REDUCING WASTE IN THE CONSTRUCTION SECTOR

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Executive Summary

In 2018, the United States generated over 600 million tons of construction and demolition waste, fueled by increasing housing demand and a lack of viable recycling markets. This problem is acute in the Triangle, where 4,700 new units of residential construction were built between Summer 2020 and Summer 2021 in Durham County alone. With support from a local design-build firm, Haven, and nonprofit, Circular Triangle, this project uses a waste assessments report and custom waste calculator to investigate the social and environmental impacts of landfilling waste, to suggest opportunities for waste diversion in the built environment, and to communicate these results to policy makers to drive government support for circularity in the Triangle. Findings from our study suggest that while untapped opportunities exist for waste diversion, a paradigm shift in legislation, attention, and financial incentives is needed to make circular systems a reality in the built environment.

Using an analysis of two accessory dwelling units under construction in Durham as a lens to articulate Haven's current waste management efforts, this study found that Haven's waste generation at the two sites is already 7% better than what is expected from the industry benchmark. To communicate broader impact and demonstrate tangible benefits of improved waste management to Haven, it is important to translate these waste numbers into global warming potential. Our carbon emissions analysis speaks to reduced environmental impact across the board if viable alternatives to landfilling waste can be scaled up and implemented. The recommendations outlined in this report, while specifically focused on these two units are broad enough to also be applied to the wider residential construction market.

Recommended next steps:

- Communicate the need for alternative marketplaces for waste
- Encourage waste measurement & engage suppliers
- Get policy support to build out the marketplace infrastructure for diversion
- Coordinate waste hauling

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Introduction

Construction and demolition materials constitute a significant waste stream in the US, estimated at over 600 million tons in 2018. Of this amount, about 189 million tons are waste debris generated from buildings and 10% of that are solely from the construction process.[i] The construction waste problem has amplified over time in Durham County, where 4,700 new units of residential construction, translating to 7.91 million sq ft, were added from July 2020 to June 2021. Ten years ago in this same timeframe, only 1,484 new residential units were built, equivalent to ~ 2.5 million sq ft of residential space.[ii] While most construction and demolition waste is legally disposed of in landfills, many opportunities exist for the productive reuse and recovery of construction materials which have considerable residual value. The responsible management of waste is an essential part of sustainable building and is important for our economic and environmental future. Waste management decisions during construction can produce measurable benefits to human health, building sustainability and pollution reduction throughout the building life cycle.

The effective management and disposal of construction waste is currently hindered by several barriers including waste stream toxicity, limited markets for recycling or reusing construction materials, and incomplete data regarding the types and amounts of waste generated. Toxic components in the waste stream can close off viable management options.[iii] While markets have historically existed for some components of construction waste including metal, clean fill, and clean wood, viable markets for other components have not been readily available. This is particularly true in the Research Triangle of North Carolina which has one of the fastest growing real estate markets in the US.[ivv] New markets for recoverable components of construction waste need to be actively identified, researched, and supported. To begin addressing the need for waste diversion in the Research Triangle, we are partnering with Circular Triangle and Haven, a local nonprofit and design-build firm respectively, to investigate the life cycle of five of the most ubiquitous building materials in single family home construction.

Circular Triangle is a non-profit dedicated to facilitating a just transition to a circular economy by generating private-sector collaboration, advocating for public-sector commitment, and educating communities. Circular Triangle's expertise in circularity and outreach to private sector partners in the Triangle will be key factors in developing alternative markets for construction waste so that recycling and recovering waste can be both cost-effective and widely available.

Haven Developers, a Durham based design-build firm, specializes in residential construction of different scales and types. As a certified B-Corps, Haven takes on the challenge of conserving resources and reusing materials as much as possible, despite its business being very customer-driven. According to its B-Corps assessment, it currently lacks a method to record construction waste, and the team feels this would bring added value to Haven's mission and vision.

Designers have a decisive role to play in managing a project in a way that incorporates sound waste management principles. Poor design and construction practices pose a major detriment to the life cycle environmental impacts of a building; thus, the implementation of sound design decisions is critical toward reducing on-site construction waste.[vi] With its in-house design-build expertise, Haven can integrate sustainable building practices throughout the construction process from limiting the burning of toxic waste at dumps, using locally sourced materials, and finding a market to reuse a specific type of waste in bulk. This study analyzes the waste streams and presents actions, backed up by quantitative justifications that will aim to increase construction waste diversion rates of two accessory dwelling units (ADUs) in Durham, NC. The ADUs are located at 1013 North Gregson Street and 1203 Spruce Street in the Trinity Park and Albright neighborhoods, respectively. As Haven uses traditional home building practices that can be replicated anywhere, our study will help Haven analyze its waste quantities under different management scenarios. These could also be applied across a variety of site-built residential construction projects of different scales so that more can be learned by organizations such as Circular Triangle to minimize impacts across the sector.

According to the National Association of Homebuilders, approximately 4.39 lbs of waste is generated in 1 sq ft of new residential construction. Using this estimation, one would expect Haven to generate 6,585 lbs or 3.29 tons of waste in the 1,500 sq ft of ADU space. Haven's current wood waste, which encompasses nearly the entire waste stream is only 3.08 tons, which is a 7% reduction from the industry benchmark. This is in line with Haven's aspiration to limit impacts as much as possible. Our study would put this effort into greater perspective, seeing how source reductions can be complemented with other waste diversion methods to further amplify the environmental impact capabilities of Haven.

Methodology

The two methodologies used to investigate waste streams produced by single-family home construction are (1) a waste assessment report and (2) a waste impact calculator. The waste assessment report, which constitutes the written portion of this project considers the cradle to grave impacts of some of the most common construction materials in single-family home building and uses that information to provide insight on the immediate options available for Haven to source more sustainable materials and divert waste from the landfill. The waste impact calculator will supplement the waste assessment report by quantifying the environmental and financial impacts of current waste management practices and comparing those impacts to alternative waste diversion scenarios. Together these tools will allow both Haven and Circular Triangle to further understand where to focus waste minimization efforts.

1.1: Waste Assessment Report

The waste assessment report is an in-depth focus on five building materials that are essential to single-family home construction. The five materials of focus include concrete, asphalt shingles, dimensional lumber, oriented strand board (OSB), and wallboard. These materials were chosen for two reasons: (1) the EPA identified all five materials as having a statistically significant impact in the life cycle of a single-family home and (2) these materials collectively make up the majority, by volume, of our client's waste stream.[vii]

The waste assessment report is organized by material and encompasses the manufacturing and use of the product, the product's cradle to grave global warming potential (GWP), sustainable supply options, landfill diversion options, and recommendations for Haven. Structuring the report in this holistic manner allows us to make recommendations that address the environmental impacts across each product's entire life span. Two main sources of information for the report are environmental product declarations (EPDs) and expert interviews outlined below.

1.1.1: Environmental Product Declarations (EPDs)

EPDs are product reports that follow both life cycle analysis (LCA) methodology and product category rules (PCRs). LCAs quantify the environmental impacts across each stage in the life cycle of a product—raw material extraction, manufacturing, transportation, use and maintenance, and disposal. PCRs are rules that define how to conduct an LCA for the product category being assigned (e.g. steel framing, drywall, carpet etc.). They also define which impacts must be reported and ensure that all EPDs under the same category report the same type of information. Because EPDs are required to follow the same methodologies, they can be compared to one another and used to determine if one product is more environmentally friendly than another. This study uses third-party verified EPDs gathered from the Embodied Carbon in Construction Calculator (EC3) tool and from grey literature to look at the overall embodied carbon emissions broken down by construction material.

1.1.2: Expert Interviews

Whenever possible we conducted expert interviews with key players in the industries of each material of interest. Interviewees ranged from professionals involved in the manufacturing and waste processing phases to scientists and professors knowledgeable in the raw material extraction phase. These interviews are a unique characteristic of our literature review and bring power to our analysis and recommendations in two ways. The first is that they helped us better understand the logistical challenges involved with making a more sustainable product either through using recycled materials or through changing manufacturing processes. The second is that they helped us to combine quantitative and qualitative information to make recommendations that holistically account for environmental impacts up and down the supply chain of each material. The information gained from these interviews is interwoven and cited throughout this report and the interviewees are listed below.

Academia

- Carol Hee, Ph.D. MBA, Adjunct Professor of Life Cycle Analysis, Duke University
- Jeff Vincent, Ph.D. M.S., Chair of Environmental Science and Policy, Duke University

Industry

- John Gallagher, President, Aptus Management PLLC.
- Allie Omens, C&D Recycling, Metro Government of Nashville & Davidson County
- Susan Hines, Director of Industry Affairs, Gypsum Association
- Kim DuBose, Director of Sustainability, Enviva

Supplier

- Blaise, Sales Manager, 84 Lumber
- Richard Bechtold, Territorial Manager South-Atlantic, CertainTeed

- Amy Hockett, Manager of Architectural Services & Sustainability, National Gypsum Co.
- Jimmy Petty, General Manager, A-1 Sandrock
- Ken Waegerly, EHS Manager, Chandler Concrete Co.

1.2: Waste Impacts Calculator

To track the volume and weight of construction material generated on site, including how much is landfilled, reused, recycled, donated, or composted, the team created a waste calculator for Haven to accurately quantify the major waste streams (asphalt, gypsum, lumber, plywood and drywall) that go into home construction. Additionally, the calculator will allow Haven to visualize the financial and environmental costs of their waste. By incorporating data on global warming potential, percent carbon reduced, and cost recovery, the team hopes to promote the calculator as the primary tool for Haven to see improvements over time in their on-site waste generation. The goal for Circular Triangle is to be able to provide this tool as a best practice to other builders, designers, and contractors in the Triangle.

1.2.1: Retroactive waste calculations

Raw waste numbers for the five construction materials were obtained via a combination of tipping fee data and manual calculations. Dimensional lumber waste was already given via tipping fees, and concrete was excluded because interviews from Haven's concrete supplier Chandler found that little to no waste was generated when typically applying concrete to homes, thus obviating the need to calculate the amount of concrete used. After consulting with Matt Mayers of Haven, the team focused on quantifying manually waste streams that were not recorded on tipping fee tickets. The team proceeded with calculating asphalt shingle, OSB and drywall waste, due to their significant usage as construction materials.

To calculate asphalt waste, the team looked at architectural blueprints and assumed no asphalt waste from the Gregson site because the house had a metal roof. For the Spruce site, the team took the square root of the rise and run of the roof slope squared as obtained from the architectural drawings, divided by 12. Gabled roofing seen at the Spruce location translates into a different roof square footage than a flat surface area. This factor was multiplied by the flat surface area of the second floor. The team derived the number of shingle squares used from the roofing area, considering that 100 sq ft equals one square of shingles. 10% of this was assumed to be wastages from offcuts. The team gathered from existing literature that one square of shingles weighed 150-240 lbs., took the average and multiplied 195 lbs by the wasted shingle squares. Roofing area and shingle squares calculations were cross-checked with raw numbers obtained from an online roofing calculator tool – calculator.net which uses base area, roof pitch, eaves overhang as inputs. The results obtained were of roughly the same magnitude.

To calculate OSB waste, the team visited 1013 North Gregson Street on December 6, 2021 to gather measurements of the area of OSB sheathing, as well as the sizes and types of fenestration features, primarily windows and doors. All measurements were written down in a notebook for cross-checking against measurements obtained from architectural drawings. Because the measurements obtained manually from the Gregson site matched that recorded in the architectural drawings, the team did not see a need to visit the Spruce location. These measurements helped the team identify where OSB was used in the home, how much OSB was cut out to install fenestration features and estimate the number of OSB boards used in sheathing, flooring and roofing.

The second stage of the work was to convert the raw measurements of walls, windows and door sizes into the number of OSB boards used and total pounds of OSB waste generated. To do this, all wall sizes as well as window and door dimensions were standardized to inches and the area was calculated. All windows with dimensions larger than 24 X 36 inches were excluded for the purposes of waste calculation. While this is not a perfect threshold, the rationale for this exclusion is that OSB cutouts from larger windows can be reused in other parts of the home, so they don't ultimately count as waste. Consider a 9' high wall, typical of the homes included in this study. The standard 4X8 OSB board would still leave a 1' band all along the wall that needs to be filled in with scraps of OSB. A builder would ideally like to have long pieces of OSB to fill the band but would likely end up using smaller pieces where available. Any openings smaller than 24 X 36 are unlikely to be used by the builder and therefore would end up as waste. Existing scholarship classifying lumber waste largely agrees with this assumption[viii]. Conversions were made by dividing the wall area and total fenestration area by the area of a standard OSB board. OSB waste in pounds was derived from multiplying the number of plywood boards by 4.725 lbs if used for sheathing, 6.1l lbs in flooring and 5.4 lbs in roofing. These plywood weight numbers assume that 10% of the weight of a standard OSB board is the mass of waste produced when 10% of extra OSB volume is ordered. The area, thickness, and weight of a standard OSB board used in sheathing, roofing, and flooring is summarized in the table below:

Plywood Area	Width	Height	Thickness (inches)			Weight in lbs per board
4608	48	96	0.4375	0.5 (OSB roofing)		47.25 (sheathing) 54 (OSB roofing)
Extra 10% Margin						
46	4.8	9.6	0.4375			4.725
Flooring Plywood						
4608	48	96	0.75			61
Extra 10% Margin						
46	4.8	9.6	0.75			6.1

Lastly, to calculate drywall waste, the team aggregated square footage of each wall at both locations obtained from architectural blueprints. Drywall waste was calculated by dividing total square footage by 32, assuming a 4 by 8 drywall board to obtain the number of boards used. This study assumed the number of drywall boards used is similar or equivalent to number of OSB boards used, as drywall is the underlying material. In the absence of firsthand tipping fee data for drywall due to work stoppage at both locations in March, and a subsequent change to another subcontractor who were unaware of Haven's desire to separate out waste streams at the two locations, this is the best assumption for drywall waste even though real-life conditions may yield different results. A 10% waste factor was assumed for drywall, based on the best available information online. The team took 10% of the total boards used and multiplied by 57 lbs – the weight per board to get total drywall waste.

1.2.3: Leveraging Environmental Impact Tools: WARM and EPDs

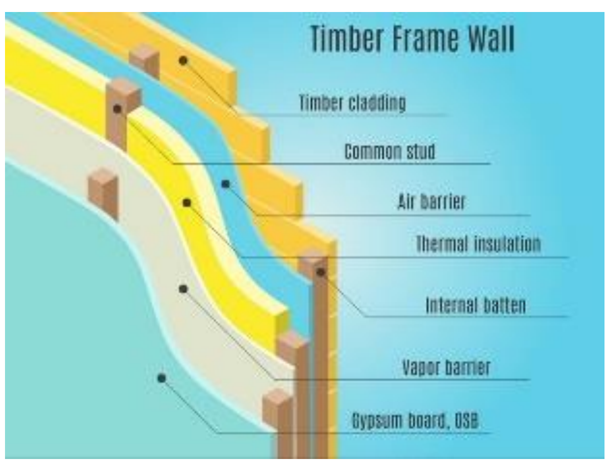
The waste in mass for dimensional lumber, drywall and asphalt shingles were inputted into the EPA Waste Reduction Model (WARM) Tool v. 15. The WARM tool translates raw waste numbers into potential GHG emissions measured in metric tons of CO2 equivalent for a wide range of materials under baseline landfill end-of-life (EOL) practices as well as alternative waste reduction practices like recycling. The WARM tool does have certain data limitations—for example, the tool does not provide a carbon content estimate per ton of OSB. The closest material is medium-density fiberboard. As emissions of wood-based products are very sensitive by type, using MDF as a proxy for OSB would not have yielded ideal results. Evaluating the environmental load of construction materials using the WARM tool, has its strengths but also its limitations, and the team felt that EPDs can provide an additional estimator of the global warming potential (GWP) of materials like OSB that was excluded from WARM, as well as the other four construction materials analyzed in this study.

The embodied carbon data for each material found from EPDs was standardized for reference purposes. All functional units were converted to tons, and GWP was converted to kgCO2e. Data from WARM and EPDs will be integrated into an Excel tool to determine GWP in carbon emissions assuming various EOL treatments. An Excel-based impacts calculator that allows for cross-comparison of GWP data broken down by material type and EOL scenario would be useful for deducing the relative carbon intensity of construction materials and its relevant environmental costs. Financial costs will be integrated into the tool based on how suggested recommendations can divert waste and thus reduce transportation costs. The impacts calculator will have a raw version reflecting current conditions, where calculated waste from the two sites is matched with GWP data from WARM, EPDs and online sources. In addition, a simplified version will allow Haven to customize its waste inputs for any of its projects and view the embodied carbon per material sent to the landfill.

Results & Recommendations

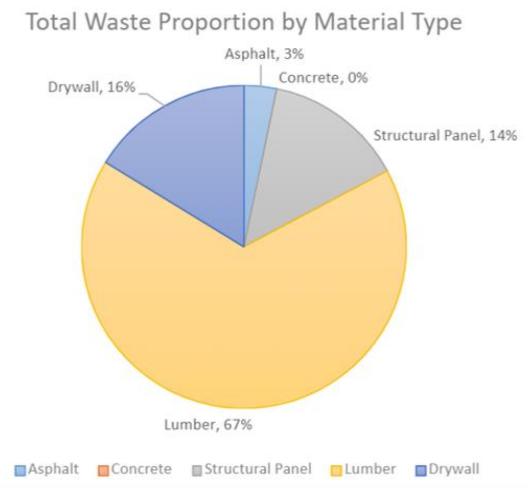
2.1 Overview

The waste assessment report follows the structure outlined in section 1.1 of the methodology section above. A summary of the results from the waste assessment report can be found in Appendix 3. To understand the report's terminology and context of construction materials used in a typical home, the image below[ix] helps to conceptualize the placement of construction materials within the wall of a home.



The larger report should be understood in the context of the total quantifiable waste of all material streams, which is the bread-and-butter input for our impacts calculator. While waste numbers are broken down via various tables to inform recommendations by material, this chart and table depicts the aggregate total of all waste generated at the Gregson and Spruce ADUs.

Waste Stream	Gregson Waste in Tons	Spruce Waste in Tons	Total Waste in Tons
Asphalt	0.00	0.10	0.10
Concrete	N/A	N/A	~0
Lumber	1.01	1.04	2.05
OSB	0.27	0.16	0.43
Drywall	0.40	>0.10	0.50



2.1.1 Concrete

Concrete is a mixture of aggregate—sand, gravel, crushed stone—and cement. When combined with water, cement takes on a pasty consistency and binds the aggregate into a rock-like mass. Cement typically comprises 10-15% of concrete mix by volume. It is created by heating limestone to 1,500°C until it decomposes into calcium oxide, a main ingredient in cement. This heating process requires a massive amount of energy, typically from fossil fuels, and the limestone decomposition process releases substantial amounts of CO_2. Due to these processes, cement accounts for 7% of all global carbon emissions, making it the second largest single industrial emitter in the world.[x] [xi]

When considering the composition of concrete, it is also important to note that concrete mixtures can sometimes include project-specific additives that can help increase concrete's electrical conductivity, strength, and corrosive resistance.[xii]Additives can complicate the recycling and reuse of concrete and are a critical component to keep in mind when considering the circularity of this material.

2.1.1a: Carbon Content

Out of the materials investigated in this report, cement has the highest total cradle-to-gate global warming potential (GWP). The EPA identified hydraulic cement as the primary source of embodied impacts within the ready-mixed concrete supply chain due to direct emissions associated with quarrying and cement kilns.[xiii]

Source	Functional Unit	Global Warming Potential (kg CO2e)
National Ready Mix Concrete Association (NRCA)[xiv]	1m^3 of cement	262.34 - 427.75

2.1.1b: Sustainable Supply Options

To most effectively reduce concrete associated emissions manufacturers need to reduce fossil-fuel use at every point in supply and production chains. One method of fossil fuel reduction is to use reclaimed cement in the manufacturing process, thereby avoiding the intensive processes of heating limestone and quarrying. We have not found any suppliers committed to using recycled cement in manufacturing or reducing fossil use in any other way.

2.1.1c: Landfill Diversion

The main method for concrete landfill diversion is sending it to a recycler to be turned into recycled concrete aggregate (RCA). RCA is crushed concrete from old concrete structures, sidewalks, building slabs, foundations, curbs, and more. It measures ¾", 1-½", or 2 ½”. It requires no processing and can be used for bulk fills, bank protection, base fill for drainage structures, road construction, and noise barriers.

When using recycled concrete as base material, a few things need to be kept in mind. Using recycled concrete typically has higher absorption and lower specific gravity than naturally sourced concrete, resulting in concrete with slightly higher rates of drying shrinkage and creep.[xv] These differences increase with the amount of recycled aggregate used. Additionally, the chloride content of recycled concrete aggregate when used in reinforced concrete requires extra scrutiny because the alkali content and type of aggregate in the system becomes more ambiguous if mixed with incompatible materials. A risk of concrete swelling, also known as an alkali-silica reaction, is possible.

2.1.1d: Recommendations

The team recommends that Haven continue to supply its concrete from Chandler Concrete Co. After pouring cement at the job site, Chandler Concrete Co. ensures any leftover concrete is either used at another job site, poured back into the quarry, or dried and crushed so that it can be incorporated into a new batch of ready-mix concrete.[xvi] If Haven has any concrete waste on the jobsite, we recommend they send it to Gorilla Materials, a local concrete recycler. The price for recycling a full trailer of concrete is $50 for a single axel trailer and $60 for a double axel trailer. If the concrete getting recycled is intermingled with large amounts of dirt those prices go up to $130 and $140 respectively.

2.1.2 Asphalt

Asphalt is most used in roofing shingles in home construction. Applications for roofing makes up 11 percent of all asphalt uses in the United States. Asphalt shingles used by Haven, and typical for accessory dwelling units in NC, consist of a traditional laminate of asphalt-fiberglass composition. This base layer is then coated with asphalt and overlain with ceramic coated opaque mineral granules. Asphalt content makes up 20% for shingles. Asphalt shingles are increasingly viewed as an economical and aesthetic product with a lifespan of 15-30 years.[xvii]

2.1.2a: Carbon Content

Source	Functional Unit	Global Warming Potential
UL Environment (Asphalt Roofing Manufacturer's Association)	1 m^2 (10.76 sq ft)	0.5 kg CO2e (EOL) 10.3 kg CO2e (Production + Construction + EOL)

The ARMA EPD is considered the best estimate as it aggregates data from at least three common manufacturers that partner with ABC Supply, Haven's primary supplier for asphalt shingles. The largest life cycle impacts are attributed to the production stage, accounting for more than 80% of all impacts. EOL impacts are miniscule in the larger life cycle but is still significant, due to the untapped opportunities that exist for diversion.

2.1.2b: Sustainable Supply Options

ABC Supply distributes product brands representing seven manufacturers in the area. CertainTeed, GAF & IKO are three manufacturers that also disclose their EPDs, signaling their commitment for reducing the environmental impact of its products by reporting them in a transparent way. From a building and waste management perspective, Haven should continue to prioritize asphalt shingles over metal roofing types. Asphalt shingles are cost-effective, provide long term performance with a wide variety of aesthetic choices as well as color choices, and contain improved warranty coverage, which would help reduce the need to buy extra shingles.[xviii] Although many suppliers are not suited to receive and process clean shingles on a small scale, opportunities for diversion exist amongst specialized asphalt paving companies.

2.1.2c: Landfill Diversion

Asphalt shingles encompass less than 12-15% of construction and demolition waste, on par with lumber, yet 85% of shingles are landfilled.[xix] The asphalt content in shingles is only around 20%, which means only 3% of C&D waste is actual asphalt. Haven's asphalt waste mainly comes from roofing shingle tabs, generated when new asphalt shingles are trimmed off during construction. Shingle disposal fees can reach $90-$110 per ton in most metropolitan areas. Recycling of asphalt shingles has been an established practice for decades yet remains a barrier because recycling centers may be located far away from the construction site. The largest recycling market remains hot-mix-asphalt (HMA). HMA that contains recycled shingles is now allowed in road construction in North Carolina since 2011. However, the brittle nature and lower performance of recycled HMA mix has caused hesitancy amongst paving companies in accepting shingles[xx].

2.1.2d: Recommendations

The team recommends that Haven follow the lead of large suppliers such as CertainTeed and divert clean asphalt shingles by sending them to Barnhill Contracting or S.T. Wooten Corporation, two of the biggest players in central North Carolina incorporating recycling asphalt shingles into pavement mixtures. If asphalt shingles contain metal or dirt, or if grinding is needed, Haven should contact A1 Sandrock who will screen those shingles at a rate of $20-32 per ton for Barnhill[xxi]. Grinded asphalt is versatile in many ways. It can be added to a base mixture, that can then be applied as a ground cover or stabilizer in wet and muddy areas. Barnhill Contracting also uses recycled shingles in its asphalt mix as a substitution for crude oil. The wasted shingle squares at the two locations amount to 0.0975 tons as calculated below, and the team believes that all can be reused. In the grand scheme of home construction costs, the financial savings are small, but the environmental benefits amount to 60.73 kg or 0.06 MT CO2e reduced, which the team obtained by converting the GWP correlated with the EPDs functional unit to the actual scenario.

ASPHALT						
Location	Floor Flat Surface Area	Pitched Roof Surface Area	Shingle Squares Used	10% Waste	Weight in lbs	Tons
Gregson	764	1139	0	0	0	0
Spruce	703	893	8.9	1	195	0.0975
					195	0.0975
One shingle square is $100					Recycling Benefits	$890.00

2.1.3: Dimensional Lumber

Dimensional lumber is commonly used in low-density housing construction and is a highly sustainable construction material due to its carbon storage potential. Lumber usage and its waste has risen as a topic of concern in the residential housing industry due to the growing construction market. It is estimated that 44% of lumber construction waste can be effectively recovered in the US. The lumber industry and its projected demand are expected to remain strong, as it supplies roofing materials, flooring, doors and window casings and base moldings in home construction. Despite its widespread utility, the amount of lumber waste generated in the home construction market, especially in accessory dwelling units, produces much smaller economies of scale than home demolition and commercial construction[xxii]. This limited stream decreases the incentive for contractors to recover lumber relative to other construction materials. Due to the enormous sustainability potential, widespread use and lack of advanced recycling and reuse techniques for lumber, the options for recovering lumber will be rudimentary, but worthwhile.

2.1.3a: Carbon Content

Source	Functional Unit	Global Warming Potential
EC3 https://buildingtransparency.org/ec3/material-search	1 cubic meter or 1,010 lbs	44.7 kgCO2e in Production 328 kgCO2e in EOL emissions exc. prior sequestration -508 kgCO2e in EOL total inc. sequestration -463.3 kgCO2e (C-to-Grave)

The above table shows the GWP of dimensional lumber. Production will have a negative environmental impact while the end-of-life phase holds significant potential in sequestering carbon. The GWP from cradle-to-grave could be multiplied by a factor of 4.05 since Haven's 4,100 lbs of lumber waste is 4.05 times larger than the functional unit. The results show that Haven's dimensional lumber waste generates a total GWP of –1.88 MTCO2e, meaning it has a net positive impact of reducing emissions via carbon sequestration. GWP from the WARM tool matches this number, which gives power to the accuracy of the simulated impact potential of landfilling lumber in the real world.

This baseline number assumes the current EOL treatment that all waste ends up in the landfill. The potential to divert some or all the waste can further mitigate the GWP. Suppose Haven can divert all lumber, thereby eliminating EOL emissions; the GWP would be further reduced by 0.328 MTCO2e per functional unit, equivalent to a further 1.33 MTCO2e reduction given Haven's waste quantity.

Source	Functional Unit	Global Warming Potential
EC3, Conversions are self-calculated	4,100 lbs or 2.05 tons	-1.88 MTCO2 if landfilled. Further reductions of 1.33 MTCO2e in EOL emissions. -3.21 MTCO2e assuming 100% diversion

2.1.3b: Sustainable Supply Options

Haven sources its wood from Mebane Building Center, Fitch Lumber and 84 Lumber. These suppliers often sell lumber made from spruce-fir trees, one of the hardest softwoods in strength and density. Softwoods are considered structural lumber. As softwoods are not generally considered "high value" timber, we infer that much of the sourced timber are "low-value". The timber material can be transformed into framing lumber or raw materials for particleboard production.

Most of Haven's suppliers produce a large supply of lumber. These major suppliers are not equipped to deal with the multitude of segmented players working at a scale much smaller than theirs[xxiii]. This is where Haven comes in. Haven can resell scrap lumber to other homebuilders, encouraging them to reuse them in the manufacture of components such as roof trusses and floor trusses. Specialized component use is becoming more popular in homebuilding and presents a whole new area where there will be demand for structural lumber.

2.1.3c: Landfill Diversion

During the cutting and framing process, entire pieces of lumber are cut to a small piece. Additionally, framing, warped, twisted, or bent lumber pieces are usually discarded by the framer. These two processes contribute the most to timber waste during the construction process. Tighter oversight of these processes, educating crews to consider defective lumber as something of value and the continual commitment to reusing lumber of sensible lengths should be best practices moving forward[xxiv].

The lumber sourced by Haven comes in sizes of 2 in X 4 in by 10 ft made from spruce-pine-fir trees dominant in North Carolina. The lumber measures approximately 6.67 board feet and weighs approximately 14.77 lbs when pressure-treated and dried. It is usually cut by the contractor, rather than the supplier, allowing Haven to better control the amount of lumber it needs and minimize scrap lumber waste. During the cutting and framing process, entire pieces of lumber are cut to small pieces. Additionally, framing, warped, twisted or bent lumber pieces are usually discarded by the framer. These two processes contribute the most to timber waste during the construction process. Tighter oversight of these processes, educating crews to consider defective lumber as something of value and the continual commitment to reusing lumber of sensible lengths should be best practices moving forward.

Due to the volatile nature of lumber prices, Haven should prioritize reducing its inventory of small pieces of lumber less than 2 ft in length because it is risky to keep a large backstock of small and uneven lumber sections where the demand for it is not as high as it might be for larger offcuts.[xxv] Thus, the current practice of landfilling small sections of lumber is reasonable, but we still recommend that Haven attempt to resell timber of all sizes as often as possible at 80% of the original price. This option best recaptures potential value because it acknowledges the other uses of smaller pieces of lumber in the broader market, such as for fire blocking in interior walls. A standard piece of lumber supplied by 84 Lumber would cost $14.89, which is barely enough to cover the costs incurred by the supplier. However, due to recurring demand for scrap lumber, Haven can sell lumber for lower at $10-12 a piece and still make a run for it. This practice could be done for all of Haven's lumber sourced from suppliers that do not have a take-back option. For suppliers like 84 Lumber that do accept unused lumber, Haven can send it back to them if resale profit is not a business priority.

2.1.3d: Recommendations

Haven should develop a site-centered supply chain system where contractors and developers can pick up lightly used timber from Haven directly at the construction site. Haven can advertise resalable timber on Facebook Marketplace or Craigslist to find potential buyers, building on the current demand there exists for people wanting scrap lumber. Because dump runs are usually not made that often, the site can act as a temporary storage facility and shop front. This approach will save on offsite cartage costs and reduce tipping fees, which would be a valuable approach especially for used timber that have diminished resale value. We believe that the successful resale of all timber waste through bolstered digital marketing would generate over 3.3k in savings for Haven, while reducing a further 1.33 MT CO2e from baseline EOL assumptions. While this recovers only a tiny fraction of the total costs incurred in purchasing lumber, it still recaptures significant value in the lumber that would otherwise end up as waste. As shown below, the Gregson site generated 1.01 tons of scrap lumber and the Spruce site generated 1.04 tons of scrap lumber, which can potentially all be resold.

Site	Timber Waste in lbs *	Boards of Timber **	Resale Value at $12/board	Total Timber Used	Timber Original Value at $14.89/board ***	Costs Recovered
Gregson	1.01 tons	136	$1,632	13,675	$203,620	
Spruce	1.04 tons	141	$1,692	14,083	$209,695	
All Locations	2.05 tons	277	$3,324	27,758	$413,315	0.81%
*Assumes that 10% of timber used end up as waste						
** Assumes timber weight/piece is 14.77 lbs, obtained from Builder's Calculator using spruce-pine-fir softwood and inputting size of 2 in X 4 in X 10 ft.						
*** Value obtained from a sales specialist at 84 Lumber						

2.1.4 Oriented Strand Board

Oriented strand board (OSB) is in the wood panel family along with plywood, particleboard and fiberboard. Within this category of products, plywood is most similar to OSB and both are typically used as sheathing in walls, flooring, roof decking, and webs of wooden I-joists. Some reasons builders will choose OSB over plywood are (1) it has double the amount of shear strength, (2) it is cheaper, and (3) it is a consistent product. OSB is a more consistent product than plywood because it is made of cross-oriented layers of wood strands and waterproof resins and wax, whereas plywood is comprised of rolled out sheets of wood that have been rotary peeled off a log—imagine pulling a piece of tape off a roll—and glued together. This means that plywood is more subject to the characteristics of the tree itself (i.e. age, knots, splits).[xxvi] Additionally, because plywood is made of rolled out sheets of wood it requires a much larger starting log than is needed for OSB which creates an interesting environmental differentiation between plywood and OSB.

OSB is typically made from trees around 10–12 inches in diameter at breast height (DBH) whereas southern pine plywood is made from logs with an average DBH of 14 inches.[xxvii,xxviii] Therefore, OSB can be made from smaller, faster growing trees which expands the harvesting boundary for trees that can be turned into wood sheathing. This could add value to more land in a way that allows landowners to use it for something other than development and thus brings more environmental value to OSB. On the other hand, this also means that forests that once had limited management may become more intensively managed via increased investment in harvesting and replanting, thinning, fertilizing, and other actions.[xxix] This is just to point out that the environmental impact of all materials, but especially wood products, extends beyond the product's GWP.

2.1.4a: Carbon Content

An OSB Environmental Product Declaration conducted by the American Wood Council reveals that the most environmentally impactful process for OSB is its end-of-life fate. In this study, the end of life was set as 100% landfill because there is currently not a system for effectively recycling or reusing OSB.

Source	Functional Unit	Global Warming Potential
AWC EPD	The production of one cubic meter (1 m^3) Mass: 620kg Thickness: 9.5mm Density: 620 (kg/ m^3) Moisture Content: 7%	242.58 kg $CO_{2\ eq}$

2.1.4b: Sustainable Supply Options

Because the largest Global Warming Potential (GWP) impact from this product comes from its end-of-life and because most, if not all, manufacturers in this industry use a similar manufacturing process, there is no standout sustainable supplier of OSB. When considering the manufacturing process, drying is the most energy demanding and polluting step. If any supplier advertises that they've changed this step of the process that would be a good indicator that their product has a lower impact than the industry standard OSB.[xxx]

Also of note, Plantd Materials, a start up in Durham, NC, is working to produce structural paneling out of non-wood materials such as reeds. This company is currently only preselling its products to large home developers; but it is one of the first companies to try to innovate the structural panel manufacturing process and should be kept in mind when discussing sustainable paneling.

2.1.4c: Landfill Diversion

Two main factors complicate diverting OSB from the landfill: 1) its low durability and moisture sensitivity, compared to traditional timber products, and the increasing use of sprayfoam insulation make it difficult to reuse and 2) the resins used to bind wooden strands in the manufacturing process and the increasing use of sprayfoam insulation make it difficult to recycle.[xxxi]

Because of the complications associated with recycling and reuse of OSB, the most feasible opportunities for landfill diversion at this time are incineration and reselling the product in a similar way to dimensional lumber. Waste incineration has historically been criticized because it is seen as a scapegoat for not finding a higher use for the discarded product and it is often associated with pollutants and human health impacts. However, we still recommend this as an immediate option for landfill diversion because there is currently no other option, and the incineration industry has advanced in the last decade to mitigate pollutants.

2.1.4d: Recommendations

For immediate waste diversion, there is a local Durham business, Durham Tree Service that recycles wood products and/or resell OSB waste in a similar way as described in the dimensional lumber section, 2.1.3d.

Just as with reselling lumber, there are financial benefits of reselling OSB. For example, the two Haven construction sites generate 0.43 tonnes of OSB waste which can be resold at $50/board. If all OSB waste is resold, Haven would gain approximately $875 in financial proceeds from the sales.

Location	Pieces of OSB Used	Pieces of OSB Waste	Lbs of OSB Waste of Resalable Valu	Cost per boarc	Total Purchasing Costs	Resalable Value	Recuperated Cost	% Costs Recovered
Gregson	108	11	551.7	$64.49	$6,965	$50	$550	7.90%
Spruce	64	6.5	314.1	$64.49	$4,127	$50	$325	7.87%

A breakdown of OSB waste by site and application is detailed below. Note that OSB waste was non-existent in flooring from the Spruce site. This is because of a lack of a second-floor OSB deck in the Spruce site.

Location	OSB Boards Sheathi	OSB Boards Flooring & Decking	OSB Boards Roofing	Sheathing Waste	Flooring Waste	Roofing Waste	Total Waste
Gregson	60	13	35	281.7	78	192	551.7
Spruce	36	0	28	163.4	0	150.7	314.1
Total						In lbs	865.8
						In Tons	0.4329

2.1.5 Wallboard

Wallboard, also known as drywall, gypsum board, and plasterboard, is a common building material used for interior walls and ceilings. It is valued for its inherent fire resistance and its ability to be easily cut and painted. There are also several types of gypsum boards with specialized characteristics such as mold resistance, extra fire resistance, and soundproofing.

Wallboard is primarily composed of gypsum (calcium sulfate dihydrate), paper, and additives such as mica, clay, and resin.[xxxii] Raw gypsum is obtained through both natural and synthetic means. Naturally occurring gypsum is mined directly from the earth while synthetic gypsum, also known as flue gas desulphurization (FGD) gypsum, is collected as a byproduct of coal fired power plants. According to the Gypsum Association, as of 2013 50% of all gypsum used in the U.S. is FGD based. This is important when considering the future of gypsum because the U.S. is also increasing pressure to divert energy production away from coal fired power plants. Therefore, although the next section explains why recycling gypsum is not necessarily the most sustainable change that can be made to gypsum board production, recycling gypsum will be increasingly necessary as coal fired power plants continue to shut down. Another reason gypsum recycling needs to increase is that when gypsum board is disposed of in landfills the sulfate component can have adverse effects such as groundwater contamination and off-gassing as hydrogen sulfide, a smelly, poisonous gas. These processes have negative health consequences on both landfill workers and communities surrounding landfills.

Recycling gypsum board does not save much energy relative to the entire gypsum board manufacturing process because the manufacturing step, rather than the raw material collection step, is the most energetically intensive.[xxxiii] For this reason, the gypsum boards that are considered the most environmentally friendly are the ones where manufacturers reduce carbon emissions by reducing the amount of water used in the manufacturing process. Less water requires less heat and decreases associated emissions and energy needed to dry the mix. This results in a lighter weight product which subsequently has lower transportation associated emissions. However, some of the negative aspects of lightweight wallboard are that it includes ingredients on the red list and more raw material that does not necessarily come from the U.S.[xxxiv] It also requires more insulation on site to achieve the same acoustics as standard wallboard and taking away gypsum content away from the product decreases fire resistance.

2.1.5a: Carbon Content

Source	**Functional Unit**	**Global Warming Potential ½" Regular Wallboard**	**Global Warming Potential 5/8" Type X Wallboard**
Gypsum Association	1000 sq. ft	233.3 kg $CO_{2\ eq}$	315.4 kg $CO_{2\ eq}$
CertainTeed	1000 sq. ft	-	285.0 kg $CO_{2\ eq}$

2.1.5b: Sustainable Supply Options

Because the largest Global Warming Potential (GWP) impact from this product comes from its manufacturing phase and because most, if not all, suppliers in this industry use a similar manufacturing process, there is no standout sustainable supplier of wallboard. When considering the manufacturing process, drying is the most energy demanding and polluting step. If any supplier advertises that it has improved this step of the process that would be a good indicator that their product has a lower impact than the industry standard OSB.

2.1.5c: Landfill Diversion

There are four main avenues for diverting gypsum from the landfill:

1. Recycling and reusing it to manufacture new drywall – This is considered the best practice and highest use for gypsum.
2. Incorporating it into the production of Portland cement
3. Grinding into a soil amendment
4. Grinding it into a compost amendment

2.1.5d: Recommendations

There are two drywall recycling facilities in North Carolina: Greenway Recycling located at 2100 Speedrail Court, Harrisburg, NC 28205 and Foxhole Recycling Center at 17131 Lancaster Hwy, Charlotte, NC 28277. To make the emissions and added costs associated with diverting waste to either of these facilities, Haven would need to coordinate waste hauling with other local contractors. Additionally, because this is an ever-evolving topic, we recommend that Haven join the Construction and Demolition Recycling Association's (CDRA) new gypsum recycling committee to stay at the forefront of best practices for wallboard landfill diversion.

Discussion

3.1: Key Takeaways

This analysis demonstrates that for all materials, recycling or reuse reduces emissions when compared to landfilling. The analysis also highlights that the raw materials processing and manufacturing stages have the highest GWP for each of the materials studied. Therefore, the emission reduction benefits of diverting these materials from the landfill will be significantly amplified if that waste can be reincorporated into the manufacturing of new construction materials. Recycling waste from the pre-occupancy phase of a house can sometimes be more feasible than recycling waste from the post-occupancy demolition phase because (1) the origin of pre-occupancy waste is known and (2) pre-occupancy waste is often cleaner. Knowing the origin of the product increases the likelihood that the waste can be recycled back into the same product as opposed to downcycled for use in other industries.

Two of the main barriers to upcycling construction materials into the production of new materials of equal value are (1) research and development to guarantee recycled products will have the necessary quality and safety certifications and (2) the need for coordinated aggregation and transportation of waste to manufacturing facilities. Policy makers and organizations like Circular Triangle should devote time and resources to addressing these two issues to help increase circularity in this industry.

3.2: Limitations of the Study

One of the limitations posed by this study was the constriction of our project scope to only include the pre- and post-occupancy life stages of certain materials of a single-family accessory dwelling unit. The occupancy phase was not included, because Haven specifically requested research insight into waste streams in the new construction phase. The occupancy phase is the longest in the life cycle of a home, generating the most environmental impact. The largest source of environmental impact in this phase is energy consumption. Additionally, during this phase, there may be renovation or reconstruction projects that this study would not account for. This study is not an analysis of the entire structure—for example siding and insulation products are not included; however, it does analyze all the major materials that are a part of residential construction. Combined with information readily available regarding the life cycle impacts of construction the materials, this study is a holistic assessment of the environmental impacts of a typical residential home. By only using a singular metric—GWP—to determine environmental costs, the study may fail to capture the more nuanced differences in impact between materials.

The study authors are confident that the quantity of waste calculated in tons is a close approximation of reality. However, in March of 2022, construction was stopped on the Gregson and Spruce locations and the team has substituted expected tipping fee data with manual calculations. This is expected to have minimal impact on high-level waste results, given that major framing and structural construction have already been completed.

GWP numbers have their limitations as well. Typical LCAs for wood-based products assume that biogenic carbon emitted is eventually sequestered through plant growth. However, from an end-of-life environmental impact perspective, our study is not concerned with the mass of biogenic carbon, but rather the global warming potential of the material. Existing scholarship disputes the notion that biogenic carbon is indeed carbon neutral during production, claiming that there is an additional global warming impact the longer the biogenic carbon remains in the atmosphere. If this is true, the inputs would change, which would affect the GWP estimations in existing EPDs.

In addition, EPDs for OSB only include a cradle-to-gate analysis and exclude the mitigated impacts from sequestered carbon during landfilling, the default end-of-life treatment for wood-based products as well as transportation at EOL. This means that EPD data for OSB only encompasses the environmental costs of production and cannot be compared with end-of-life greenhouse gas (GHG) emissions reductions estimated through the WARM tool. On the other hand, EPDs for non-wood-based materials, such as asphalt, separate out impacts by life cycle stage, allowing for a more direct comparison of end-of-life (EOL) impacts between EPDs and other estimation tools.

Finally, EPDs rely on estimations of impacts, and it is hard to get an accurate estimate given the diversity of production sites of OSB, wood, cement, and asphalt that may each use different byproducts or employ different processes throughout the life cycle of the product. EPDs is only one estimation tool of three that the team studied, the others being Sustainable Minds and EPA WARM. Each of these tools yielded different GWP numbers due to different inputs. The inability to arrive at a uniform GWP across all estimation tools is yet another limitation.

3.3: Extended Benefits

3.3.1: Environmental Justice and Equity

Various waste and manufacturing facilities are often located near each other, and disadvantaged households are disproportionately located near these facilities. As a result, disadvantaged households typically face higher cumulative pollution risks from the manufacturing and end-of-life life cycle phases of construction materials. While recycling and reuse in the construction and demolition industry will have benefits for everyone, they have the potential to have even greater benefits for the communities they are closest to.[xxxv]

When considering how to alleviate the disproportionate effects landfills have on marginalized populations it is essential to understand the organizational structure of U.S. waste management. The Resource Conservation and Recovery Act (p.L.94-580) gives the EPA and federal government the authority to deal with hazardous waste. As a result, the federal government classifies what is considered hazardous and anything non-hazardous gets measured at the state level. States create their own laws and regulations on how to manage non-hazardous waste which are then managed and enforced at the county or city level. This intermingled web of authority results in finger pointing when trying to place responsibility for the environmental justice implications of waste management.

To address these environmental justice issues at the state and local level, legislators need to both support zero-waste solutions occurring at the federal level and incorporate the opinions and perspectives of the communities near landfill sites. Federal zero-waste solutions, such as government support for circular economies, will help prevent waste from impacting the communities and community involvement can be used to create solutions that create good jobs and build up local economies.

3.3.2: Scaling Up Impact

Our study seeks to scale up impact by educating the public on data-driven recommendations to build circularity in the design and construction space. While the landfill reduction numbers for Haven may be small because of the scope of this study, this is a huge problem in terms of landfills per square feet in the Triangle. As shown in the table below, Durham County and Wake County generates millions of tons of landfilled construction waste. This includes multi-family residential homes too as it is hard to disaggregate data for single-family homes, thus the numbers may be magnified. However, one can imagine that if all the waste was diverted, there will be innumerable benefits to carbon emissions, diesel costs and man hours.

County	Population	New Residential Units 2021	Sq. Ft.	Waste in Tons
Durham	290,767	4,708	7,918,856	39,435,903
Wake	1,129,410	16,230	27,298,860	135,948,323

3.4: Future Directions

The recommendations made above, in tandem with an impacts calculator are intended for Haven to use in its residential projects of similar type to the ADUs analyzed in this study. Implementing these recommendations is conceptual at this stage and will take more time and resources. Doing so may require a more comprehensive scope of the entire marketplace for reused construction materials. This study can inform the work of the Triangle J Council of Governments. Partnering with a regional body to expand the study scope beyond single family homes can serve as the genesis for steering the conversation towards circular construction solutions in the broader industry. The authors hope that these recommendations can translate into a more established recycling marketplace, so that even the most motivated B-Corps like Haven can find landfill alternatives to be mainstream in the years to come.

Conclusion

Since September 2021, our team of two graduate students from the Nicholas School of the Environment has both qualitatively and quantitatively analyzed Haven's waste stream in the construction of two 800 square feet accessory dwelling units in Durham, North Carolina. Throughout the six-month construction process, the team continuously tracked waste mass via tipping fee dump tickets, conducted three on-site waste inspections, interviewed with industry experts, and calculated the financial and environmental costs of Haven's waste stream under the business-as-usual scenario. The results of these efforts informed key recommendations for Haven to revise their current waste management strategy.

1. Prevention: Haven should enshrine clear rules for on-site waste management, keeping and valuing parts longer, and minimizing materials where needed in all project agreements with subcontractors.
2. Diversion: Haven should maximize diversion opportunities by sending concrete waste to existing waste haulers.
3. Resale and Reuse: Haven can launch a significantly expanded and centrally coordinated resale system of all dimensional lumber and OSB. Asphalt shingles can also be reused if marketed to the right consumer base.

For Haven to achieve both its waste and larger business sustainability goals, it will require implementing these recommendations on a broader scale. Constricted by homeowners' willingness to pay and need to balance different but competing goals, we recommend that Haven use our research and calculations to begin implementing the most preferred options in a pilot phase, then expanding it to cover more materials and a wider scope. The team is grateful for the opportunity to work with Haven and Circular Triangle in helping to embed circularity in design-build home construction.

Appendix

Appendix 1: Waste Emissions Calculator

This tool allows the user to input metric tons of waste and will then output the embodied CO2e (kg) for each material. This will allow the user to measure and monitor the embodied CO2e they are sending to or diverting from the landfill. We also recommend the user incorporate a financial analysis into using this tool once they have established which waste diversion methods they are going to use. This will help demonstrate the financial benefits that accompany waste diversion.

The emissions numbers used in this tool come from the Environmental Product Declarations cited in each material's section above.

Input	
Output	

		Environmental Product Declarations	
Major Waste Streams	**Weight in metric tons**	**Embodied Carbon CO2e (kg) per metric ton of waste**	**Embodied Carbon Sent to Landfill Total CO2e (kg)**
Concrete	10	164	1640.00
Dimensional Lumber	10	88.5	885
OSB	10	356	3560
Asphalt	10	792	7920
Drywall	10	224	2240

Appendix 2: Raw Calculations

Raw calculations for all waste streams used in sheathing, flooring and roofing for both locations is shown in the following link. A screenshot of key calculations for OSB is shown in the first two images. Asphalt and drywall calculations are shown in the third image.

Raw GWP data from Environmental Product Declarations before metric standardization is depicted in the fourth image.

Plywood Waste Calculations for 1013 North Gregson Street

Construction Drawings Reference	Wall Orientation	Window #1	Window #2	Window #3	Door Area	Total Fenestration Area (Windows+Doors)	Wall Length	Wall Height	Wall Area		Pieces of Plywood Boards Used	Plywood Waste in lbs	Total Plywood used in lbs
Page A2.01	East 1st Floor	4320	3240		2856	2856					0.6	2.93	
	East 2nd Floor	3960											
Page A3.01	East Wall (North Section)						212.5	161.0	34,213		7.4	35.08	
Page A3.01	East Wall (South Section)								30,888		6.7	31.67	
	East Wall Total facing Gregson St.										14.1	66.75	667.5
										Plywood Waste Weight (East Wall)	11.0	52.11	
	West 1st Floor	480	480	3960	2688	7608					1.7	7.80	
											0.2	0.95	
	West Wall (Subtotal)						212.5	209.0	44,413				
	West Wall (Minus Taller Terraced Roof)						125.5	48.0	5,773				
	West Wall (North Section)								38,640		8.4	39.62	
	West Wall (South Section)								30,888		6.7	31.67	
Page A2.03	West Wall Total opposite Gregson Street										15.1	71.29	712.9
										Plywood Waste Weight (West Wall)	13.6	64.44	
	North 1st Floor	1440	720	3960		2160						0.00	
	North 2nd Floor	1440	1440			2880					1.9	8.98	
Page A3.02	North Wall (Terraced Extension)								43,571				
Page A3.02	North Wall Total						384	262	100,608		21.8	103.16	1031.6
										Plywood Waste Weight (North Wall)	19.9	94.19	
Page A1.11 & A2.02	South 1st Floor	5940									1.3		
Page A1.12 & A2.02	South 2nd Floor	2376	2376	720		5472					1.2	5.61	
	South Wall Total						384	209	80,256		17.4	82.29	822.9
										Plywood Waste Weight (South Wall)	15.0	70.95	
										Grand Total (All Walls)	59.6	281.68	3235.0
	Plywood Area	Width	Height	Thickness (inches)			Weight in lbs per board		Floor Area				
	4608	48	96	0.4375	0.5 (OSB roofing)		47.25 (sheathing) 54 (OSB roofing)		58,896		12.8	77.97	779.7
	Extra 10% Margin									Grand Total (Walls+Floors)	72.4	359.65	4415.7
	46	4.8	9.6	0.4375			4.725					0.187 tons of waste	
	Flooring Plywood										From WARM Tool	0.450 MTCO2E	
	4608	48	96	0.75			61			Roofing	35.59375	192.20625	
	Extra 10% Margin												
	46	4.8	9.6	0.75			6.1						

ASPHALT

Location	Floor Flat Surface Area	Pitched Roof Surface Area	Shingle Squares Used	10% Waste	Weight in lbs	Tons
Gregson	764	1139	0	0	0	0
Spruce	703	893	8.9	1	195	0.0975
					195	0.0975
One shingle square is $100					Recycling Benefits	$890.00

DRYWALL

Location	Total Surface Area	Column1	Drywall Boards Used**	10% Waste	Weight in lbs*	Tons
Gregson	764		140	14	798	
Spruce	703		36	4	202.35	
* Each board weighs 57 lbs					1000.35	0.500175
** Assume boards of OSB sheathing equals drywall boards used						

Appendix 2 (cont.): Raw Calculations

		Plywood Boards Used	Windows+Doors
North Wall Length	376		831.25
North Wall Height	108		1398.25
North Wall Attic Facade Height	176		1398.25
North Wall Area	53392	11.6	3627.75
Left Side South Wall Length	268		1636.25
South Wall Height	176		2880
Right Side South Wall Length	104		2880
South Wall Area	32736	7.1	7396.25
West Wall Length	384		834.25
West Wall Height	108		2612.5
West Wall Area	41472	9.0	3446.75
East Wall Length	334		1517.25
East Wall Height	108		1517.25
			2470
			1152
			1152
East Wall Area	36072	7.8	7808.5
Total		35.5	
Waste in lbs		163.4	
Roof Plywood		9.25	
Waste in lbs		49.9	
Total Waste		213.3	

Appendix 3: Summary of Results

This chart summarizes the diversion recommendation for each of the five materials of interest.

12	GWP (kgCO2e/ ton)	Diversion Recommendation	Economic opportunity
Asphalt	834	Reuse in Pavement	reduce tipping fee
Concrete	164	Recycle	N/A
Lumber	88.5	Resell	$3,324
OSB	356	Recycling or Resell	reduce tipping fee
Drywall	224	Coordinate hauling to Greenway or Foxhole Recycling	reduce tipping fee

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