A Toolkit for Circular Construction of Retail and Commercial Spaces

JOSHUA D. LEE
Carnegie Mellon University

RYAN VAZ
Carnegie Mellon University

YARDEN HARARI
CallisonRTKL

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Retail interior fit-outs have an average lifespan of only 4.5 years[1] while commercial fit-outs average just 7.8 years.[2] This extremely rapid turnover is significantly shorter than other project typologies and contributes an outsized portion of the 188 million tons of building-related construction, renovation, and demolition debris generated annually in the United States.[3] Construction professionals that focus on retail and commercial projects can support resilient futures by identifying circular paths for construction materials.

Our team of academic researchers and industry experts developed a tool that utilizes standardized economic values, performance testing criteria, and a variety of sustainability rating tools to evaluate the reuse potential of individual materials, focusing on the retail and commercial interior fit-outs. This information allows architects, contractors, and clients to evaluate the reuse potential while being cognizant of the number of years a material can remain in use. Initial trials indicate high wastage factors among commonly used materials due to early planning decisions. We also found that commercial interiors such as offices tend to use large volumes of modular, commodity materials that could be easily reused whereas specialty retail environments tend to use customized products in limited quantities but with higher resale value by unit.

This tool can also aid project teams in making informed decisions while decommissioning existing facilities and planning new ones. Building owners can use the tool to capitalize on the benefits of circularity between existing and new projects within their portfolio. Architectural salvage companies can rationalize resale prices based on anticipated material performance that still remains. By focusing first on the building sectors with the highest turnover rates we hope to significantly decrease the millions of tons of construction, renovation, and demolition debris produced each year. In the future we plan to improve the tool's robustness and usability and we will evaluate other sectors to provide sector-based benchmarks that will further aid decision making across a wider range of project types.

INTRODUCTION

Retail interior fit-outs have an average lifespan of only 4.5 years[4] while commercial fitouts average just 7.8 years.[5] In 2021 over 5,000 new stores opened, while nearly as many closed.[6] This extremely rapid turnover is significantly shorter than other project types and contributes an outsized portion of the 188 million tons of building-related construction, renovation, and demolition (C&D) debris generated annually in the United States.[7] It also indicates that products' functional life spans may outlast the projects in which they are installed.

Conventional mitigation efforts focus on crushing and recycling concrete, wood, steel and other metals, which decreases the environmental impact of C&D debris, but also results in unnecessary downcycling (degradation of material quality) and requires significant reprocessing energy. Fortunately, there are already a variety of alternative strategies that would result in far less waste. For example, the movement towards material circularity in the built environment[8] offers a rich conceptual framework that recognizes two fundamental material systems-- technical nutrients and biological nutrients-- with appropriate design approaches that include 1) reduction of material quantity at the design phase, 2) maintenance 3) reuse, 4) refurbishment and remanufacture, and 5) recycling.

Reduction of material quantity at the design phase is a strategy that can be utilized for all building types by asking "do we really need a new building" and questioning material choices along the way. Some types, such as traditional religious and civic buildings, are assumed to endure for long periods of time so building for durability and long-term maintenance offers a helpful strategy. However, due to intense market forces, the retail and commercial interiors sectors in the U.S. and other similar countries are highly unlikely to embrace strategies that foreground long-term maintenance. Fortunately, material reuse has become increasingly popular among some retail chains and commercial building owners to reduce renovation costs and/or communicate their commitment to corporate sustainability.

Figure 1. ***Typical demolition of a commercial interior***. Photo by Yarden Harari.

Standard demolition material quantity estimates use weight tickets and volume percentages of filled dumpsters to roughly quantify materials removed from C&D sites. These methods are not conducive to direct reuse efforts or predicting specific quantities available for reuse. For example, knowing that a C&D site has 14 tons of steel does not provide sufficient detail when trying to calculate how many open-web joists of 32'-0" might be reused for a new office fit-out. The same issue would apply to many reusable components such as doors, lighting fixtures, ceiling tiles, and many others. This common practice unnecessarily privileges disposal and recycling over reuse due to its lack of specificity.

Retail and commercial fit-outs offer two important affordances in this regard. First, the kind of materials typically used for these projects are often durable, standardized, and designed for efficient assembly. Therefore they should theoretically be able to be disassembled and reused. Second, is the availability of data. Since the last fit-out is probably relatively recent, existing drawings and documentation are still often accessible, providing more information about what is already there and available for reuse or resale.

However, current reuse markets tend to be informal and focused on residential component recovery of one-off items that are either unique or high-value. By starting to leverage the commercial industry, we can start to standardize design and recovery processes and increase the scale of reuse dramatically by focusing on commodity products as well.

The current version of our Reuse Potential Tool described in the next section is initially focused on mass-produced products such as vinyl floor tile, gypsum wallboard, acoustic ceiling tile, and electrical outlet boxes to address this gap in the current reuse industry. However, we do plan to expand this as the tool evolves. Data inputs are gathered directly from existing project documentation that teams develop as part of the standard design and construction project process.

As the scale increases we can start to extrapolate this information to a city or regional level. This would enable jurisdictions to start making decisions around policy mechanisms that can help facilitate getting the most common or the most valuable materials back into the market. It would also aid reuse businesses in making decisions around their own business models and encourage manufacturers to improve their take back programs.

REUSE POTENTIAL TOOL

Background

Our systematic evaluation of reuse potential is predicated on standardization and data-informed analysis. Figure 2 shows the comparison between existing tools and the Reuse Potential Tool in terms of their markets and core functionalities. Existing circularity tools use metrics to produce specific strategies and recommendations on the reuse of a material. For example, Arup's circularity tool assists teams in making a decision on what circularity strategies are better suited for the project based on stakeholder inputs. Rheaply creates a marketplace within closed ecosystems to promote reuse and optimize inventories. Evaluation tools, such as the WARM tool by the EPA and Smartwaste by the BRE Group, use material manufacturing and lifecycle data to provide information on the benefits of reusing a material.

The intent of our tool - "Reuse Potential Tool" - is not to compete with these but work in tandem as a decision making tool for individual products within a project or ecosystem. To this end, the team of researchers and industry experts have developed a spreadsheet tool that utilizes quantifiable metrics reliant on existing data sources to evaluate the reuse potential of individual products.

Tool Development

To establish a data-driven approach towards identifying reuse potential, a material must be quantified along key parameters that influence the tool's automated decision making process. To simplify data analytics and provide data driven recommendations to different stakeholders, key parameters were grouped into broader categories in our Reuse Potential Tool. The categories are as follows (Figure 3):

1. Technical: Compliance with functional and aesthetic requirements of a material. This includes the volume that can be reused, performance metrics as per code, and visible defects of the material.

2. Economical: Analysis of monetary and cost benefits associated with material reuse. This includes the salvage, logistics,

Tool	Current Performance	Future Performance	Cost of Reuse	Environmental Impact	Marketplace	Green Credits	Quantify Reuse Potential	Tax Credits	Strategy Recommendation
Rheaply Resource Exchange		✓		✓	✓		✓		
SmartWaste (BRE Group)	✓		✓	✓		✓			
WARM Tool (EPA)				✓					
Circularity Tool (Arup)									✓
Our Tool	✓	✓	✓	✓		✓	✓	✓	✓

✓	Tool Supports this functionality		Core Functionality of Tool

Figure 2. ***Comparison of Tools***. Image by authors.

and resale costs along with any indirect monetary benefits from reusing the material.

3. Environmental: Impact of reuse on waste and emissions from regional to global scales. This includes offsets in material extraction and greenhouse gas emissions.

Parameters that are identified as significant influencers are then given an equal weightage over their respective categories. As the aim is to compare material characteristics using existing standards, the data input under selected parameters must be standardized, reportable, and predictable. This enables the tool's depreciation models to predict the performance of the material over a fixed time period. Based on these criteria, the tool relies on the following parameters to evaluate the reuse potential under each category in Figure 3.

A major concern faced by the team and beta testers was the lack of standardization in material reporting. Currently, material features and generic identifiers are used to record material stock. Development of a deconstruction material database built upon existing construction numbering systems like MasteFormat enables users to search for reuse stocks within a database based on how they would specify or procure materials themselves. This method also sheds light on how the material was used in its previous life. To enable this, the tool relies on CSI MasterFormat standards to create a profile of the material and reassign an identification code to the material, as it did in its initial use. The division number and the subsequent code corresponding to the construction activity allows the material to be indexed in a format commonly followed across the United States.

A crucial element to ensuring accuracy in reuse recommendation is the quality and legitimacy of data. As the onus of producing material data historically falls on the contractor and salvage crew, most deconstruction reports capture information pertaining to its economic feasibility such as cost, volume, weight and physical identifiers. However, information that is essential to identifying reuse potential is seldom documented. This would include current performance, age, warranties and contextual data that may affect the reusability of a material. Another aspect is the variation in the units of measurement during construction/ resale and typical demolition. During procurement and installation carpet tiles are measured in square feet. This material is then demolished in pounds or kilograms and finally sold again in square feet. Variations in measurements make it hard to quantify wastage at different stages and even harder to determine the economics of reuse. Development of a standardized material collection form would alleviate the risk of varying data while assigning responsibility to the deconstructing agency. Looking at the tool from an owner's perspective, estimates, specifications and drawings available to clients can be used to calculate the returns on deconstruction at the end of life rather than writing off a significant investment. As retail and commercial projects have smaller lifecycles, much of this information would be available or can be planned for ahead of construction.

Division of technical parameters into functional and aesthetic requirements is based on the assimilation of use cases that a material or component can be subjected to. If brick, for example, were to be used as an aesthetic finish in its next life, material reuse would be evaluated on its physical conditions and presence of defects rather than its structural performance metrics. Technical parameters are evaluated through a pass /

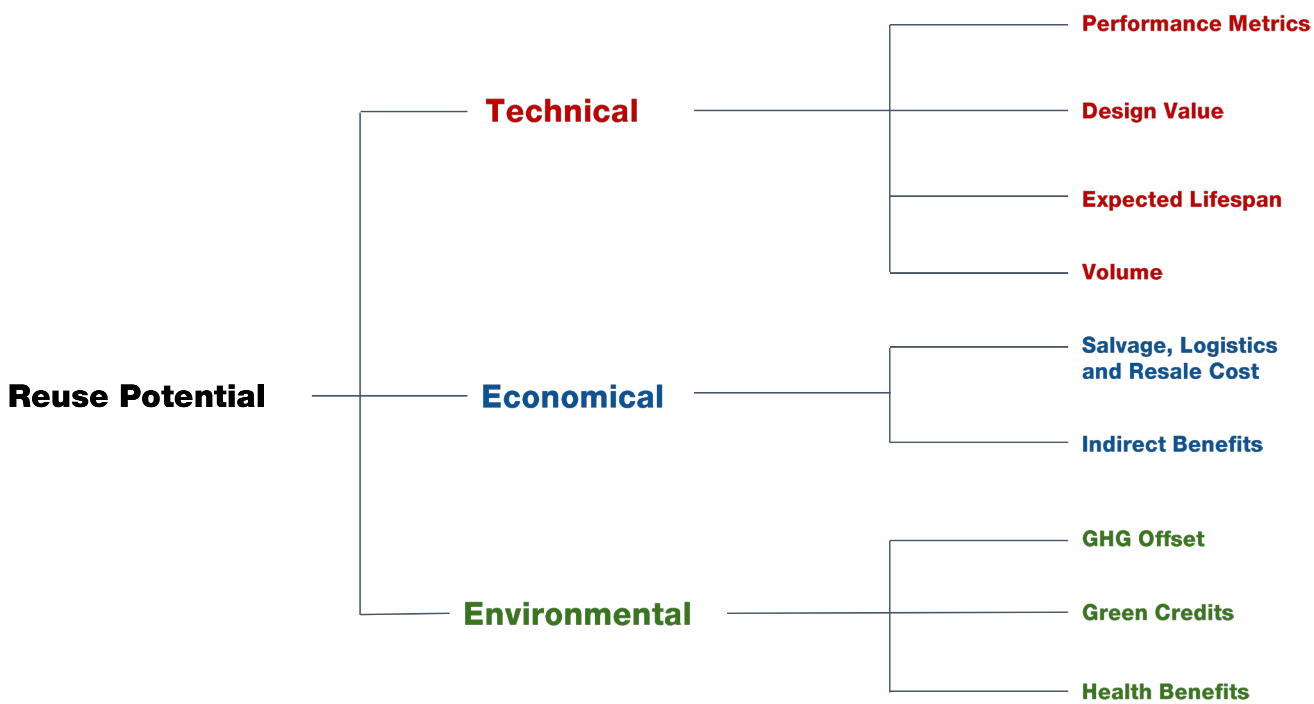

Figure 3. *Reuse Potential Framework*. Image by authors.

fail criteria as a material is expected to meet certain conditions to ensure quality and safety is uncompromised. To set these benchmarks, the tool relies on ASTM and IS standards with a potential to incorporate building codes. If a material must comply with multiple metrics, specifications can be added. Failure to comply with any of these criteria would result in a direct recommendation against its reuse.

An economic evaluation of a material and its reuse potential is beneficial to not only contractors and salvage crews, but also owners looking to deconstruct their buildings or purchase reusable materials. Even architects may see benefit in reusing materials to value-engineer certain areas and use the savings elsewhere. The tool relies on a dataset of up-to-date and region-specific costs that would provide an estimate of construction and deconstruction per material and activity. This data can also be sourced from R.S. Means or other estimating databases and plugged into the tool. Providing a masterformat number that is accurate and specific to the cost activity is essential for the tool to automatically retrieve data on the costs associated with the supply and installation of the material. Users of the tool looking to understand the depreciation of material and its future value can account for initial construction costs and current salvage values. By using a linear regression model, the tool can estimate a recommended resale price and even the book value of a material at the end of its next life. Reuse centers and contractors can work in tandem to determine the resale price by factoring in variables such as refurbishment costs, overhead, and profits. To provide an initial estimate of the material procurement price, less expenses, the tool uses single line depreciation based on the age of the material, usable lifespan and initial construction costs. This can be overridden to factor in current market demand and supply.

The outcome of this economic evaluation is the profit or loss that would be made based on cost input. It can be used to determine asking prices and profits or the economic benefits of reusing materials. As other externalities influence costs and decision making, the tool will eventually be updated to account for taxes and indirect benefits associated with material reuse.

Environmental impact and analysis is the third category of evaluation within the tool. Unlike other categories, the intent of studying environmental impacts is to educate and inform users about the benefits of reuse over providing any recommendations. Based on the technical and economical evaluation, a user must input the diversion strategy they would like to employ for each material. This would be used as the basis of determining the greenhouse gasses that are produced and offset by the material. The tool also automatically collates information on the weight or volume of material that would be sent to the landfill and recycled. All this information can be obtained from manufacturer data, rating and testing agencies along with industry wide data generated by monitoring agencies such as the Environmental Protection Agency. As the data is open-sourced and consistent for material composition, product ranges and manufacturers, the tool will require incremental updates for new and previously unused materials rather than annual changes. As most of this data is published in units of measurements that differ from how construction material is measured, the tool automatically converts the quantities to KgCO2e or other units commonly followed for tracking environmental impacts. It is important to retain these units for comparisons against new construction or reporting benefits at later stages. However, the onus on retrieving data in certain units and ensuring the accuracy of such data falls on the user, which can lead to human errors at the time of data entry. Conversions between imperial and metric units further exacerbate the problem and can only be remedied by ensuring that published data provides multiple unit formats for ready reference.

Additionally, the tool can be used to identify and inform a user of green credits that may be applicable on the project at the time of publishing this. Green rating systems such as LEED, BREEAM and Green Globes initiatives have clearly defined expectations for material reuse of materials in new construction, fit-out and renovation projects. As the tool is currently developed for interior fit-outs within the commercial and retail segment, the credits for each rating system have been input into the tool. Each rating system relies on different parameters with varying weightages. Therefore, credits applicable by one rating system may not translate to a proportionate number of credits from other systems. It is worth noting that the tool only considers applicable credits directly linked to material reuse and, therefore, would be unable to guarantee a certification. Other factors involved in making a decision on how many credits to pursue are the scale of the deconstructed project against the new construction, distance traveled for material reuse, and the projected cost of new construction. This information would be readily available to a client, so long as the deconstruction crew records the information for each material.

Technical, economical, and environmental criteria are evaluated separately, providing recommendations based on stakeholder priorities. However, the information generated by each criteria may be used to evaluate the feasibility of other criteria, showing an interdependence of factors at some scale in decision making. Individual evaluations also highlight the benefits of certain materials over others, by category. This may help stakeholders decide on what materials can be prioritized during recovery and reuse if a site or project related limitations for complete material reuse exist.

A detailed tutorial is provided for first time users. During the development and beta testing of the tool, the team observed trends in data that led to key inferences as stated in the following section.

PRELIMINARY OBSERVATIONS

The tool allows architects, contractors, and clients to evaluate the reuse potential while being cognizant of the number of years a material can reasonably remain in use. For example, Nylon 6 carpet tiles meet and exceed the technical specifications set in the ASTM standards while drastically reducing greenhouse gas emissions through reuse over any other diversion strategy. Manufacturers of this product provide material warranties of 15+ years implying high durability and low variation in functional performance over this timeframe, far exceeding the actual lifespan of most commercial and retail spaces. Assuming economic viability, Nylon 6 carpets have a high potential for reuse and even a third life based on average lease lengths. Vinyl wall bases and resilient vinyl flooring are other notable examples of materials that show reuse potential with their high durability, relative ease of deconstruction and significant reduction of greenhouse gasses through reuse. The tool provides recommendations for the economic viability of reuse by factoring all these criteria for the given material. By collating and displaying all this information, a user can make an informed decision on a case-by-case basis.

The process of creating and testing the tool raised several important observations that need to be addressed by building industry professionals, including avoidance of unnecessary wastage, important differences between nuances of retail and commercial buildings in terms of materiality, and warranty limitations.

Our tests with a variety of as-built projects indicate high wastage factors amongst commonly used materials due to early planning decisions. As we gathered take-off measurements to input the units in the appropriate cells in the spreadsheet, it became apparent that the normative design decision to center modular ceiling grids and floor tiles leads to a significant amount of waste, sometimes as much as 70%. As a general rule, as the room square footage goes down the percentage of waste goes up. Cut tiles are difficult to reuse or resell, so we suggest starting the grid from a corner instead. This small change would result in half the perimeter tiles remaining uncut. The same issue would also apply to other modular materials such as floor tiles and wall panels.

We also observed that commercial interiors such as offices and big-box retail tend to use larger volumes of modular, commodity materials that could be easily reused, whereas luxury retail environments tend to use specialty products in limited quantities but with higher resale value by unit. Therefore, at this time our tool works best for commercial interiors rather than retail spaces.

Commercial warranties often exceed project life spans but restrict material reuse due to limited control by the manufacturer. "Lifetime" warranties are effectively meaningless in commercial and retail spaces that have rapid turnover and severely limited reuse potential. For example, many of the warranties we reviewed are void if there is a change in ownership, if the product is moved, if the use of the space changes, or someone besides the original installer is used. These limitations should be addressed by manufacturers and specifiers to tailor

Information about the Project	
Name	Carnegie Mellon University
Location	Pittsburgh
Deconstruction Project's Area (In S.F.)	10,000 sq.ft
Deconstruction Project's Cost of Construction (In $)	1,234
Expected Reuse Lifespan (In Years)	

Common Information about tool												
CSI Masterformat No.	Material Name	Division	Manufacturer	Product Name	Quantity (As Built)	U.O.M.	Wastage and Damaged Factor	Reusable Quantity	% of Use Case Composition	Usable Lifespan		Age of Material (In Years)
096813100200	Carpet tile, tufted nylon, cushion back, 20 oz., 18" x 18"	09 - Finishes		As per Manufacturer	4000.00	S.Y.	15.00%	3400.00	80%	20	Years	2

Technical Parameters															
Technical Specification 1							Technical Specification 2								
Specification	U.O.M	Performance as per Manufacturer	Minimum Reuse Performance at E.O.L. (As required by	Current Performanc e (Tested)	YoY Performance Depreciation	Performance after Reuse of Years	Specification	U.O.M	Performance as per Manufacturer	Reuse Benchmark Performance at E.O.L. (As required by	Current Performanc e (Tested)	YoY Performance Depreciation	Performance after Reuse of Years	Physical Condition	Reuse Potential
ASTM E 648 Class 1. Radiant Flux >0.45	W/cm 2	0.83	0.45	0.8	0.02	0.80	Smoke Density (Flammable Mode) <450 DMC	DMC	237	450	280	-21.50	280	Minor Visible Defects	Yes

Economical Parameter											
Current Cost of Supply and Install of New Material / Unit (In $)	Cost of Material / Unit as per Construction Estimate (In $)	Salvage Cost (In $) / Unit	Incurred Refurbishment Expenses / Unit (In $)	Deconstruction + Reinstallation Cost / Unit (In $)	Total Cost of Reusable Material / Unit (In $)	O&P on Reuse (in %)	Cost to Reuse inc. O&P / Unit (In $)	Cost to Reuse inc. O&P of Total Reusable Material	Reuse Potential (Cost based)	Expected Salvage Value / Unit after 0 Years	Other Indirect Benefits (Tax or Certification Credits) (Under Development)
$20.38	15	9.00	$0.44	$6.11	15.55	10.00%	$17.11	$58,157.00	0.16	$9.00	

Environmental Parameter											
Diversion Strategy	Distance Travelled for Reuse (In Miles)	Reuse Possibilities (Use-Case)	Virgin Material Used for Production (kg)/ Unit (sf)	Post Consumer Recycled Material Used for Production (kg) / Unit (sf)	Material disposed at EOL (kg) / Unit (sf)	GHG on Production (KgCO_2e / Unit	GHG by Landfilling (KgCO_2e / Unit)	GHG produced Through Diversion (KgCO_2e / Unit)	GHG Offset by Material Reuse (KgCO_2e)	Warranty Applicable	Reuse Benefits
Reuse / Redistribute	5	Recycled to produce fibers, carpet pads or use in other industries. Reuse possible if undamaged and free of stains.	100.00%	0.00%	0.00%	13.16	0.05	-1.00	48298.67	Lifetime Limited Warranty. Applies only for original owner. Buy back program at end of life.	

Figure 4. Overview of the Technical, Economic, and Environmental Parameters. Image by authors.

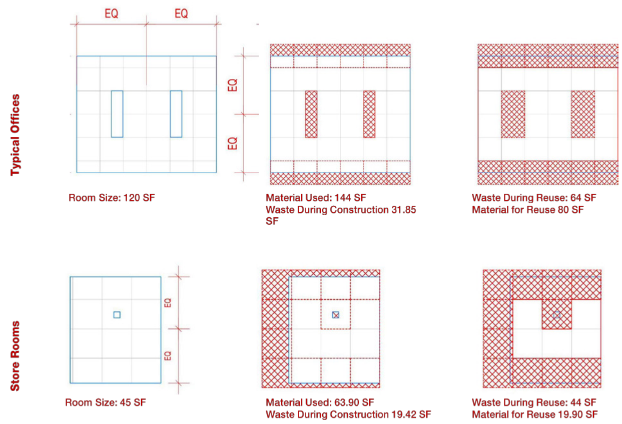

Figure 5. ***Relationship between room size and wastage of modular materials***. Image by authors.

product warranties that better align with the realities of retail and commercial environments.

CONCLUSIONS

This tool can aid project teams in making informed decisions while decommissioning existing facilities and planning new ones. Building owners can use the tool to capitalize on the benefits of circularity between existing and new projects within their portfolio. Architectural salvage companies can rationalize resale prices based on anticipated material performance that still remains. By focusing first on the building sectors with the highest turnover rates, we hope to significantly decrease the millions of tons of construction, renovation, and demolition debris produced each year.

Future Work

This tool is iteratively evolving and the team is working on improvements to its usability, robustness, and utility. Usability studies are underway to refine the user interface. Our ultimate aim is to develop a user-friendly interface that can be incorporated into CAD and BIM platforms as a plug-in. The current set of materials is limited but linking various data fields in the tool with RS Means, MasterFormat, Declare, and manufacturers will dramatically increase its range. We also plan to make the tool more useful by testing it with projects from other building sectors. This would provide sector-based benchmarks that will further aid decision making across a wider range of project types.

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Corresponding author

Please contact Joshua D. Lee at jdlee2@andrew.cmu.edu with any questions or to request a demonstration of the tool.

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