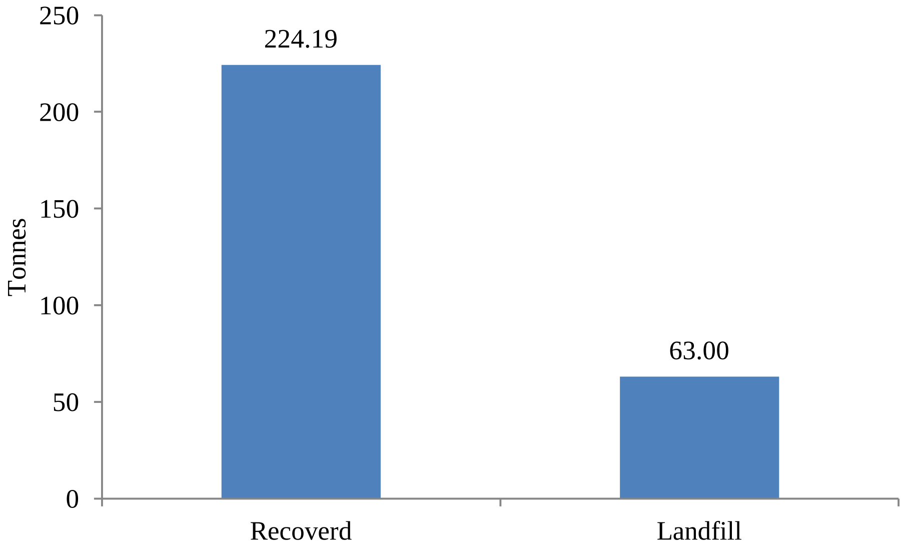

Figure 33: All waste recovered versus waste sent to landfill at 1 Prowse St, Beaconsfield.

Figure 34 provides a breakdown of waste streams from the demolition of 1 Prowse St, Beaconsfield. It demonstrates that 78.05% (224.19 tonnes) of all waste is being recovered, with recycled aggregate concrete making up the largest proportion of this at 69.60% (199.89 tonnes). The other three recycled waste streams all produced less than 5% of recyclables. It also shows that 21.93% (63.00 tonnes) of all waste generated was sent to landfill.

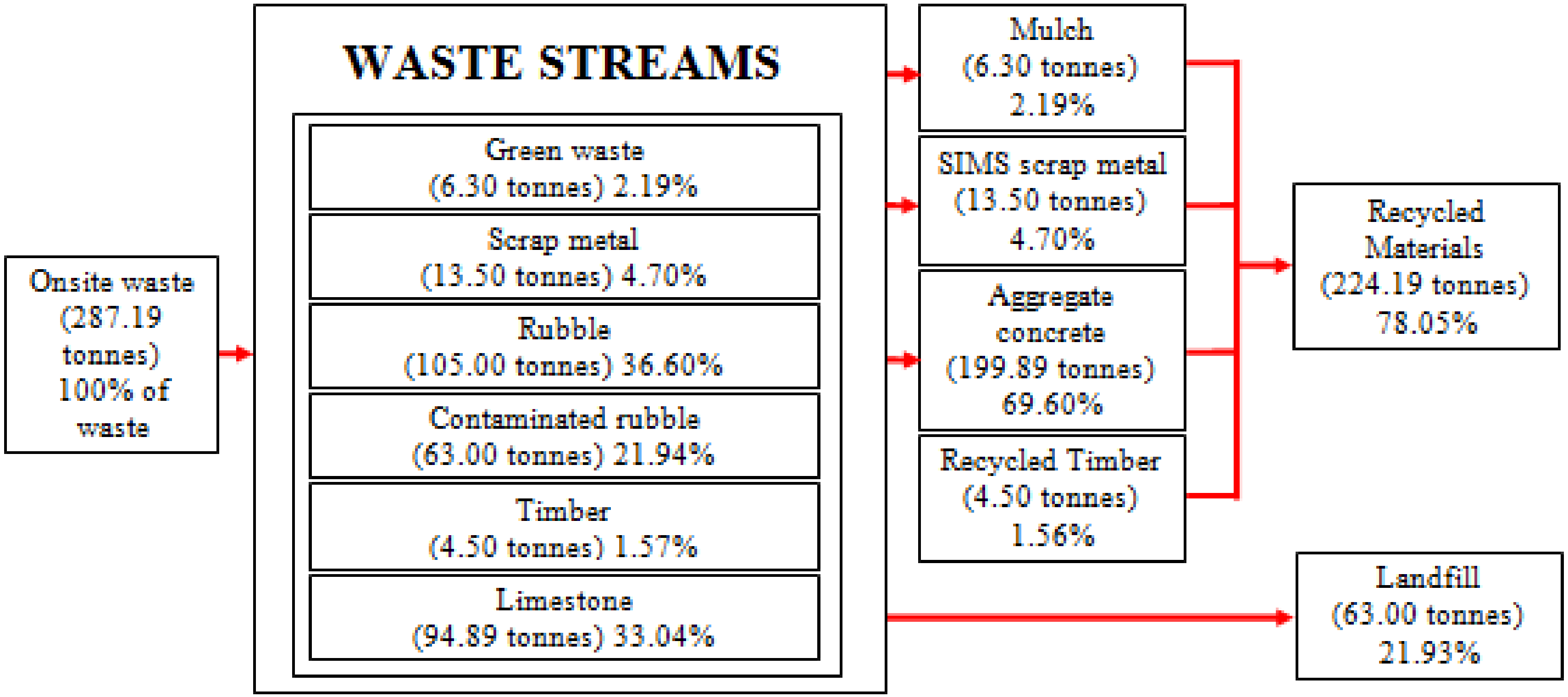

Figure 34: Mass flow diagram of waste produced at 1 Prowse St, Beaconsfield.

Economic Analysis

The range, mean, and standard deviation costs of waste disposal per cubic metre for landfill with bobcat and truck hire, resource recovery facility with bobcat and truck and skip bins are summarised in Table 6. The skip bin providers had the highest range and standard deviation in cost per cubic metre (Table 6). Landfill cost per cubic metre had the second highest range and standard deviation, but it also had the highest mean cost per cubic metre. Table 6 also shows that resource recovery facilities have the most consistent price and the lowest cost per cubic metre.

Table 6: Shows the cost per cubic meter of the range, mean and standard deviation of waste disposed of either to landfill, resource recovery facility or skip bin to resource recovery.

	Landfill with bobcat and truck ($\$/m^2$)	Resource Recovery facility with bobcat and truck ($\$/m^2$)	Skip bins ($\$/m^2$)
Range	85.25-137.00	47.50-71.15	58.00-145.43
Mean	114.98	61.84	89.62
Standard deviation	19.17	7.95	21.19

The mean, median, and highest and lowest prices for the three options considered for waste disposal are shown in Figure 35. It highlights that resource recovery facilities are the most cost effective option, followed by skip bin providers when considering the mean, median and lowest possible cost per cubic meter. When looking at the highest cost for disposal of waste, the skip bin providers are the highest followed by landfill and then resource recovery facilities (Figure 35).

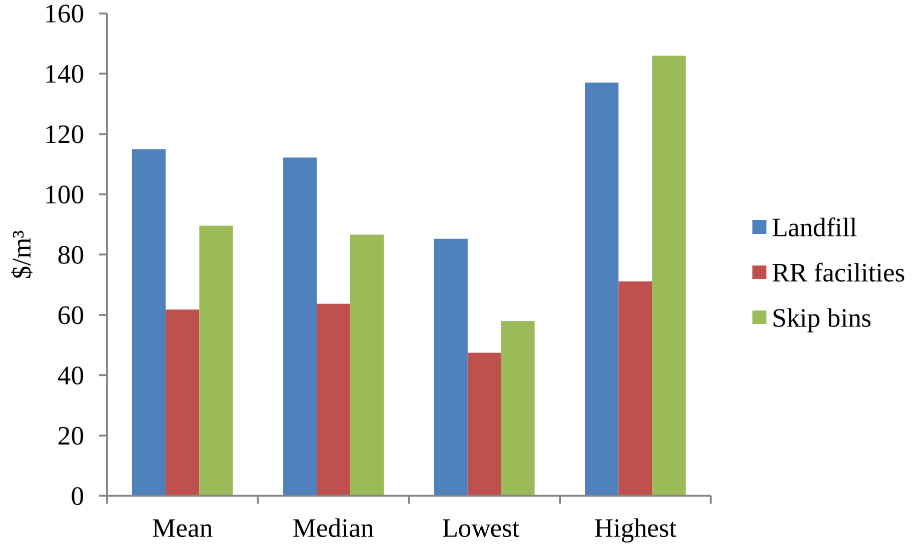

Figure 35: Comparison of cost per cubic metre of waste disposed of either to landfill, resource recovery facility or skip bin to resource recovery.

Figure 36 indicates the cost for all waste from threes sites audited to determine the average cost of waste from these projects. The total amount of waste in tonnes was multipled by the mean prices given in Table 6.

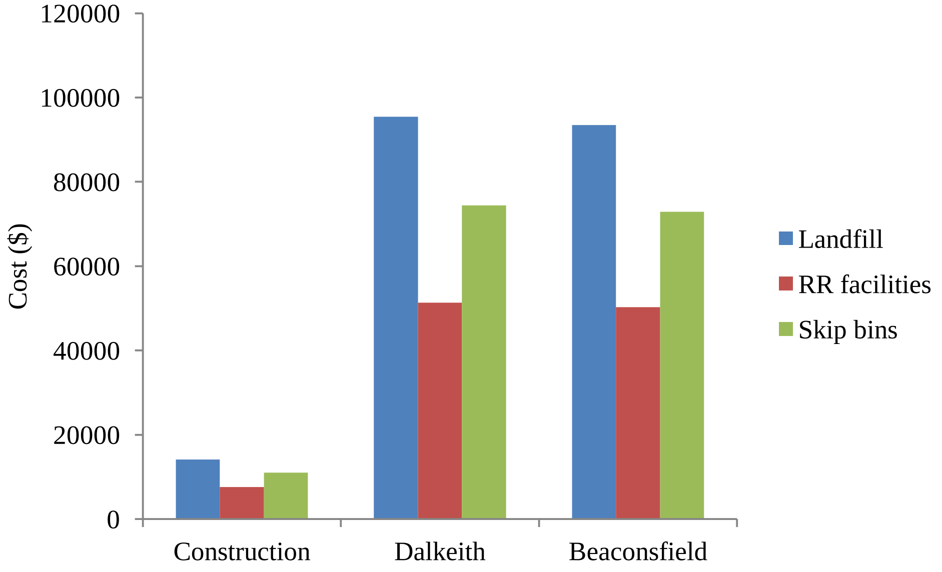

Figure 36: Cost of removing all waste from the 3 study sites, overall construction of a house, and Dalkieth and Beaconsfield demolitions.

DISCUSSION

C&D waste has proven to be a major issue in WA and the results from this report reaffirm this notion as the overall construction waste produced was 43.31 tonnes for the construction of a 3 bedroom, 2 bathrooms double brick house and the demolition waste produced was nearly 300 tonnes per site. Given the large volume of waste associated with C&D there is a significant cost for its disposal, which varies considerably depending on the rate of recovery and how it is disposed, with resource recovery facilities being more economically viable then landfill. There are also many barriers and limitations including cost that can affect the disposal of waste streams from residential C&D waste. The results from this study provide significant insight into waste generation of C&D materials throughout construction and demolition, and provide a basic economic analysis, which can provide the basis for future management practices to ensure C&D waste generation is minimised.

Construction

Stage 1

During stage 1 of construction the largest contributor of waste generated was sand from the earthworks which accounted for 71.90% of all waste by weight, at the Lynwood site. The second largest waste stream generated at this stage was cement from the slab pours which was 23.86% of all waste by weight. These are the main areas for concern for this stage of construction which came primarily from the earth works and slab pour.

The earthworks waste material is a significant issue as it is created on site and not ordered as a building material. The earthworks process is related to the installation of stormwater sumps and other utilities. According to the site supervisor, it is difficult to recover this sand from earthworks for reuse within the industry because of requirements of consistent characteristics (Dino Tallarzo pers. comm, 2015). This waste material is inevitable on all construction sites as earthworks are required for all builds. As this waste stream is made up of sand, dirt and other rubble materials it can be relatively easy to recycle, as all these materials can be recycled into fill materials which can then be used again to fill holes, and elevate land (All Earth Group 2015).

The other waste stream that is of concern from this stage is cement from the slab pour, as a certain percentage is always ordered as excess to allow for spills and other mishaps. The excess that has been ordered needs to be disposed of as the integrity of the product is in question after a period of time. This waste can be disposed of into recycled aggregates once it has been set (All Earth Group 2015).

Stage 2

During this stage 219.86 tonnes of waste material was produced with the largest proportion of that being mixed rubble (86.78%). This waste stream comprised of lumps of dried concrete, unused bags of cement and lime, broken bricks along with hardened wall render screeding and plaster surplus. This was due to the waste pile being comingled, therefore materials became contaminated by each other and hard to separation once some materials set, such as concrete and render.

The waste stream generating the second largest amount of waste by weight was bricks generating 1.628 tonnes (8.20%). This brick waste stream was comprised only of undamaged and uncontaminated bricks, therefore they could be used at a later date. In this case the owners of the home wished to keep the left over bricks. There are a range of strategies that could be implemented to reduce this waste stream. Firstly, the ordering processes could be reviewed to ensure that ordered quantities are calculated more accurately, thus ensuring product is not oversupplied. Onsite construction practices could also be reviewed to ensure materials are being used to the best advantage. While some wastage is unavoidable, onsite separation of cut or broken leftover bricks allows for wastage to be returned to the manufacturer or go directly to recycling or for repurposing. On site separation of waste bricks would ensure bricks remain uncontaminated and that they can be sent with mixed rubble for recycling into aggregates. Alternatively small loads of natural clay bricks can be returned to a number of leading Perth manufacturers for reuse purposes. Full bricks could be left stacked onsite for landscaping purposes and future needs.

Ceiling plasterboard and cornices, only contributed 2.04% by weight, but left a large footprint in terms of size. A couple of large sheets and a considerable number of full lengths of cornice remained after ceiling fixing was finished and it was noted that they were stored out of the weather for reuse elsewhere. There were many offcuts of plasterboard and cornice that although too short to be reused were big and bulky and took up a lot of space when discarded. While it is expected there would be considerable waste from this process it would be advantageous for builders to review ordering processes as well as onsite practices to ensure that materials are used efficiently. Furthermore on site separation of the unusable plasterboard and cornice would allow for the material to remain uncontaminated so that it can be repurposed. CSR Gyprock are introducing schemes where uncontaminated waste materials are returned and put back through their manufacturing processes to produce new materials (DSEWPaC 2012).

Stage 3

During this stage 27.97 tonnes of waste were generated. The main waste streams being road base generating 60.06% of all waste by weight and the sand generating 12.01% by weight. These two waste stream combined make up the majority of the waste therefore these are considered to have most impact from this stage of construction.

The road base material was an unavoidable waste stream as it is required to make the site more accessible to contractors. Once the housing construction is nearly complete this material becomes a problem as it needs to be removed from site for the driveway to be constructed. In this case it was approximately $10m^3$. This waste stream could have a high variability on different sites as drive sizes can be very different, therefore different amounts of excess road base brought in may be removed.

The next major waste stream from this site was left over sand, which was also generated during stage 1 and 2. Two other waste materials produced are worth noting during this stage which are the tiles and pavers used. The excess unbroken tiles and unused pavers were sent back to the suppliers as they were clean and not contaminated, therefore they could be reused elsewhere. The unbroken tiles that were not sent back to the supplier where kept by the owners in case of future breakages.

Overall Construction

Overall during the construction of a 3 bedroom, 2 bathroom double brick house there was much overlap with the main waste stream from all three stages comprising of sand from earthworks, brick process, and rendering process. Also a large pile of mixed rubble was produced during the second stage and a large quantity of road base during the third stage. However the findings do suggest that there are some waste streams that are very well managed already and only produce small amounts of waste in comparison. There are other waste streams that are worth noting as they were generated during all stages.

During the waste audit it was observed that tradespeople such as electricians and plumbers supplied their own hardware and materials and left very little waste, mainly leaving packaging materials. It was reasoned that this was likely as tradespeople realise the full cost of supply and thereby purchased precise amounts and retain any surplus for future work to minimise their own costs.

While some wastage is unavoidable, better management of cement, sand and rubble materials could provide a considerable reduction in discarded waste quantities. Better management could include simple tasks such as reviewing ordering practices to ensure ordered quantities are calculated more accurately to reduce the amount of materials being discarded such as full bags of cement or unused brickies sand. Both were observed to be left in the waste pile and eventually covered and mixed with other wastes.

It was also observed that both existing soil and yellow brickies sand was transported around the site by boots and wheel barrows as well as offsite by boots, delivery trucks and erosion. Unintentional removal of soil could be reduced by (where possible) restricting vehicle access to the site by having one entry and exit zone, installing sediment control barriers that can be reused on other sites to prevent erosion (KESAB environmental solutions 2015) and providing dedicated wash down zones for cleaning tools and equipment. Unintentional removal of yellow brickies sand could be reduced by segregation and containment of stockpiles. This would reduce the potential for the sand to be eroded by wind, reduce transport off site by boots or vehicles or become contaminated by other waste streams. Segregation or containment could be as simple as placing stockpiles of sand well within the site and as far away as possible from dedicated wash down zones, and covering stockpiles or installing sediment control barriers around stockpiles. These practices help to minimise waste generation, save costs and reduce environmental impacts.

The waste audit also found that small amounts of general rubbish waste such as food scraps, glass bottles and takeaway food containers were also generated onsite. While the glass bottles are recyclable the majority of this type of waste is putrescibles by nature and is largely unable to be put with construction waste for disposal. As local government councils do not issue bins until construction is complete this issue could be resolved by a general waste wheelie bin being located on site, which would allow separation and containment of the general waste. Bins could be transferred from one site to the next as needed. Currently there is no best practice solution to this issue so further investigation is needed to find viable options.

There were a number of limitations throughout the construction process which have highlighted gaps within the construction audit. The main ones are as follow:

- Not all materials ordered for the sites were available throughout this study, therefore there was limited comparability.

- There were some scheduling issues due to bad weather, and contractors taking excess time.

Demolition

11 Brown St, Dalkeith

During the demolition of 11 Brown St, Dalkieth the results showed that 97.56% of all waste by weight was recovered, and 2.44% was sent to landfill. The reasons for the recovery rate being so high could be that it was a double brick home generating high volumes of clean rubble for recycling, and also the internal strip out of the house was completed before the audit was started, therefore recyclable material such as floor boards, white goods and any other house hold items that could be recycled were already removed.

The main waste streams that were identified during this demolition were mixed rubble, green waste, timber and landfill. Mixed rubble was the greatest generation of waste by weight at 269.5 tonnes, which was all turned into recycled aggregate concrete. Recycled aggregate concretes have been used widely across Australia for the base of roads and footpaths, although there are still some major barriers to its acceptance in the industry (All Earth Group 2015). Barriers for the use of recycled aggregate concrete products include the lack of awareness, lack of government support and the lack of proper standards. Therefore, more effort is required in creating awareness, and relevant specifications to clearly differentiate where recycled aggregate concrete can be safely used (Rao *et al.* 2007). All Earth Group in WA creates a recycled aggregate concrete that can be used as a road base which meets the specifications set by Main Roads WA and the Institute of Public Works Engineering

Australia (WA) Branch, but that does not mean this product is utilised to its potential (All Earth Group 2014).

The other waste streams only generated small amounts of waste in comparison to the mixed rubble stream, with them making up less than 11 tonnes each. The timber waste was sent to a resource recovery facility at Henderson. The green waste was sent to a facility to be turned into mulch for agriculture. The remaining waste was sent to landfill and was not recovered at all. The results from this demolition site indicate that high resource recovery rates are possible, indicating that this method is successful and should be adapted for all applicable demolition sites in Perth.

1 Prowse St, Beaconsfield

The demolition of 1 Prowse St, Beaconsfield showed that 78.06% of all waste by weight was recovered using a variety of different resource recovery options. The remainder of the waste by weight ended up going to landfill. Again the main waste stream generated was rubble, both clean and contaminated.

The landfill waste stream was the second largest for this demolition which was wholly the contaminated rubble. Contaminated rubble is a hard waste stream to try and reduce as large volumes are generally generated and the time and effort for sorting through these materials is vastly outweighed by saving made on recovery. This is an issue that has been identified by previous reports and represents a significant hurdle for improving resource recovery on demolition projects (Zhao *et al.* 2010).

Scrap metal was the third largest waste stream generated on this site and was sent to SIMS scrap metal. There are many companies within WA that will pay for recycled scrap metal as there is a very viable market for scrap metals overseas. One of the most profitable recycled metals is copper pipe, so before demolition copper pipes are stripped from houses and taken to be recovered at metal resource recovery facilities (Zhao *et al.* 2010). All other metal is stockpiled until the demolition is complete and then taken to a resource recovery facility. The demolition manger for this project suggested that for him the process of sorting the waste metals from the pile was not worth the time, as the profit for the material did not cover the time spent separating (Tilbrook pers. comm. 2015).

This demolition site had a large volume of green waste for its size as it was highly vegetated, producing 6.30 tonnes, which was sent to a resource recovery facility where it was turned in to mulch for agricultural purposes. The timber waste stream was also recycled. It was recycled by separating out the timber and the demolisher taking it back to his yard to be turned into fire wood or reused by friends on various projects. Also the timber pile was placed outside of the fenced off demolition site with a sign saying free wood, which represents a cheap and easy way to improve resource recovery.

Once the demolition was completed the site has to be cleared out and levelled to specified conditions before handing over to the builders. During this process a large amount of limestone was found underground that was required to be dug out. This lime stone generated a large amount of the material that was to be recovered in recycled aggregate concrete. As this is not a common occurrence on demolition sites, this made the waste generation value for this property larger than expected.

Overall Demolition

Several limitations were noted during the demolition of these houses, which indentified gaps within the demolition audit. They are as flows:

- Limited space for separate waste streams to be piled, thereby limiting waste separation at the source.
- Materials removed during strip out of the house before demolition were not recorded.
- Volumes of waste being generated by demolitions is large, making it physically impossible to manually weigh all waste. Therefore further research into how best to audit demolition sites is required.
- As the two demolition sites were vastly different in size a comparison of the two was not able to be conducted. Therefore future research into demolition sites of the same size and type is needed to generate average values for demolition sites of similar sizes.
- House plans or lot size were not obtained as they are not required to demolish a house, therefore amount of waste generated per m^2 of house could not be calculated.

Economic Analysis

The results from the simple economic analysis illustrated that resource recovery with the use of a bobcat and truck is the cheapest option per cubic meter of waste with an average price of $61.84 per cubic metre. The resource recovery option with bobcat and truck was also the cheapest option for all factors considered. Landfill was the most expensive option overall

($114.98). These results are promising as it indicates that resource recovery is a more viable option than going to landfill and can be used to make resource recovery a more attractive option in the future. This strategy could be made more attractive to builders and demolition teams by governments subsidising the cost of resource recovery facilities. By providing a monetary incentive you are more likely to get a positive response and result in greater resource recovery on a whole (Duran *et al.* 2006). As noted previously there is limited information regarding the cost of C&D waste generation and how the prices found here compare internationally. This may be a factor that is limiting resource recovery in Western Australia.

The waste assessed in this economic analysis was considered commingled mixed waste. Therefore minimal source separation is required as there are many single waste stream resource recovery facilities. Therefore the economic analysis was based on the cost of disposing all waste at one location. There were three main options considered for this cost analysis, that was landfill with bobcat and truck, resource recovery facility with bobcat and truck, and skip bins with some resource recovery. These three options were chosen due to their being the easiest possible solution for builders and demolishers, as they do not lose extra time from source separation, which limits the potential loss in profits. This analysis was chosen due to the feedback from some builders and demolishers, indicating they don't believe source separation of waste is a viable option for their businesses.

There were limitations to consider when conducting this simple economic analysis such as:

- Not all landfill sites, resource recovery facilities or skip bin operators were willing to disclose information.
- Not all of the facilities contacted accepted C&D waste, which reduced the data set available.
- There are many single waste stream resource recovery facilities that only accept single waste streams and therefore fall outside of the scope of this analysis. In future a full survey/questioner could be used to obtain information from all facilities that receive waste to determine what waste streams are accepted and what is not, as well as to determine the price and areas they service.

Overall

During the waste audit it was found that a number of items from unknown sources were dumped illegally in the waste pile. On average there is 5-6m^3 of mixed waste dumped illegally on construction sites, which can range from tyres to asbestos to dead animals (Tilbrook pers. comm. 2015). While there is legislation for illegal dumping (DER 2015), there is often little evidence of where the items came from to be able to report it to authorities. Suggestions to combat this issue include having lockable waste cages/bins on site; however, more investigation is required to find viable solutions to the issue of illegal dumping. Illegal dumping occurred at stage 1 and 2, but did not really occur during stage 3 as skip bins were used and waste piles were stored away from the verge, therefore discouraging people from dumping their rubbish. Also skip bins were not ordered until there was enough waste to fill a bin. During this study illegal dumping occurred more during the construction of a property rather than the demolition of a property. This could be due to the time period it takes to build as opposed to demolish a house. The period to demolish a house is only about a week, whereas the period of time to construct a home is several months. This represents a significant waste stream and comes at an extra cost to the builder and may discourage them from seeking resource recovery. This issue needs to be policed harder if resource recovery is to be maximised.

Something needs to change in the C&D industry in Western Australia, as the waste recovery rates from construction in particular are very low when compared to international studies (Esin & Cosgun 2007; Sáez *et al.* 2012).

There were many limitations during this study which have highlighted gaps. They are as follows:

- The lack of transparency from recovery facilities regarding their recovery rates (Industry standard anecdotal evidence is 80% recovery; 20% "non-recyclables" to landfill) and regarding the end products of the generated waste.
- Time delays to projects can push back schedules and updating these schedules are not always a priority, therefore days of waste collection can be missed allowing gaps to occur in data sets.
- Throughout the literature, C&D waste is clumped together and not separated out by renovation, demolition and construction as well as not being separated out by sector (commercial, industrial, residential etc.).
- There are a number of legislation/regulations in relation to C&D waste but none of them directly relate to the recycling on waste from C&D sites, which makes the reduction and recycling of waste a difficult task as the current legislation/regulations only require minimum standards.
- A more complex economic analysis can be completed after a more robust data set has been collected on the amount and type of waste produced for C&D buildings of

similar sizes. At this stage there is not enough data to determine whether it is financially viable for source separation of materials. Therefore a comprehensive survey on all resource recovery facilities and landfill sites would be required.

CONCLUSION

This study showed that the residential construction industry would generate approximately 881,000 tonnes of waste during 2015 using the predicted housing figures from HIA and UDIA. Also it shows that there is great variation with the generation of demolition waste due to the different site characteristics. This was shown by the two demolition sites of different sizes both generating nearly 300 tonnes of waste. The waste streams produced highlight that the main area of concern is rubble materials, concrete, sand, dirt, and broken bricks and tiles. Therefore better waste management of these wastes and possible recycling into waste derived materials would be ideal.

The simple cost analysis illustrated that resource recovery facilities are the most cost effective options for people within the C&D industry. The implementation of waste management plans could help reduce the amount of waste being sent to landfill as well as improve productivity on site as less waste means less work is required to dispose of this waste. This cost analysis did determine that resource recovery is the cheapest option although it did not include single waste stream facilities which could be cheaper if waste is separated at source. Therefore this needs to be further research conducted.

From this report it is clear that future research projects are needed to get a clearer picture of waste generation and the cost of it. Future studies on waste generation as well as cost benefit analysis projects would assist in legislative change and government programs to reduce the amount of waste being sent to landfill from this industry.

This project also found that there were a variety of gaps and limitations to the legislation and regulation of waste as well as the amount of waste management plans and programs. The legislation that does exist does not directly relate to waste management, but more to the control of waste. Although there are some waste management plans and programs they do come at a financial cost, but the environmental and productivity improvements should outweigh this.

Undertaking scientific research like this plays an important role in improving waste reduction and resource recovery from residential C&D projects. This will aid in identifying areas that can help improve Australia's resource recovery rate to eventually equal or exceed those of the European countries.

RECOMMENDATIONS

The research presented in this study has indicated there are a number of short falls in the waste management industry. There are a range of recommendations below that could be used to improve resource recovery and reduce the amount of C&D waste going to landfill.

- More educational programs for builders and demolishers.
- Implementation of waste management plans.
- Legislative change to regulate and encourage resource recovery.
- Government subsidies for waste recovery facilities and programs.
- Improved material management through ordering processes.
- Encouraged resource sharing within the building industry (e.g. like “Gumtree”).
- Future works in cost-benefit analysis of C&D waste.
- Further research into waste composition with larger data sets.

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APPENDICES

Appendix A. Local Government Laws.

Mindarie Regional Council (MRC)			
Town of Cambridge	Health Local Law 2001 5.13 Construction site refuse On every building construction site the builder shall – f) Ensure that an appropriate refuse receptacle is provided on site for the storage of building rubbish on any premises in which building or construction work is being carried out; g) Ensure that all rubbish from the site is placed in the receptacle as directed by an authorised person, any building surveyor of the local government or an environmental health officer; h) Ensure the receptacle is maintained on the site for the duration of the construction work; i) Ensure the receptacle does not overflow; and j) Ensure that any refuse in the receptacle cannot be blown out by wind.	Adopted 24/04/2001	Amended 07/09/2007
City of Joondalup	Health Local Law 1999 5.13 Construction site rubbish On every building construction site the builder shall: a) Ensure that, on any premises in which building or construction work is being carried out, an appropriate refuse receptacle is provided on site for the storage of building rubbish; b) Ensure that all rubbish from the site is placed in the receptacle as directed by an authorised person, an building surveyor of the local government or any environmental health officer; c) Ensure the receptacle is maintained on the site for the duration of the construction work; and d) Ensure the container does not overflow.	Adopted 13/07/ 1999	Amended 27/08/1999
City of Perth	The City of Perth Health Local Law 2000 Division 2 – Disposal of Refuse Deposit of Refuse 46. (1) A person shall not deposit or cause or	Adopted 23/01/2001	Amended N/A

	permit to be deposited any rubbish or refuse in or any street or on any land other than a refuse disposal site. (2) A person shall not deposit rubbish or refuse in or on a refuse disposal site except – a) At such place on the site as may be directed by the person in charge of the site; or b) If the person in charge is not in attendance at the site as may be directed by a notice erected on the site. Removal from Refuse Disposal Site 47. (1) A person shall not remove any rubbish or refuse from a refuse disposal site without the written approval of the Council. (2) A person who obtains approval from the Council shall comply with any conditions imposed by the Council and set out in the approval. Removal of Rubbish from Premises or Receptacle 48. (1) A person shall not remove any rubbish or refuse from premises unless that person is - a. the owner or occupier of the premises; b. authorised to do so by the owner or occupier of the premises; or c. authorised in writing to do so by the Council. (2) A person shall not, without the approval of the Council or the owner of a receptacle, remove any rubbish or refuse from the receptacle or other container provided for the use of the general public in a public place. Deposit of Liquid Refuse 36. A person shall not deposit or cause or permit to be deposited liquid refuse or liquid waste - (a) on a street; (b) in a stormwater disposal system; or (c) on any land or place other than a place or depot approved for that purpose. Disposal of Liquid Waste 37. (1) The owner or occupier of premises shall - (a) provide, by one of the methods prescribed in this clause, for the disposal of all liquid waste produced on the premises; and (b) at all times maintain in good working order		

	and condition any apparatus used for the disposal of liquid waste. (2) Liquid waste shall be disposed of by one of the following methods— (a) discharging it into the sewerage system of a licensed water service operator in a manner approved by the licensed water service operator; (b) discharging it into an apparatus for the treatment of sewage and disposal of effluent and liquid waste approved by the Executive Director, Public Health or the Council; (c) collection and disposal at an approved liquid waste disposal site in a manner approved by the Executive Director Public Health.		
City of Stirling	City Waste Management Local Law 2010 2.2 Deposit of liquid refuse A person must not deposit, or cause or permit to be deposited, liquid refuse or liquid waste - a) on a street; b) in a stormwater disposal system; or c) on any land or place other than a place or depot duly authorised for that purpose. 2.3 Disposal of liquid waste (1) The owner or occupier of premises must - a) provide, by one of the methods prescribed in this clause, for the disposal of all liquid waste produced on the premises; and b) at all times maintain in good working order and condition any apparatus used for the disposal of liquid waste. (2) Liquid waste must be disposed of by one of the following methods— a) discharging it into the sewerage system of a licensed water service operator in a manner approved by the licensed water service operator; b) discharging it into an approved apparatus for the treatment of sewage and disposal of effluent and liquid waste; or c) collecting and disposing it at an approved liquid waste disposal site in a manner approved by the CEO. 3.2 Receptacles An owner or occupier of premises must— (a) at all times keep the lid of the receptacle closed except when depositing refuse or cleaning the receptacle; (b) except for a reasonable period before and after collection time as determined by an authorised person, keep the receptacle on the premises and	Waste management law adopted 06/07/2010 Prevention and Abatement of dust and liquid waste adopted 21/05/2002	Waste management amended 06/08/2015 Prevention and Abatement of dust and liquid waste amended 07/06/2012

	located - (i) behind the street alignment and so as not to be visible from a street or public place; or (ii) in such other position as is approved by an authorised person; (c) within a reasonable period before collection time, and no later than 6am on the designated collection day, place the receptacle on the verge (or other area as stipulated by an authorised person) adjoining the premises as close as practicable to the street alignment of the premises but so that it does not unduly obstruct any footpath, cycle way, right-of-way or carriage way; (d) if the receptacle is lost, stolen, damaged or defective, notify the City within 3 days after the event; and (e) ensure that the premises is provided with an adequate number of receptacles. Prevention and Abatement of dust and liquid waste Local Law 2002 PART 3 – PROHIBITED ACTIVITIES 4. An owner and occupier of land must take effective measures to – a) stabilise dust on the land; b) contain all liquid waste on the land; c) ensure no dust or liquid waste is released or escapes from the land whether by means of wind, water or any other cause; and d) notify the owners or occupiers of adjoining land in writing 48 hours prior to the commencement of any activity that has the potential to cause the release or escape from the land of dust or liquid waste giving details of; i. the nature of the activity; ii. the proposed time and location of the activity and iii. the name of the person responsible for carrying out the activity and how and where that person may be contacted		
Town of Victoria Park	Town of Victoria Park Health Local Law 2003 Deposit of Liquid Refuse 36. A person shall not deposit or cause, or permit to be deposited liquid refuse or liquid waste - (a) on a street; (b) in a stormwater disposal system; or (c) on any land or place other than a place or depot duly authorised for that purpose. Disposal of Liquid Waste	Adopted 16/12/2003	Amended N/A

	37. (1) The owner or occupier of premises shall - (a) provide, by one of the methods prescribed in this clause, for the disposal of all liquid waste produced on the premises; and (b) at all times maintain in good working order and condition any apparatus used for the disposal of liquid waste.		
City of Vincent	N/A		
City of Wanneroo	City of Wanneroo Private Property Local Law 2001 12.1 Wind blown sand No person shall allow any land in the district to be kept in such a condition so as to allow soil or dust to be released or escape whether by means of wind, water or other causes, from that land onto adjoining or nearby land. 12.3 Litter control on building sites (1) No person, owner or occupier shall allow or commence or continue the construction of any building works on any land, unless one of the following measures is implemented to prevent building litter or rubbish of any kind whatsoever from being blown from the construction site - c) provide a receptacle of a capacity not less than 4m3 fitted with a lid on site for the disposal of all rubbish; or d) provide an equivalent wire enclosure on site with a lid for the disposal of all rubbish. (2) All rubbish which is capable of being wind blown and other offensive matter on the construction site is to be placed and kept in the receptacle. (3) The lid is to be kept secure on the receptacle at all times.	Private Property Law adopted 2001	Private Property Law amended April 2010
East Metropolitan Regional Council (EMRC)			
Town of Bassendean	Town of Bassendean Health Local Law 2001 4.16 Removal of Rubbish from Building Sites (1) During all periods of construction on any building site: a) The builder shall provide and maintain on the site a rubbish disposal bin of sufficient capacity to enable all waste generated on site to be effectively disposed of; b) The builder shall keep the site free of rubbish and offensive material, whether temporary or otherwise;	Adopted 09/07/2001	Amended 13/08/2002

	c) The builder shall maintain the street verge immediately adjacent to the site free of rubbish and offensive matter, whether temporary or otherwise; d) The builder shall on completion of construction immediately clear the site and the street verge adjacent thereto of all rubbish and offensive matter and shall remove there from all or any rubbish disposal bins thereon by the builder. (2) In this section the word “rubbish” shall include stones, bricks, lime, timber, iron, tiles, bags, plastics and any broken, used or discarded matter whatsoever.		
City of Bayswater	City of Bayswater Health Local Laws 2001 4.15 Removal of rubbish from Building Sites (1) During all periods of construction on any building site – e) the builder shall provide and maintain on the site a rubbish disposal bin of sufficient capacity to enable all waste generated on site to be effectively disposed of; f) the builder shall keep the site free of rubbish and offensive material, whether temporary or otherwise; g) the builder shall maintain the street verge immediately adjacent to the site free of rubbish and offensive matter, whether temporary or otherwise; h) the builder shall on completion of construction immediately clear the site and the street verge adjacent there to of all rubbish and offensive matter and shall remove there from all or any rubbish disposal bins there on by the builder. (2) in this section the word “rubbish” shall include stones, bricks, lime, timber, iron, tiles, bags, plastics and any broken, disused or discarded matter whatsoever.	Adopted 10/12/2001	Amended Oct 2007
City of Belmont	N/A		
Shire of Kalamunda	Shire of Kalamunda Health Local Law 2011 4.3 Interpretation In this Division unless the context otherwise requires— occupier means a person having the charge, management or control of a building site and where two or more persons share or jointly have the charge, management or control of a building site, each of those persons and includes the holder	Adopted 07/10/2011	Amended N/A

	of a building licence issued under the Local Government (Miscellaneous Provisions) Act 1960; and building site means premises on which the construction, structural alteration, erection or demolition of a building is being undertaken. 4.4 Occupier obligations The occupier of a building site shall— a) at all times ensure the provisions of containers or enclosures approved by the Manager Health Service for the deposit of trade and other refuse whether of light or heavy bulk, on the building site; and b) on completion of construction, structural alteration, demolition or erection on the building site, clear the same of all refuse. The disposal of such refuse shall be in accordance with the requirements of the Manager Health Service.		
Shire of Mundaring	Shire of Mundaring Health Local Laws 2003 Building Construction 4.2.10 (1) During all periods of construction on any building site, the builder shall - a) when requested by an environmental health officer, provide and maintain on such site a rubbish disposal bin, being either − (i) a bin of not less than 4 cubic metres in capacity; or (ii) a receptacle or other container approved by the Principal Environmental Health Officer; a) keep such site free of rubbish and offensive matter; and b) maintain the street verge immediately adjacent to such site free of rubbish or offensive matter. (2) On completion of construction, the builder shall immediately clear the site and the adjacent street verge of all rubbish, waste materials and offensive matter and all rubbish bins provided by the builder. (3) In subsection (1) the word “rubbish” shall be deemed to include all discarded stones, brick, lime, timber, iron, tiles, bags, plastics and any broken, used or discarded matter whatsoever whether of the same kind or type or otherwise. Division 2 - Construction and Use Requirements General Construction Requirements 8.2.1 The general construction requirements of a lodging house shall comply with the Building Code and the Act.	Adopted 2003	Amended N/A

City of Swan	N/A		
Rivers Regional Council (RRC)			
City of Armadale	City of Armadale Environment, Animals and Nuisance Local Laws 2002 Responsibilities of the builder, owner or occupier (Heading amended GG 54 of 4th April 2008) 40. (1) From the time of commencement of— a) construction work on a building site until the time of completion of such work, the builder; or b) work likely to generate refuse on a development site until the time of completion of such work, the owner or occupier shall— (i) ensure all refuse arising on the building or development site is (ii) contained and prevented from being blown from the site by wind. (iii) keep the building or development site as free as is practicable of (iv) any refuse; (v) maintain the street verge immediately adjacent to the building or (vi) development site free of refuse arising from the building site; and (vii) ensure any refuse receptacle is emptied when full. (2) In the case of— a) a building site, the builder; or b) a development site, the owner or occupier shall ensure that, within two days of completion of construction or development works, as the case may be, the site and the street verge immediately adjacent to it is cleared of all refuse and all refuse receptacles are removed from the building or development site.	Enviro, animal and nuisance law adopted 2002	Enviro, animal and nuisance law amended 02/07/2012
City of Gosnells	City of Gosnells Health Local Laws 1999 Rubbish Bins on Building Sites 44. (1) During all periods of construction on any building site: a) The builder shall provide and maintain on such site a rubbish disposal bin approved by Council being either: - a bin of not less than 4 cubic metres in capacity; - a bin of not less than 200 litres in capacity in which case such bin shall have an effectively operating lid; or	Adopted 24/11/1999	Amended 07/09/2007

	- other approved container. b) The builder shall keep such site free of rubbish and offensive matter, whether temporary or otherwise. c) The builder shall maintain the street verge immediately adjacent to such site free of rubbish or offensive matter, whether temporary or otherwise. d) (d) The builder shall on completion of construction immediately clear the site and the street verge immediately adjacent thereto of all rubbish and offensive matter and shall remove there from all or any rubbish disposal bins placed thereon by the builder. (2) In this clause, the word "rubbish" shall be deemed to include stones, bricks, lime, timber, iron, tiles, bags, plastics and any broken, used or discarded matter whatsoever, whether of the same kind or type or otherwise.		
City of Mandurah	Waste management Local Law 2010 5.2 Removal of waste from premises (1) A person must not remove any waste from premises, or the verge associated with premises, unless that person is - (a) the owner or occupier of the premises; (b) authorised to do so by the owner or occupier of the premises; or (c) authorised in writing to do so by the City or an authorised person. (2) A person must not, without the approval of the City, an authorised person or the owner or custodian of the receptacle or waste container, remove any waste from a receptacle or waste container. 6.1 Deposit of liquid refuse or liquid waste A person must not deposit, or cause or permit to be deposited, liquid refuse or liquid waste - (a) on a street; (b) in a stormwater disposal system; or (c) on any land or place other than a place that has been approved by the City or an authorised person for that purpose.		
Shire of Murray	N/A		
Shire of Serpentine Jarrahdale	N/A		
City of South Perth	N/A		

Shire of Waroona	Shire of Waroona Health Local Laws 2001 Division 5 - Building Sites - Rubbish Building Sites - Rubbish 3.5.1 (1) During all periods of construction on any building site: a) The builder shall provide and maintain on such site a rubbish disposal bin approved by the local government being either - (i) a bin of not less than 4 cubic metres in capacity; or (ii) a bin of not less than 0.20 cubic metres in capacity in which case such bin shall have an effectively operating lid. b) The builder shall keep such site free of rubbish and offensive matter, whether temporary or otherwise. c) The builder shall maintain the street verge immediately adjacent to such site free of rubbish or offensive matter resulting from construction on the building site, whether temporary or otherwise. d) (d) The builder shall on completion of construction immediately clear the site and the street verge immediately adjacent thereto of all rubbish and offensive matter and shall remove there from all or any rubbish disposal bins placed thereon by the builder. (2) In this section the word "rubbish" shall be deemed to include stones, bricks, lime, timber, iron, tiles, bags, plastics and any broken, used or discarded matter whatsoever, whether of the same kind or type or otherwise. (3) In this section the word "builder" shall include the person or persons or firm or corporation who shall be the holder of any building licence issued in respect of such building works by the local government and shall also include any person or persons or firm or corporation who shall be in effective control of such building site whether or not such person or persons or firm or corporation shall be the holder of any such licence.". Site Conditions 5.6.3 The owner or occupier of premises shall take effective measures to prevent the discharge of dust which may involve - (a) reducing the stocking rate immediately to a level that does not cause the discharge of dust; or (b) stabilisation of the soil surface to a level that	Adopted 2001	Amended N/A

	does not cause the discharge of dust; or (c) provision of adequate windbreaks to effectively prevent the discharge of dust.		
South Metropolitan Regional Council (SMRC)			
City of Cockburn	N/A		
Town of East Fremantle	N/A		
City of Fremantle	N/A		
City of Kwinana	N/A		
City of Melville	N/A		
Western Metropolitan Regional Council (WMRC)			
Town of Claremont	N/A		
Town of Cottesloe	N/A		
Town of Mosman Park	N/A		
Shire of Peppermint Grove	N/A		
City of Subiaco	N/A		
OTHER COUNCILS			
City of Canning	N/A		