recycling

MDPI

Article

Developing a Reclamation Framework to Promote Circularity in Demolition Projects

Mariah Saad, Rajeev Ruparathna, Nihar Biswas and Edwin Tam *

Department of Civil and Environmental Engineering, University of Windsor, Windsor, ON N9B 3P4, Canada; saad43@uwindsor.ca (M.S.); rajeev.ruparathna@uwindsor.ca (R.R.); biswas@uwindsor.ca (N.B.)
* Correspondence: edwintam@uwindsor.ca

Abstract: The construction, demolition, and renovation industries are among the largest contributors to global carbon emissions and waste. With decreased landfill capacities, increased waste diversion targets, resource shortages, and the recognition that material waste is critical to climate change, diverting demolition waste is now a significant priority in waste management. Deconstructing a structure and reusing its building components can significantly reduce the environmental burdens imposed. However, to optimize the reuse of building materials and components for their environmental, societal, and economical benefits, the reclamation procedure must be undertaken in a more rational and robust manner. There are currently gaps in frameworks and tools that involve the assessment of reusable building components in demolition projects. This paper develops a reclamation framework to assess the viability of recovering and reusing building components. The framework first describes a process for conducting a technical audit and uses an assessment tool to suggest a level of deconstruction based on the physical parameters of the building circumstances. The framework complements this initial outcome by then assessing additional comprehensive parameters, such as the cost, the heritage value, and the available timeframe to arrive at a suggested outcome of actions, which can range from complete demolition and basic material recovery to deliberately removing salvageable items. The framework is then applied to an older, detached office building as a conceptual case study for demonstration. The recommended level of deconstruction appears appropriate based on the visual assessment of the structure. The result of this paper promotes the circular economy and supports the United Nations Sustainable Development Goals (UN SDGs) by presenting a notably more insightful and guided approach to capturing deconstruction waste.

Keywords: demolition; waste; reclamation; framework; circular economy; reuse potential; building materials; deconstruction

check for updates

Citation: Saad, M.; Ruparathna, R.; Biswas, N.; Tam, E. Developing a Reclamation Framework to Promote Circularity in Demolition Projects. *Recycling* **2024**, *9*, 114. https://doi.org/10.3390/recycling9060114

Received: 30 August 2024
Revised: 21 October 2024
Accepted: 17 November 2024
Published: 22 November 2024

1. Introduction

The construction and demolition industry in Canada produces a significant portion of total solid waste across the country, contributing to strains on landfill capacities, resource shortages, and national carbon emissions. It has been estimated that the construction, renovation, and demolition industry in Canada produces over 4 million tonnes of solid waste each year [1]. Most materials are often disposed of or recycled, rather than recovered and reused. It has been estimated that less than 1% of the materials discarded in construction or demolition are effectively repurposed [2]. It has also been estimated that a typical home deconstruction can result in the recycling of up to 70% and the reuse of up to 25% of the materials [3].

As the circular economy gains momentum across the globe, a greater shift towards the reuse of products to extend their lifecycles and preserve their value is becoming an increased priority. The linear economy strains natural systems and communities by producing, consuming, and disposing of resources without recovering the products at their end of life [4]. Globally, the construction industry consumes approximately 40% of all raw materials [5]. According to a 2021 report by the National Zero Waste Council, if every building in Canada that is renovated or demolished were selected to be disassembled and reused instead, an estimated 1.3 million tonnes of embodied CO_2e could be avoided annually [6]. A study using a grey model and lifecycle assessment conducted by Wang, Li et al. found that recycling 1 ton of construction waste in Shanghai, China could save 100.4 kg CO_2e [7]. This study analyzed the emissions when recycling brick, steel, wood, concrete, and mortar [7]. To reach global sustainability and waste reduction targets, there must be a significant increase in the amount of building components being reclaimed and reused. Reclamation audits involve the assessment of the reusable products in a structure. Reclaimable building components can be identified, removed, and reused for environmental, economic, and societal benefits [2]. Some of these benefits may include increased job opportunities, a decreased need to manufacture new products, or the preservation of significant components in the built environment. Reclamation audits can divert a large quantity of waste generated by the construction and demolition industry, if executed in a strategic and systematic manner.

Existing research has been conducted on reclamation audits and the reuse potential of specific building materials and components. The existing literature investigates the identification process of reusable components. In addition, frameworks have been previously developed to assist in conducting a reclamation audit and deconstructing a structure, which can be seen in [2,3,8,9]. Despite this, there are currently research gaps, which are identified and discussed below.

The reclamation industry has large potential for expansion. There is a pressing need for more resources and tools to assist in diverting building materials away from landfills [10]. The purpose of this research paper is to develop a reclamation framework that includes a deconstruction assessment tool with a scoring system. The framework will suggest the level of deconstruction that is most feasible by considering several parameters throughout the framework. This article is a revised and expanded version of a paper entitled Circular Economy in the Construction Industry: Reclamation Audits to Increase Material Reusability in Demolition Projects, which was presented at the Canadian Society for Civil Engineering Annual Conference, Niagara Falls, Canada, 5–7 June 2024 [10]. The objective of this research is to promote the circulation of building components by presenting a framework that considers several factors that will impact the reclamation procedure.

2. Literature Review

There are several benefits to reusing building components, namely economic, environmental, and societal benefits. The reclamation of building materials lowers project expenses and can decrease the transportation and disposal costs when reusing products on-site. Reusing building materials can require additional steps to keep the building products in circulation; these steps may include the assessment, recovery, and sorting of products, which can provide additional job opportunities and in turn benefit the local economy [2]. Recycling has significant environmental impacts due to the energy required in the recycling process. The reuse of building components is a way to avoid the environmental impacts of both recycling and landfilling, while simultaneously avoiding the need to manufacture new products. From a societal point of view, the environmental impacts of the construction and demolition industry are becoming more of a pressing concern across the globe. As climate targets increase, there may be increased legislation and policies that require the reuse of products in construction projects or the salvage of components in demolition projects. The reuse of building components can help to adhere to the current or future regulations regarding material reuse requirements. The reuse of building products also preserves components in the built environment, which can hold historical, cultural, or heritage value.

Buildings with hazardous materials can not only make certain components unsuitable for reclamation but may also pose hazards to workers and communities. Buildings that include lead, asbestos, mercury, mold, and other hazardous substances can release toxins and impose health risks to workers and the environment. In addition to the risks posed by hazardous materials, studies have found that exposure to construction dust can increase the risk of chronic respiratory diseases [11]. The deconstruction procedure should be executed with the attempt to minimize exposure to hazards such as dust and pollution. To minimize the risks of deconstruction, materials must be handled and managed properly. Various regions have specific legislation and policies involving exposure to harmful materials. Several countries restrict the exposure of asbestos, lead, and other harmful materials among individuals who are conducting a demolition; it is also possible for regions to require the hazardous materials to be removed prior to demolition [12]. According to a guide by the Canadian Council of Ministers of the Environment, a waste management plan can address the management of hazardous materials [13]. Proper waste identification, removal, and disposal are critical and may need to be conducted by trained professionals.

Reclamation audits assess the reusable components in a structure before it is demolished. The reclamation audit lists important information regarding the specific products, including the locations, conditions, deconstruction methods, quantities, and suggested reuse destinations. There are several commonly reclaimed construction and demolition materials, such as wood, concrete, and masonry [14]. Frameworks and guidelines have been previously developed for reclamation audits and the assessment of reusable building components. Several frameworks were reviewed to determine gaps in this area of research; the results are summarized below in Table 1. Most of the main frameworks and tools currently accessible on the internet do not include structured scoring systems. This could assist significantly in the decision-making process by providing specific suggestions based on the reclamation audit. It was also noted that certain frameworks do not consider multiple factors that can impact the final decision, such as the heritage value, budget, and timeframe. The objective of this framework is to develop various criteria to arrive at the final recommendation. The goal is to not only consider the technical feasibility and the presence of specific components, but to also consider the economic feasibility and overall attainability of the suggested deconstruction level based on the project circumstances. To develop this framework, various existing frameworks, tools, and guidelines were reviewed to assist in the framework and scoring system's development. Several existing works involve building information modeling (BIM), although they are not included in the table below. The primary focus is often on determining the deconstructability from the design stage, as shown in [15–17]. It should be noted that any BIM information saved can significantly assist with deconstruction once a structure reaches its end of life. An increasing quantity of buildings are currently being designed and built with deconstruction in mind; however, there is still a significant number of older buildings that were designed without deconstruction in mind, using construction methods that do not facilitate reclamation, such as the use of industrial adhesives [18]. The framework developed in this paper is geared towards existing buildings, which may not have considered deconstructability during the design phase. In the table below, "incorporates" considers whether the tool or framework in the source document includes the parameter as a value to work with.

Table 1. Existing frameworks and guidelines for waste reclamation and reuse.

Source	Focus	Framework/ Guidelines	Assessment Tool	Scoring System	Incorporates Heritage Value?	Incorporates Timeframe?	Incorporates Budget?
[2]	Identification of reusable products and how to conduct a reclamation audit	Yes	Yes	Not included	Yes (considers product heritage, scarcity, historical value, etc.)	Limited (often refers to the timeframe of the reclamation audit, rather than the deconstruction)	Partially (mentions possible cost savings from reclamation, considers market demands, etc.)

Table 1. *Cont.*

Source	Focus	Framework/ Guidelines	Assessment Tool	Scoring System	Incorporates Heritage Value?	Incorporates Timeframe?	Incorporates Budget?
[3]	Deconstruction potential assessment of a structure	Yes	Yes	Not included	No (briefly mentions historic preservation, but it is not a parameter to work with in the tool)	Yes (mentions different timeframes in the spectrum of deconstruction, often refers to time)	Partially (mentions economic benefits, different deconstruction approaches to optimize cost, etc.)
[8]	Determining a level of deconstruction	Partially	Yes	Partially (rating certain damage)	Partially (considers certain architectural features in the tool, but not necessarily historical/heritage significance)	Yes (mentions different timeframe suggestions)	Limited (discusses how market values impact the decision, mentions that funding availability can be considered to help in decision making)
[9]	Steps to conduct a waste audit and keep a materials inventory	Yes	Yes	Not included	Limited (mentions the importance of considering the age and history of the structure)	Limited (mentions that time will affect material recovery, but it is not a parameter to work with in the tool)	Limited (mentions that economic feasibility will affect material recovery and discusses reuse value)
[19,20] (unknown if the model is available for public use)	Estimate cost, revenue potential, and project management from the deconstruction of wood-framed one-/two-story structures [19]	Partially	Yes	Yes	Partially (considers year built [19,20]/ briefly mentions it and considers if the building is in a historic district [20])	Partially (considers time/if there is enough time for deconstruction, identifies most feasible level of deconstruction) [20]	Yes (estimates costs and salvage revenues, considers local disposal fees, etc.) [19]

3. Discussion

The presented framework recommends the most feasible level of deconstruction for a structure, while simultaneously considering several factors that influence the final recommendation. The framework guides the user through a series of steps to rationally address decision making using identifiable markers and understandable process steps and provides additional rigor on how to interpret different aspects that might be encountered. The construction and demolition industry, in Canada and globally, must embrace more innovative waste diversion strategies. Increasing the quantity of tools and guidelines that help to assess reusable components is a step towards solving several pressing challenges in the construction and demolition industry, notably construction and demolition waste, carbon emissions, landfill capacity pressures, and resource shortages. This type of guidance is critical given that the decision maker will not necessarily be an expert, may suffer from incomplete information, and may be faced with a wide variability of buildings, materials, and other factors.

There are future improvements to be made that can fine-tune this framework. Future work would involve adapting the timeframe and scoring scale to the structure's size. Currently, the point allocation is appropriate for average-sized residential homes and smaller commercial buildings. This is based on existing work, such as the Delta Institute Deconstruction and Building Material Reuse tool [3], which suggests that a full deconstruction can take 3–10+ days depending on the structure's type and size—hence, the highest level of deconstruction proposed in the tool developed is 5+ days. The United States Environmental Protection Agency (EPA) has a Deconstruction Rapid Assessment Tool, which is applicable to residential structures planned for demolition, although it still can be utilized in different scenarios for other purposes, such as developing community support or providing deconstruction evaluation training opportunities [8]. In this framework, the recommended timeframes in Stage 1 would not be suitable for larger structures. Future work should adapt the scale, point allocations, and timeframe recommendations to the structure's size to improve its applicability. Another area of future work is the different final outcomes. This framework assumes the budget and timeframe to have a positive correlation. However, it is possible that there could be a large project budget with a short timeframe, and vice versa. In addition, the subjectivity could be addressed using fuzzy analysis. Finally, future work could also incorporate an environmental impact assessment regarding the recovery of specific building components. This tool is meant to provide a recommendation and allows individuals without significant experience in the reclamation industry to initially estimate and understand what the most feasible end-of-life option may be. If the Stage 1 suggestion is deemed unreasonable, the auditor can still adjust their decision process in the final stages to arrive at a more appropriate outcome. This tool combines both technical feasibility and professional judgment to allow for a comprehensive assessment.

3.1. Application of the Proposed Framework to a Case Study

To demonstrate the application of the proposed framework, the methodology has been partially applied to a detached office building on the University of Windsor campus (Figure 1). This demonstration is based on a prior analysis presented in [10]. The structure was originally a residential home; however, it is now part of the university campus and is used as a commercial office space. The building was renovated and now includes offices and storage spaces [21]. This framework demonstration began with a preliminary visual assessment of the structure to estimate the technical feasibility of deconstruction. Stage 2 would consider the budget and timeframe; this was not applicable in this case as the building assessed is not currently slated for demolition and is only used as an example. Stage 3 demonstrates a heritage value consideration and how it can influence the final decision.

Figure 1. Detached office building assessed.

3.1.1. Case Study Stage 1: Technical Feasibility Assessment

To complete Stage 1, the Reclamation Audit Assessment Tool template was filled out (Figure 2). The building was visually assessed, and several applicable categories were scored.

The total assessment score was found to be 10, which is in the range of 0–20. This signifies that, based on the technical feasibility assessment alone, the structure appears to be most suitable for a 5+ day deconstruction. The building had a good amount of lumber, stone, and bricks. As discussed in the framework methodology below, these are commonly reclaimed building components and influence the deconstruction timeframe in a positive manner. There were no significant concerns visible when considering on-site observations, structural failure, and damage. The building also had a significant quantity of architectural features such as appliances, railings, and light fixtures in working order. Based on the visual assessment, the 5+ day deconstruction recommendation appears appropriate.

RECLAMATION AUDIT ASSESSMENT TOOL

GENERAL INFORMATION						
Company/Organization Name:			**Auditor Information**		**Building Owner Information**	
Assessment Date(s):			Name:		Name:	
Structure Information			Contact (tel/email):		Contact (tel/email):	
Name (if applicable):						
Site Address:			Additional Information:		Additional Information:	
Year built:	Was the structure constructed after 1950? **If yes, add 5 points**	0				
Number of stories:						
Additional Information (building type, size, etc.):		Detached office building				

ON-SITE OBSERVATIONS	
Is there garbage on-site? Consider if this affects the reclamation procedure or causes hazardous working conditions **(score from 1–5, 1 being a little, 5 being a lot of trash)**	1
Is there adequate space on-site for the deconstruction process? **If not, add 10 points**	0
Assess if there are any hazards on-site (asbestos, live wires, mold, pests, etc.) **If yes, add 5–10 points, 5 being a little and 10 being a lot of hazards** (consider if trained professionals will be needed to handle the hazards)	0
Consider the accessibility of components in the structure. Do hazards make it difficult to access certain elements? **If yes, add 5 points** (consider if trained professionals or an increased timeframe are required)	0
STRUCTURE FAILURE AND/OR DAMAGE	
Are there concerns with the structure's foundation? **If yes, add 1–5 points, 1 being a little, and 5 a lot** (consider if the building has sections collapsing, holes, cracks in the foundation/walls, etc.)	0
Are a significant portion of bricks damaged, missing, and/or cracked? **If yes, add 5 points**	5
Does the structure have any roof damage? (consider holes, collapsing sections, etc.) **If yes, add 1–5 points, 1 being a little, and 5 being a lot**	0
Does the structure have fire damage? (consider any smoke damage, soot, etc.) **If yes, add 1–5 points, 1 being a little, and 5 being a lot**	0
Does the structure have water damage? (consider wall discoloration, mold, etc.) **If yes, add 1–5 points, 1 being a little, and 5 being a lot**	0
Are wooden building elements rotting? (could result from water damage, infestations, natural disasters, etc.) **If yes, add 5 points**	0
MATERIALS/RECLAMATION INVENTORY	
Are any of the roof trusses reclaimable? **If not, add 5 points**	0
Can portions of the building's framing be reclaimed? **If not, add 5 points**	0
How much quality wood flooring is present? (preferably without strong adhesives to facilitate cleaning/reclamation) **Score the quantity from 0–5 points, 5 being a little and 0 being a lot**	3
Are layers of flooring attached together with strong glue or adhesives? **If yes, add 3 points**	0
Is a valuable quantity of lumber present? (preferably high quality old growth lumber) **If not, add 5 points**	0
Are there reclaimable mouldings in the structure? (baseboard, crown, etc.) **If not, add 2 points**	0
ARCHITECTURAL FEATURES	
Are wooden doors, window framing, or cabinetry present? **If not, add 2 points**	0
Does the structure have reclaimable stair treads and/or railings? **If not present, add 1 point**	0
Any valuable architectural woodwork? **If not, add 1 point** (If yes, take note and consider in Stage 3)	0
Are reclaimable stone components present in the structure? **If not, add 1 point**	0
Any broken glass that may have architectural value? (e.g. stained glass) **If yes, add 1 point**	0
Does the site have reclaimable fencing, gates, or railings (stairs, balcony, etc.)? **If not, add 1 point**	0
Does the building have metal roofing? **If not, add 1 point**	1
Are salvageable light fixtures present that are in working order and are good quality? **If not, add 1 point**	0
Does the building have appliances (fridge, stove, dishwasher, etc.), sinks, or countertops? **If not, add 1 point**	0

RECLAMATION INVENTORY						
Building Element	**Picture**	**Quantity, Dimensions, etc.**	**Location and Product Condition**	**Potential Heritage Value? (Consider in Stage 3)**	**Deconstruction Methods / Possible Reuse Destinations**	**Additional Comments**

FINAL COMMENTS
–Total assessment score = 10 –Structure seems suitable for a 5+ day deconstruction (if it were to be demolished) –Good quantity of stone components, bricks, and lumber –No significant hazards visible

ASSESSING THE LEVEL OF DECONSTRUCTION			
Complete demolition	Total: 81–100	General Structure Information Score /5	0
Demolition with recycling	Total: 61–80	On-site Observations Score /30	1
1–2 day deconstruction	Total: 41–60	Structure Failure and/or Damage Score /30	5
3–5 day deconstruction	Total: 21–40	Materials Inventory Score /25	3
5+ day deconstruction	Total: 0–20	Architectural Features Score /10	1
TECHNICAL FEASIBILITY RECOMMENDED LEVEL OF DECONSTRUCTION **5+ day deconstruction**		Total Assessment Score /100	**10**

Figure 2. Reclamation Audit Assessment Tool template demonstration.

3.1.2. Case Study Stage 2: Budget and Timeframe Consideration

Stage 2 would consider how the project budget and timeframe impact the decision-making process. If the 5+ day deconstruction recommendation from Stage 1 does not seem feasible, the auditor should consider this in the final decision. In this demonstration, Stage 2 is not considered since this is not a real-life deconstruction project. The auditor should consider economic factors and timeframe constraints in real-life scenarios. This process is further described below in Section 4.2.

3.1.3. Case Study Stage 3: Heritage Value Consideration

To obtain heritage information about the building, several sources were reviewed. Because homes built before 1950 typically consist of high-quality lumber and architectural features potentially suitable for reclamation [3], determining the year that the structure was built was a critical parameter in Stages 1 and 3. To determine this, the City of Windsor Directories were utilized, which provide information on the existence and ownership of properties in specific years. Since the address of this building was listed in directories older than 1950, it was concluded that the original structure likely existed prior to 1950. The extent of the previous renovation is unknown. For this framework demonstration, it was reasonably assumed that many of the main foundation and structural components remained the same.

Due to the lack of background information available regarding the history and heritage of the structure, estimating the heritage value and its influence on the hypothetical deconstruction was difficult. However, this situation is not unusual, and the lack of information may be challenging for an auditor seeking to fully evaluate the building's circumstances. In this situation, the present case study considers a visual inspection and an educated assumption about the building parameters. It would be preferable to complete a more comprehensive assessment, but the challenges faced in this case study are realistic and not atypical. The sources reviewed for building information did not specify that the structure had specific historical significance. While older buildings may potentially have items of architectural value that are worth reclaiming, based on the history of this case study structure, there is nothing unique about its history and thus this aspect would not significantly influence the deconstruction timeframe.

3.1.4. Case Study Stage 4: Final Decision

This scenario did not involve a real-time deconstruction project—nor was there one available from start to finish during this research—and, as such, there is no final decision. However, if the case study was extended, the auditor could consider each parameter and the final deconstruction outcomes. Since the heritage value consideration does not appear to have a significant impact on the decision in this demonstration, Case D is not considered. The budget and timeframe considerations would influence whether the Stage 1 recommendation is followed, extended, or shortened. Case A would be suitable if the 5+ day deconstruction is feasible and the budget and timeframe are sufficient to allow for the recommendation. The auditor would choose to follow the 5+ day deconstruction recommendation. Case B would be suitable if the budget and timeframe are greater than needed to follow the 5+ day deconstruction recommendation. The auditor would choose to allocate more time and/or resources than needed for the Stage 1 recommendation. Case C would be suitable if the project budget and timeframe were not enough to follow the 5+ day deconstruction recommendation. The auditor would choose to shorten the deconstruction timeframe and allocate less time and/or resources than needed for the Stage 1 recommendation. The different cases and deconstruction outcomes are further discussed below in Section 4.4.

4. Method for Development of Framework

The method for the creation of the proposed reclamation framework involves four stages of development: technical feasibility assessment, budget and timeframe consideration, and heritage value consideration, concluding with the preferred action. The reclamation framework was developed by reviewing several frameworks and guidelines, shown above in Table 1. A summary of the entire framework is presented below in Figure 3, and it was adapted using information from [2,8,9,22].

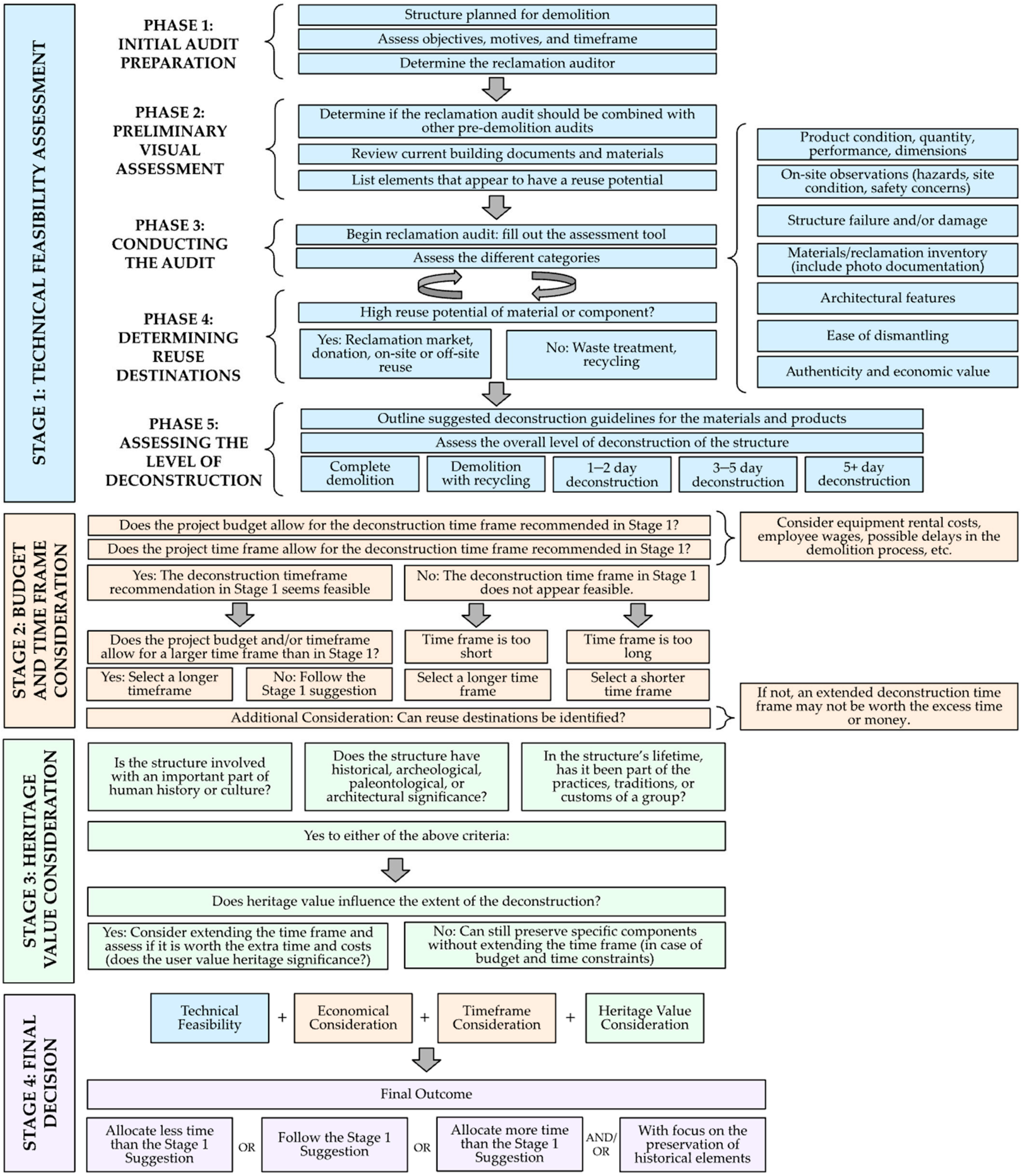

Figure 3. Reclamation framework stages.

4.1. Stage 1: Technical Feasibility Assessment

The first stage, the technical feasibility assessment, includes five phases. This stage was developed using data from [2,8,9]. The five suggested phases in the technical assessment are described below.

1. The first phase involves the initial audit preparation. It is important to determine the auditor, timeframe, objectives, and project budget to plan the extent of the reclamation audit and assessment process. The scale of the reclamation audit may be based on the objectives of the project, whether for voluntary reasons or economic incentives or to adhere to specific legislations [2].
2. The second phase is a preliminary visual assessment of the structure. The auditor can visually evaluate the structure and identify products that may have reuse potential. It should also be determined how the audit will be coordinated with other pre-demolition audits. This phase also involves reviewing building documents and any information on the existing materials in the structure.
3. The third phase involves conducting the audit and evaluating the reuse potential of the building products. In this phase, the auditor can use the assessment tool (Figure 4: Reclamation Audit Assessment Tool template) and consider each technical assessment criterion. The third phase evaluates factors such as the product conditions, site hazards, safety concerns, and structural conditions. The assessment tool in the framework does not consider the authenticity and economic value of building elements; however, the auditor should still consider this. The auditor should also consider dismantling methods for specific components, since certain products require certain expertise for the reclamation procedure [8].
4. The fourth phase involves determining the reuse destinations for the products. There can be several uses for salvaged components, such as in new projects; they can also be listed on online marketplaces or sent to donation programs [2].
5. The fifth phase involves assessing the structure's level of deconstruction. It should be determined whether the structure is most suitable for demolition, demolition with recycling, or a longer deconstruction timeframe [8]. This decision is further explained in Table 2. This initial suggestion is solely the Stage 1 technical suggestion. Economic feasibility and heritage value are considered in Stages 2 and 3; these will impact the final action obtained in Stage 4.

Table 2. Recommended levels of deconstruction.

Score	Level of Deconstruction	Overall Reuse Potential
81–100	Complete Demolition	The structure has very low overall reuse potential. Most products are not in good condition and have low market value.
61–80	Demolition With Recycling	The structure has low overall reuse potential. Most of the building elements are not in good condition; however, a significant quantity of the products should be recycled.
41–60	1–2 Day Deconstruction	The structure has decent overall reuse potential. Some elements are not in good condition, but most of the structure has good reuse potential.
21–40	3–5 Day Deconstruction	The structure has high overall reuse potential. A significant portion of the elements are in good condition.
0–20	5+ Day Deconstruction	The structure has very high overall reuse potential. Most building elements are in good condition and have high market value.

RECLAMATION AUDIT ASSESSMENT TOOL

GENERAL INFORMATION						
Company/Organization Name:			Auditor Information		Building Owner Information	
Assessment Date(s):			Name:		Name:	
Structure Information			Contact (tel/email):		Contact (tel/email):	
Name (if applicable):						
Site Address:			Additional Information:		Additional Information:	
Year built:	Was the structure constructed after 1950? **If yes, add 5 points**					
Number of stories:						
Additional Information (building type, size, etc.):						

ON-SITE OBSERVATIONS	
Is there garbage on-site? Consider if this affects the reclamation procedure or causes hazardous working conditions **(score from 1–5, 1 being a little, 5 being a lot of trash)**	
Is there adequate space on-site for the deconstruction process? **If not, add 10 points**	
Assess if there are any hazards on-site (asbestos, live wires, mold, pests, etc.) **If yes, add 5–10 points, 5 being a little and 10 being a lot of hazards** (consider if trained professionals will be needed to handle the hazards)	
Consider the accessibility of components in the structure. Do hazards make it difficult to access certain elements? **If yes, add 5 points** (consider if trained professionals or an increased timeframe are required)	
STRUCTURE FAILURE AND/OR DAMAGE	
Are there concerns with the structure's foundation? **If yes, add 1–5 points, 1 being a little, and 5 a lot** (consider if the building has sections collapsing, holes, cracks in the foundation/walls, etc.)	
Are a significant portion of bricks damaged, missing, and/or cracked? **If yes, add 5 points**	
Does the structure have any roof damage? (consider holes, collapsing sections, etc.) **If yes, add 1–5 points, 1 being a little, and 5 being a lot**	
Does the structure have fire damage? (consider any smoke damage, soot, etc.) **If yes, add 1–5 points, 1 being a little, and 5 being a lot**	
Does the structure have water damage? (consider wall discoloration, mold, etc.) **If yes, add 1–5 points, 1 being a little, and 5 being a lot**	
Are wooden building elements rotting? (could result from water damage, infestations, natural disasters, etc.) **If yes, add 5 points**	
MATERIALS/RECLAMATION INVENTORY	
Are any of the roof trusses reclaimable? **If not, add 5 points**	
Can portions of the building's framing be reclaimed? **If not, add 5 points**	
How much quality wood flooring is present? (preferably without strong adhesives to facilitate cleaning/reclamation) **Score the quantity from 0–5 points, 5 being a little and 0 being a lot**	
Are layers of flooring attached together with strong glue or adhesives? **If yes, add 3 points**	
Is a valuable quantity of lumber present? (preferably high quality old growth lumber) **If not, add 5 points**	
Are there reclaimable mouldings in the structure? (baseboard, crown, etc.) **If not, add 2 points**	
ARCHITECTURAL FEATURES	
Are wooden doors, window framing, or cabinetry present? **If not, add 2 points**	
Does the structure have reclaimable stair treads and/or railings? **If not present, add 1 point**	
Any valuable architectural woodwork? **If not, add 1 point** (If yes, take note and consider in Stage 3)	
Are reclaimable stone components present in the structure? **If not, add 1 point**	
Any broken glass that may have architectural value? (e.g. stained glass) **If yes, add 1 point**	
Does the site have reclaimable fencing, gates, or railings (stairs, balcony, etc.)? **If not, add 1 point**	
Does the building have metal roofing? **If not, add 1 point**	
Are salvageable light fixtures present that are in working order and are good quality? **If not, add 1 point**	
Does the building have appliances (fridge, stove, dishwasher, etc.), sinks, or countertops? **If not, add 1 point**	

RECLAMATION INVENTORY						
Building Element	**Picture**	**Quantity, Dimensions, etc.**	**Location and Product Condition**	**Potential Heritage Value? (Consider in Stage 3)**	**Deconstruction Methods / Possible Reuse Destinations**	**Additional Comments**

FINAL COMMENTS

ASSESSING THE LEVEL OF DECONSTRUCTION				
Complete demolition	Total: 81–100		General Structure Information Score /5	
Demolition with recycling	Total: 61–80		On-site Observations Score /30	
1–2 day deconstruction	Total: 41–60		Structure Failure and/or Damage Score /30	
3–5 day deconstruction	Total: 21–40		Materials Inventory Score /25	
5+ day deconstruction	Total: 0–20		Architectural Features Score /10	
TECHNICAL FEASIBILITY RECOMMENDED LEVEL OF DECONSTRUCTION			Total Assessment Score /100	

Figure 4. Reclamation Audit Assessment Tool template.

A Reclamation Audit Assessment Tool template (Figure 4) was adapted from [2,3,8,9] that can be utilized in the third phase of Stage 1. The United States Environmental Protection Agency's Deconstruction Rapid Assessment Tool helps to assess the level of deconstruction; their tool suggests different levels of deconstruction, including complete demolition, demolition with recycling, 1–2-day deconstruction, 3–5-day deconstruction, and 5+ day deconstruction [8]. These were utilized as the different outcomes at the end of life in the proposed assessment tool developed here. Once the final technical assessment score is tabulated, it can be compared to the scores in Table 2 to obtain the Stage 1 suggestion. There is not a significant gap between the different levels of deconstruction (for example, a score of 60 or 61 yields two different courses of action, but with very similar scores). It can be challenging to determine which level of deconstruction to choose when the scores are very close. In these situations, Stage 2 and Stage 3 will help to make the final decision. Table 2 below is based in part on [8,10]. It should be noted that recycling should still be considered at each level of deconstruction when reuse is not feasible.

4.1.1. Point Allocation

The allocation of points varies depending on the impact that each criterion has on the overall reuse potential. For example, the absence of a good staging area adds 10 points to the overall score due to its high impact on the overall reclamation procedure. On the other hand, the absence of light fixtures only adds one point to the overall score since it has a low impact on the overall reuse potential. Hazards on-site can add between 5 and 10 points, while less impactful criteria are not assigned such an influential score. To develop the scoring system, a range was created between 0 and 100. Each level of deconstruction (Table 2) was given a range between 19 and 20 points. A score from 81 to 100 suggests that the material has very low overall reuse potential, while a score between 0 and 20 suggests that the structure has very high overall reuse potential. Adding a point in the assessment tool means that the specific criterion has a negative effect on the overall reuse potential; it brings the total assessment score closer to complete demolition. In the assessment tool, certain criteria require the user to add a quantity of points based on a scale from 1 to 5, such as rating roof or water damage. For these criteria, the auditor can determine the score based on the structure scale. For example, if approximately 20% of the structure has fire damage, a score of 1 would be added, while 100% would add a score of 5.

4.1.2. Categories and Assessment Criteria

Table 3 below summarizes each category in the Reclamation Audit Assessment Tool presented above in Figure 4.

Table 3. Assessment tool categories.

Category	Significance	Additional Information (Steps, Scoring, Justification, etc.)
General Structure Information	Input important building information including size, address, and year built.	⇒ According to the United States Department of Housing and Urban Development, some criteria that suggest that a structure is well suited for extensive deconstruction are wood framing, high-quality bricks with low-quality mortar, and structural soundness [23]. ⇒ The assessment tool adds 5 points if the structure was built after 1950; homes built before 1950 are often constructed with high-quality lumber and typically have sought-after architectural features suitable for reclamation [3].
On-Site Observations	Assess hazards, safety concerns, and site condition	⇒ This category is worth up to 30 points in the overall score; it is one of the categories worth the largest quantity of points. ⇒ Mainly a visual assessment of the structure; however, some criteria must be assessed by trained professionals. ⇒ Hazards and safety concerns may require a longer deconstruction procedure, unsuitable due to possible time constraints, hazard removal costs, and difficulties in accessing building elements. ⇒ The absence of a suitable staging area adds 10 points to this category. This lack of space can make it difficult to handle the products on-site, which may extend the project timeframe and increase the transportation costs required to sort and handle the products off-site.

Table 3. *Cont.*

Category	Significance	Additional Information (Steps, Scoring, Justification, etc.)
Structure Failure and/or Damage	Assess the presence of structural concerns	⇒ This category contributes up to 30 points in the overall score, making it one of the highest-weighed categories since it has a large influence on the overall reclamation procedure. ⇒ Significant structural damage can make components unsuitable for reclamation and result in hazards and safety concerns. ⇒ Structure damage can make it more difficult to access specific building elements, potentially resulting in increased timeframes and additional costs.
Materials/ Reclamation Inventory	Assess if common components with high reuse potential are present	⇒ The presence of components that are known to have high reuse potential (e.g., wood flooring, old growth lumber, etc.) will lead to a longer deconstruction timeframe. The materials/reclamation inventory section contributes up to 25 points towards the total score. ⇒ The reclamation inventory section allows the auditor to add additional details regarding the building components, such as the dimensions, suggested deconstruction methods, and suggested reuse destinations. ⇒ The auditor can also input pictures to assist with product identification or decision-making or to be shared on online marketplaces.
Architectural Features	Assess if common high-value architectural features are present	⇒ This category is worth 10 points, one of the lowest-weighed categories, since most other categories have a greater influence on the overall reuse potential. ⇒ The absence of a high-value architectural feature will not impact the overall reuse potential as much as structure damage or hazards. ⇒ The absence of elements listed adds points to the total score, lowering the overall reuse potential.

4.2. Stage 2: Budget and Timeframe Consideration

The project budget and timeframe will have a considerable impact on the final decision. During Stage 2, the auditor should evaluate whether the technical recommendation from Stage 1 is feasible. The user of this framework should note whether the budget allows for the suggestion in Stage 1. If the suggested timeframe is determined to be too long, then the user can select a shorter timeframe. However, if the budget allows for a longer deconstruction timeframe, this should be noted as well and considered in Stage 4. The project timeframe can significantly narrow the options as well. If the project timeframe does not allow for the recommendation in Stage 1, then this allows the user to use their own judgement to make a final decision. For example, if the Stage 1 recommendation is a 3–5 day deconstruction, but the project can only allocate a maximum of 2 days to the deconstruction process, this narrows the timeframe significantly to 2 days or less. When considering the budget and timeframe, the framework user should consider important factors, such as equipment rental costs, employee wages, and overall delays in the demolition process.

An important decision factor can be possible reuse destinations for the reclaimed materials. If the user cannot locate receivers that will effectively repurpose the products, then the reclamation procedure might not be worth the required time or money. Some projects may have the goal of selling the products for profit or avoiding waste disposal costs [2]. If the user believes that there is no demand for the products, it may not be worth spending additional time to disassemble certain components, which may result in choosing a shorter reclamation timeframe. On the other hand, if the user believes that there is a high demand for several products, then this could be one of the factors that can lead to selecting a longer timeframe.

The demand for reclaimed products can come from the reclamation market, new projects, online marketplaces, or donation systems [2]. Incorporating reclaimable materials into a new project requires a link between demolition and construction and is dependent on the opportunities that may arise [2]. It is important to consider geographical factors, as the presence and quantity of local projects, marketplaces, or donation centers can influence the circulation of the building components. For example, Habitat for Humanity has several Habitat ReStores across Canada, which collect and sell reclaimed building components [24]. It is important to consider possible reuse destinations before finalizing the deconstruction timeframe.

4.3. Stage 3: Heritage Value Consideration

Buildings that are significantly older may have heritage value regarding the preservation of the components for either reuse or resale. This framework is not intended to designate historical, heritage infrastructure that might be protected by law. Instead, the focus of this framework is to help to identify the potential of components in terms of their heritage value, either as part of the infrastructure or as marketable resources that can be used as a building component elsewhere.

As an example of how this heritage potential can be assessed, the Government of Canada has a technical guide for assessing the physical and cultural heritage of structures, sites, or objects [22]. According to this source, the heritage value of structures can originate from the following criteria:

(i) Is the structure associated with an important part of human history or culture?
(ii) Does the structure have historical, archeological, paleontological, or architectural significance?
(iii) Has the structure been involved in the practices, traditions, or customs of a particular group?

This is a brief overview of heritage, and, depending on the structure, it may require a more in-depth assessment depending on whether the structure could possibly be protected under regional heritage protection legislation. Globally, the determination of heritage value can vary depending on the region. Parallel approaches exist in other international jurisdictions: for example, in the United Kingdom, Historic England has a Conservation Principles Policies and Guidance document, which discusses the assessment of heritage significance and considers several types of value, such as evidential, historical, communal, and aesthetic value [25].

An environmental assessment would consider how a project can cause changes to the environment and how those changes affect the heritage of a structure, site, or object [22]. In Stage 3, the auditor may not choose to conduct a complete environmental assessment, but rather consider the general scope of the structure regarding components with heritage, historical, or cultural significance. Heritage value can influence the final decision and should be considered in Stage 4. In the reclamation framework's stages (Figure 3), Stage 3 presents heritage value criteria from a Government of Canada source [22]; however, it can be assessed based on criteria or frameworks from another region depending on the location of the project. It should be noted that certain structures may be protected under certain heritage acts or legislation, and, as a result, in certain circumstances, legal mandates may supersede any proposed actions from this framework. However, the framework may still be helpful in contextualizing issues not affected by legal mandates.

4.4. Stage 4: Final Decision

The final stage involves reviewing the entire framework and determining a final deconstruction timeframe. Stage 1 provides a recommendation based on technical feasibility, Stage 2 evaluates the project budget and timeframe, and Stage 3 considers the heritage value of the structure. The above factors must be considered simultaneously in Stage 4 to reach a final suggestion that considers multiple determining factors. Table 4 lists the different outcomes (A, B, C, and D), along with the determining factors in relation to the Stage 1 recommendation.

Table 4. Stage 4—final deconstruction outcomes.

Case	Determining Factor			Final Outcome/Course of Action
	Budget (Stage 2)	Timeframe (Stage 2)	Heritage (Stage 3)	
A	●	●	N/A	- Follow the Stage 1 outcome
B	⇧	⇧	N/A or ⇧	- Allocate more resources and/or time than the Stage 1 outcome
C	⇩	⇩	N/A	- Allocate fewer resources and/or less time than the Stage 1 outcome
D	⇩	⇩	⇧	- Allocate fewer resources and/or less time than the Stage 1 outcome, but emphasize preserving heritage components

As shown below, a circle indicates that the determining factor is sufficient to accommodate the action(s) for the case. An upward arrow indicates that there is a larger budget or more time to accommodate the action(s); conversely, a downward arrow indicates that there is a smaller budget or less time available to permit the action(s). An upward arrow for heritage indicates that there is high heritage value to be considered; however, there is no downward arrow because a lack of heritage value simply means that it is not considered—it would not affect any action(s).

As presented above in Table 4, Case A implies that the Stage 1 outcome is feasible. In this case, the budget and timeframe considered in Stage 2 are sufficient to allow for the technical recommendation, but they are not greater or less than what is required to extend or shorten the timeframe. Moreover, in this case, heritage value was deemed not to be a factor and therefore does not have an impact on the decision. As a result, the final course of action (Stage 4) is to follow the level of deconstruction outcome obtained from the assessment tool in Stage 1.

Case B implies that the budget and project timeframe are greater than needed to fulfill the Stage 1 recommendation. This allows for an extended deconstruction timeframe and allows the auditor to allocate more time than the Stage 1 outcome from the technical feasibility assessment. High heritage value may or may not influence this decision.

Case C implies that the project budget and timeframe are too small to follow the suggested outcome from Stage 1. In this case, heritage value does not have an impact on the outcome. Since the project timeframe and budget are not suitable for the technical feasibility recommendation, the user should choose to shorten the deconstruction timeframe in this case and allocate less time than in the preferred Stage 1 outcome. Note that the tool presumes complete demolition, with no effort to recover materials, to be the most basic outcome. Case C therefore considers situations in which more involved actions for recovery are initially desired but, after incorporating budget and time constraints, may default to simply demolition.

Case D implies that the project budget and timeframe are too small to follow the technical outcome in Stage 1. This is the same as in Case C above; however, Case D has high heritage value. The user values the heritage of the structure; although the budget and timeframe do not allow for the Stage 1 suggestion, Stage 3 assigns importance to preserving certain heritage components. The practical outcome of Case D is that fewer resources and/or less time than desired may be allocated to preservation, but that there would still be a directed effort to recover meaningful items from the building. However, it is unlikely that all heritage-related goals would be met, and trade-offs would have to be decided—for example, targeting the heritage items that have the greatest market value. Note that the focus on heritage components could still be incorporated into other cases as well, even if the Stage 1 outcome is followed or extended in Case A or Case B.

5. Conclusions

To reduce the negative environmental impacts of the construction and demolition industry, there must be a shift towards normalizing the deconstruction of structures. Reclamation audits have the potential to significantly reduce and divert demolition waste. There are currently gaps in the available tools and guidelines involving reclamation assessments. The framework developed in this paper helps to promote the effective circulation of building materials by providing a scoring system after considering several factors, including the budget, timeframe, and heritage value, which influence the final outcome. This work supports the United Nations Sustainable Development Goals (UN SDGs) and can be used as a guide to obtain an initial suggestion regarding the feasibility of deconstruction. To achieve global waste reduction and diversion targets, there must be a greater focus on deconstruction and the effective circulation of building elements to extend their lifecycles and reduce the negative environmental impacts of the construction and demolition sector.

Author Contributions: Conceptualization, R.R.; methodology, M.S., E.T. and R.R.; formal analysis, M.S.; investigation, M.S.; resources, N.B.; data curation, M.S.; writing—original draft preparation, M.S. and E.T.; writing—review and editing, M.S., E.T., R.R. and N.B.; project administration, R.R., N.B. and E.T. All authors have read and agreed to the published version of the manuscript.

Funding: Funding has been provided partially through the NSERC Discovery Grant 2021-03389 and the University of Windsor ELEVATE program.

Data Availability Statement: The original contributions presented in the study are included in the article itself.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of the data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Government of Canada. Reducing Municipal Solid Waste. Available online: https://www.canada.ca/en/environment-climate-change/services/managing-reducing-waste/municipal-solid/reducing.html (accessed on 1 February 2024).
2. Deweerdt, M.; Mertens, M. *A Guide for Identifying the Reuse Potential of Construction Products*; Interreg North-West Europe FCRBE: Lille, France, 2020.
3. Delta Institute. *Deconstruction & Building Material Reuse: A Tool for Local Governments & Economic Development Practitioners*; Delta Institute: Chicago, IL, USA, 2018.
4. Government of Canada. Circular Economy. Available online: https://www.canada.ca/en/services/environment/conservation/sustainability/circular-economy.html (accessed on 2 August 2023).
5. Dsilva, J.; Zarmukhambetova, S.; Locke, J. Assessment of building materials in the construction sector: A case study using life cycle assessment approach to achieve the circular economy. *Heliyon* **2023**, *9*, e20404. [CrossRef] [PubMed]
6. *Waste Prevention: The Environmental and Economic Benefits for Canada*; National Zero Waste Council: Vancouver, BC, Canada, 2021.
7. Wang, T.; Li, K.; Liu, D.; Yang, Y.; Wu, D. Estimating the Carbon Emission of Construction Waste Recycling Using Grey Model and Life Cycle Assessment: A Case Study of Shanghai. *Int. J. Environ. Res. Public Health* **2022**, *19*, 8507. [CrossRef] [PubMed]
8. United States Environmental Protection Agency. *Deconstruction Rapid Assessment Tool*; United States Environmental Protection Agency: Washington, DC, USA, 2015.
9. European Commission. *Guidelines for the Waste Audits Before Demolition and Renovation Works of Buildings*; EU Construction and Demolition Waste Management; European Commission: Brussels, Belgium, 2018.
10. Saad, M.; Ruparathna, R.; Biswas, N.; Tam, E. Circular Economy in the Construction Industry: Reclamation Audits to Increase Material Reusability in Demolition Projects. In Proceedings of the Canadian Society for Civil Engineering 2024 Annual Conference, Niagara Falls, ON, Canada, 5–7 June 2024.
11. Wang, M.; Yao, G.; Sun, Y.; Yang, Y.; Deng, R. Exposure to construction dust and health impacts—A review. *Chemosphere* **2022**, *311*, 136990. [CrossRef] [PubMed]
12. Ahkola, H.; Junttila, V.; Kauppi, S. Do hazardous substances in demolition waste hinder circular economy? *J. Environ. Manag.* **2024**, *364*, 121362. [CrossRef] [PubMed]
13. Canadian Council of Ministers of the Environment. *Guide for Identifying, Evaluating, and Selecting Policies for Influencing Construction, Renovation and Demolition Waste Management*; Canadian Council of Ministers of the Environment: Winnipeg, MB, Canada, 2019.
14. United States Environmental Protection Agency. Sustainable Management of Construction and Demolition Materials. Available online: https://www.epa.gov/smm/sustainable-management-construction-and-demolition-materials (accessed on 20 August 2024).

15. Akinade, O.O.; Oyedele, L.O.; Bilal, M.; Ajayi, S.O.; Owolabi, H.A.; Alaka, H.A.; Bello, S.A. Waste minimisation through deconstruction: A BIM based Deconstructability Assessment Score (BIM-DAS). *Resour. Conserv. Recycl.* **2015**, *105*, 167–176. [CrossRef]
16. Akanbi, L.A.; Oyedele, L.O.; Omoteso, K.; Bilal, M.; Akinade, O.O.; Ajayi, A.O.; Davila Delgado, J.M.; Owolabi, H.A. Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. *J. Clean. Prod.* **2019**, *223*, 386–396. [CrossRef]
17. Janani, S.; Renuka, S.; Umarani, C. Quantification of the deconstruction potential of buildings with innovative connections using BIM based DAS (Deconstructability Assessment Score) tool. *Mater. Today Proc.* **2022**, *65*, 1964–1975. [CrossRef]
18. Urban Sustainability Directors Network. Encouraging and Mandating Building Deconstruction. Available online: https://sustainableconsumption.usdn.org/initiatives-list/encouraging-and-mandating-building-deconstruction (accessed on 20 August 2024).
19. Guy, B. Building Deconstruction Assessment Tool. In Proceedings of the CIB Task Group 39—Deconstruction Meeting CIB World Building Congress, Wellington, New Zealand, 6 April 2001.
20. Guy, B.; Ohlsen, M. Creating business opportunities through the use of a deconstruction feasibility tool. In Proceedings of the 11th Rinker International Conference, Gainesville, FL, USA, 7–10 May 2003.
21. Toufeili, R. Life Cycle Thinking Based Methodology for the Evaluation of Building Energy Retrofits. Master Thesis, University of Windsor, Windsor, ON, Canada, 2019.
22. Government of Canada. Technical Guidance for Assessing Physical and Cultural Heritage or any Structure, Site or Thing. Available online: https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/technical-guidance-assessing-physical-cultural-heritage-or-structure-site-or-thing.html (accessed on 7 August 2024).
23. United States Environmental Protection Agency. Best Practices for Reducing, Reusing, and Recycling Construction and Demolition Materials. Available online: https://www.epa.gov/smm/best-practices-reducing-reusing-and-recycling-construction-and-demolition-materials#:~:text=Using%20durable%20materials%20that%20are,instead%20of%20sealants%20and%20adhesives (accessed on 1 August 2024).
24. Habitat for Humanity ReStore. Available online: https://www.habitat.org/restores (accessed on 5 August 2024).
25. *Conservation Principles Policies and Guidance for the Sustainable Management of the Historic Environment*; Historic England: London, UK, 2008.