Circular Economy Design towards a Resilient Zero Waste Future

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Striving to be more resilient, the city of Montréal, is aiming to reduce the amount of waste it generates. Like many cities worldwide, the goal is to achieve zero waste towards meeting the Paris Agreement Goals. One major component of urban waste flows is construction, demolition, and renovation (CRD) waste. Globally, CRD waste accounts for approximately 100 billion tons of generated waste annually with about 35 percent of that sent to landfills[1]. In Canada, CRD waste represents 20-30% of the solid waste stream by weight[2]. However, research shows that innovative waste management approaches could deliver significant reductions in waste. One such promising approach is that of circular economy (CE) which envisions a resilient future where CRD waste is designed out of the built environment by keeping construction materials in use. This research project seeks to minimize CRD waste by answering two questions: (1) Which circular economy principles and methods could be effective in ensuring sustainable CRD material management for Montréal; and (2) What kind of stakeholder partnerships are necessary to advance towards zero CRD waste? A series of methods for data collection are outlined, a BIM model of typically housing typology is used as a means to understand the composition of materials in the housing stock of Montréal, finally collected data is mapped and organized using data visualization methods. The research holds significance in providing the most pertinent circular economy best practices to building related CRD material recovery for future use architecture and carbon preservation.

INTRODUCTION

A circular economy (CE) aims to *"design out waste and pollution; keep products and materials in use; and regenerate natural systems"* . Such an approach encourages a paradigm shift away from the current status quo linear material throughput economy as illustrated in Figure 1. A linear economy enables a culture of *take-make-waste*. A CE promotes resilient built environments which aim to benefit human health, economic growth and the environment. Existing and emerging scholarly and grey literature in the area of circular materials management outline effective measures and guidelines for achieving CRD recovery[3-5]. However, the fragmented and disjointed nature of data and information regarding circular CRD materials management, makes strategic evidence-based decision-making particularly difficult for those developing zero waste plans[6,7]. To assist decision-makers and help in mobilizing collaboration across a wide range of stakeholders, the goal of this proposed research is to deliver a simplified and organized format for what is now a complicated web of fragmented streams of data.

This paper presents a series of methods used to collect and organize data towards advancing circular thinking within CRD material management decision-making in Montréal and mobilizing engagement with the relevant data. Relevant data and information entails: i) identifying the materials most pertinent to Montréal CRD waste stream, ii) understanding the 'materials banks' potentially available in Montréal housing stock, iii) gaining knowledge by mapping the CRD waste flows in Montréal. Subsequently, the collected data and information is organized and visualized towards identifying circular methods most pertinent to tackling CRD waste recovery in Montréal. The next section highlights the research problem being addressed including our research questions as well as the objectives of the study.

RESEARCH PROBLEM AND OBJECTIVES

The objective of this proposal is to stimulate CE principles across the built environment value chain to significantly reduce CRD waste. It will focus on the research domain of data visualization as a key enabler of circular CRD materials management decision-making. Identifying the data critical in supporting such evidence-based decision-making involves a deep understanding of the key challenges facing both CRD recovery and the transition to a circular approach. Hence, the proposed project strives to answer the following research questions:

<u>How best can CRD waste be eliminated?</u> CRD waste is a by-product of an entrenched linear throughput material economy. A CE offers a new paradigm where waste is designed out. However, transiting from a linear to a CE requires data that clearly outlines the environmental, social, and economic

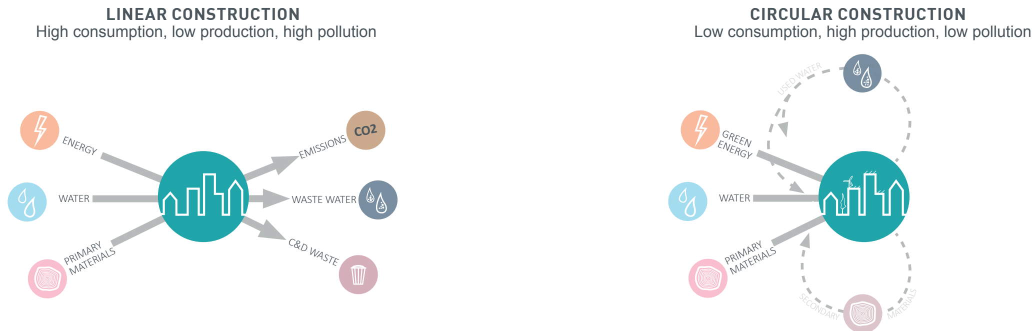

Figure 1.Difference between linear and circular economy construction. Source: Keena and Dyson, 2020, Graphics: Ninni Westerholm.

impacts of current conditions, versus those of potential circular alternatives. Taking the current Montréal context as a baseline, a key objective of this research is to demonstrate the potential benefits of taking a life cycle approach in redesigning CRD materials management. It will do this through various data collection methods, mapping of the context, and modeling the existing housing stock to understand the materials composition of housing in Montréal.

Which CE principles and methods are most relevant and effective in ensuring sustainable CRD material management design and implementation for Montréal? A key obstacle to CRD waste recovery is the varying quality of construction materials at end-of-life stages[8]. This hinders the ability to successfully recover materials for reuse, repair or remanufacturing, rather than merely recycling or downcycling, or as a last resort landfill. Coupled with this, the composite nature of many construction assemblies increases the difficulty with which to prise materials apart at the renovation or deconstruction phase[9]. Here the role of architecture is critical as it is the architect who chooses materials and designs construction assemblies. Ultimately, such upstream design choices determine the possibilities which are feasible at end-of-life, such as the potential for materials to have second and third life cycles. Given that waste is a design flaw, this research project investigates the CE measures, including state-of-the-art precedents, which successfully design out CRD waste with a focus on each stage in the material life cycle. Depending on the material types most pertinent to the Montréal CRD waste stream, different circular strategies can inform design choices at the early design stages, e.g. design for disassembly, modular construction, the use of biodegradable materials and material passports. Therefore, another key objective is to raise awareness of best practices and principles of circular design among the local building sector design community. Such information is compiled and visualized.

What kind of stakeholder partnerships will it take to advance towards zero CRD waste? Tackling problems associated with CRD waste and shifting towards a circular approach requires a change in mindset and built environment culture which traditionally is siloed and conservative[10]. Multi-stakeholder engagement and collaboration is crucial. By mapping the current material resources within Montréal in ***Circular CRD***, this project aims to reveal the potential for material exchange. It also highlights key collaborations necessary for the success of such exchange.

These research questions are in keeping with key principles outlined in Montréal's master plan "***Montréal, objectif zéro déchet***"[11], to guide and enable CRD waste recovery. These principles involve (1) stimulating a circular economy and (2) mobilizing relevant stakeholders. To advance these principles, accessible and reliable data on the current status of CRD waste in Montréal is necessary. The next section outlines the theoretical approach this research has employed which informed the methodological approach used to collect and visualize relevant data.

THEORETICAL APPROACH

The theoretical approach of this research proposal involves considering the built environment process (BEP) (pre-building, building, post-building) through the lens of material life cycle (i.e. encompassing the initial material extraction, manufacturing, construction, operation and final deconstruction), with a particular focus on the end-of-life phases where CRD activities reside[12-14]. When we frame the BEP in this way certain assumptions become apparent. This framing highlights the environmental impacts of our built environment but also the organizational barriers throughout the BEP. According to the U.S. Department of Energy[15], the compartmentalization and lack of communication between building professionals in each sector results in suboptimal designs and less than optimal building operations while contributing to environmental impacts. A McKinsey report[16] echoes this view, explaining that unlike other sectors, such as manufacturing and transportation which now operate more as ecosystems, the building sector continues to operate within siloes. It predicts that faced with sustainability demands such as the need to reduce waste, the

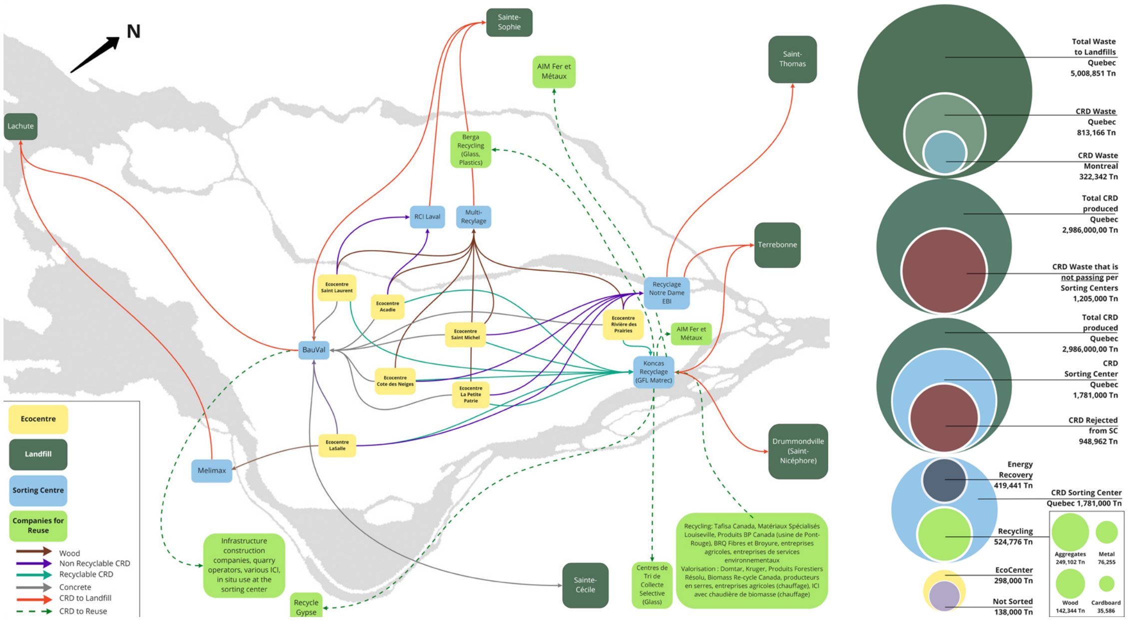

Figure 2. Mapping of CRD flow for Montréal metropolitan area and quantitative data for CRD in Quebec. Image courtesy of authors.

sector will need to reassess such rigid organizational structures. These observations help explain a number of current innovations in the field of architecture which revolve around the adoption of CE approaches. By asserting more agency over the entire life cycle, rather than solely the 'pre-building' phase, a shift is occurring in the field of architecture with architects, such as 'Rotor Deconstruction' and 'Lendager Group', creating circular organizational structures for 'urban mining', i.e., deconstructing, collecting and reusing construction materials. The logistical challenges which disrupted supply chains during the current Covid-19 pandemic, stress the challenges faced with managing material flows and the necessity for operational agility to respond to societal, economic, and environmental shifts. CE marries the concepts of (1) taking a life cycle approach and (2) promoting engagement of different actors across the entire life cycle. Employing CE as a key theoretical grounding, this research project questions if transitioning away from a linear throughput material economy to a circular one can build resilience allowing for adaptability in the face of future changing landscapes.

METHODOLOGY

To answer this project's research questions, the following methods were followed 1) collecting relevant pilot data, 2) mapping and modeling, 3) engaging a wide range of stakeholders via semi-stuctured interviews. Finally, all data was organized, integrated and visualized towards disseminating key findings of best CE practices for building materials recovery. These methods are described in detail below.

1. COLLECTING RELEVANT PILOT DATA

Firstly, a detailed literature review will be carried out investigating scholarly articles; grey literature; reports from building sector professional bodies; as well as key global, federal, state and local government reports and datasets.

From this lit review we could map the waste streams in Montréal from companies that promote material reuse, to recycling in Eco centers and Sorting centers to landfill sites which are located outside the city, as illustrated in Figure 2. This mapping helped us in understanding the organization structure of CRD waste. But also, that in terms of recycling four materials dominated: aggregates, metals, wood, and cardboard. Hence, it became clear that the collected CRD data thus far, included other construction sectors beyond just buildings. The next step was to focus on narrowing the scope of our data to CRD materials from buildings with a focus on housing. This step allowed for an understanding of the CRD associated with the building sector.

2. MAPPING AND MODELLING

In 2021 Statistics Canada reported that 62% of Canadian homeowners planned a home renovation and that figure was 59% in Montréal[17]. By examining CRD in buildings, where a lot of renovation is happening in Montréal, the goal was to identify the building materials most pertinent to Montréal CRD waste stream. A detailed investigation was conducted of Montréal's housing stock. Examining the residential buildings of Montréal revealed that over 78% are attached homes of 5 storeys or less.

By developing BIM models of these archetypical houses and noting their construction types etc. the following materials were identified as most pertinent to Montréal CRD waste stream as illustrated in Figure 3 and the quantities of these materials were ascertained by volume, mass, and embodied carbon impacts. Two key CE scenarios were identified: reuse

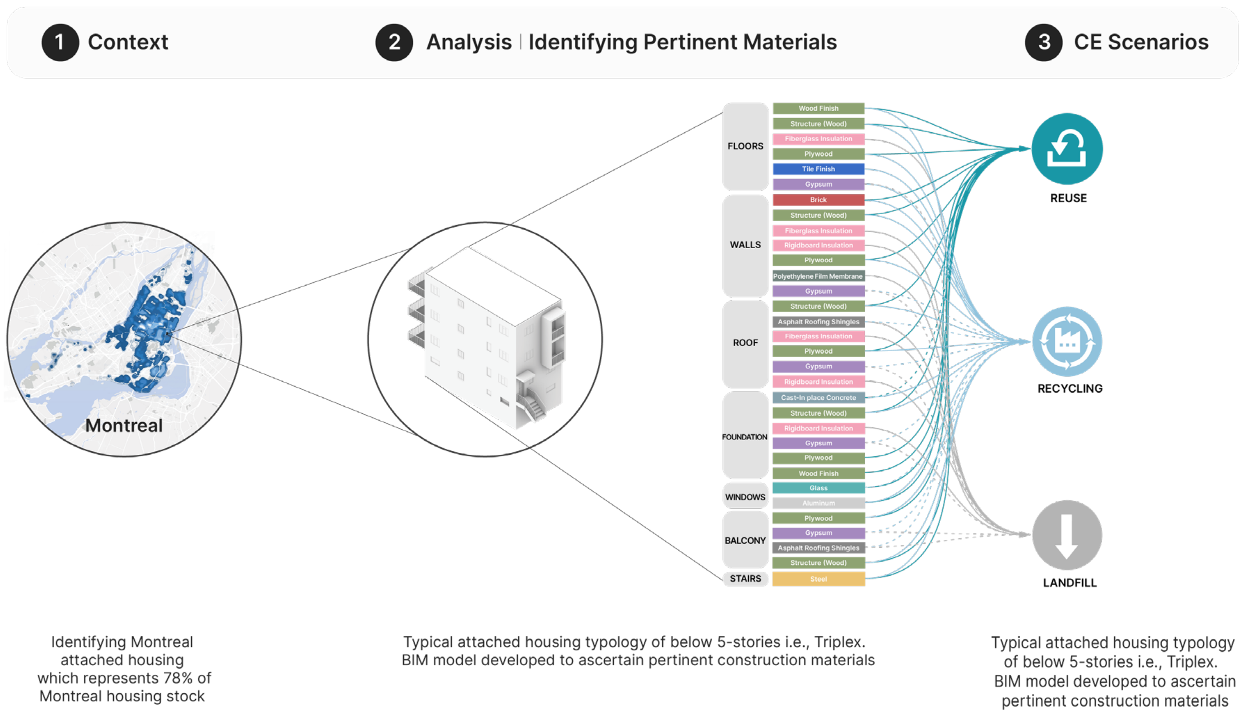

Figure 3. Identifying the material composition of a typical montréal housing type and the potential circular scenarios for buildings at end of use phase. Image courtesy of authors.

and recycling. Given that incorporating CE scenarios of reuse and recycling relies on the communication and involvement of stakeholders from across the building value chain. The next step was to talk to stakeholders across the value chain to understanding these two processes in the context of Montreal. As is outlined in the next method, this highlighted the importance of mobilizing relevant stakeholders and the need for stakeholder partnerships.

3. ENGAGING A WIDE RANGE OF STAKEHOLDERS VIA SEMI-STRUCTURED INTERVIEWS

This next method involved conducting a series of semi-structured interviews with multiple building sector stakeholders including policymakers, designers, contractors, end-of-life contractors, waste haulers, reuse organizations, developers, citizen groups and CE experts. Detailed description of these semi-structured interviews including a thematic analysis is reported elsewhere[18] and beyond the scope of this paper. However, as a brief overview, the thematic analysis involved categorizing the stakeholder groups and mapping their relationships within the building environment ecology. Collecting and analyzing this information from various viewpoints, allowed for the generation of a series of scenarios for rethinking CRD waste comparing landfill, recycling and reuse and investigating opportunities to integrate key circular design principles in an aim to close the resource loop. The different processes needed for each scenario were broken down by material type. It highlighted the different stakeholders needed to be involved in the circular options of recycling and reuse. This means at the end-of-use phase of a building, it's not just end-of-use constructors and waste haulers who are involved but other upstream life cycle stakeholders. As outlined in the paper refernced above[18], the challenges with each method per material type were also studied. Key findings from the semi-structured interviews were incorporated into the data set discussed here.

RESULTS

IDENTIFYING THE MOST PERTINENT CE PRINCIPLES ACROSS THE BUILDING LIFE CYCLE

The results of compiling our data on the case of Montréal, as well as precedents from around the world on novel circular methods, aimed to answer our research questions of how can novel circular methods be used in the building sector to tackle CRD waste recovery? As illustrated in Figure 4, effective CE principles involve first extending building lifespans, thereby reducing the embodied carbon expended over the life of the building. So adaptive reuse of buildings enhances longevity. During a new construction phase non-virgin building components can be incorporate and reused. This is where during construction phases, design for disassembly and modular construction can enable dismantling at the end of life to retain the building elements value and potential for reuse. Coupled with this, studies show that digitalization in the construction process towards prefabrication and modular construction has also been proven to reduce waste by 23-100 percent [1,19,20]. Non-virgin materials can be reused and often this involves bringing them back to the component manufacturer for maintenance and repair or quality assessment. The same goes for the material processing phase, where recycled materials can become the feedstock for the production of new construction materials. But with each of these options there is a progressive loss in the material's initial value and /or a need for further processing as you move down the life cycle.

ORGANIZING, ANALYZING AND VISUALIZING THE COLLECTED DATA TO HIGHLIGHT OPPORTUNITIES FOR INTEGRATING CIRCULAR DESIGN PRINCIPLES

Using the BIM model of the typical attached house in Montréal, we considered the potential CE scenarios and highlighted the most likely processes and the potential to design-out-waste which we concluded are based on three key aspects: 1) the material type, 2) the material use in the building, and 3) the service life of a material. This is highlighted in Figure 5. Using a reinterpretation of the Steward Brand diagrams, Figure 5 illustrates the materials from the Montreal BIM model and the potential service life of the materials or building components as follows: foundations 100+ years; structure 50+ years; exterior façade materials 25+ years; building systems 15+ years; interior partitions 10+ years; all 'things' within a building including furniture, fixtures and fittings 1+ years. The idea here, is that the use of material determines its service life. For exmaple, occupants typically change furniture (due to their agency over it) more frequently than foundations or structural systems which can last for hundreds of years. A key circular principle is to extend the service life of materials, building components, and buildings themselves with practices such as conservation and adaptive reuse.

One of the key challenges that many stakeholders addressed is the timeframe of a building. If we are to use secondary or recycled materials in a renovation or new construction, the materials have to be available and depending on the use of a material, it will have a different service life. As described above, structural materials can last 50+ years but materials used for fixtures and fittings can have a shelf life of one year or more. Hence, we looked at the vintages of Montréal housing and the construction types associated with those vintages. This information was mapped to explore the potential timelines when materials are to become available assuming the material and component service life described above and shown in Figure 5. Vintages of Montréal housing stock are typically defined as follows in line with census data:

Vintage of Housing	Construction Typology
Before 1920	Quebec (QC) Plank Frame w/ load bearing Masonry
1920-1950	2 x 4 Balloon Frame w/ Brick Cladding

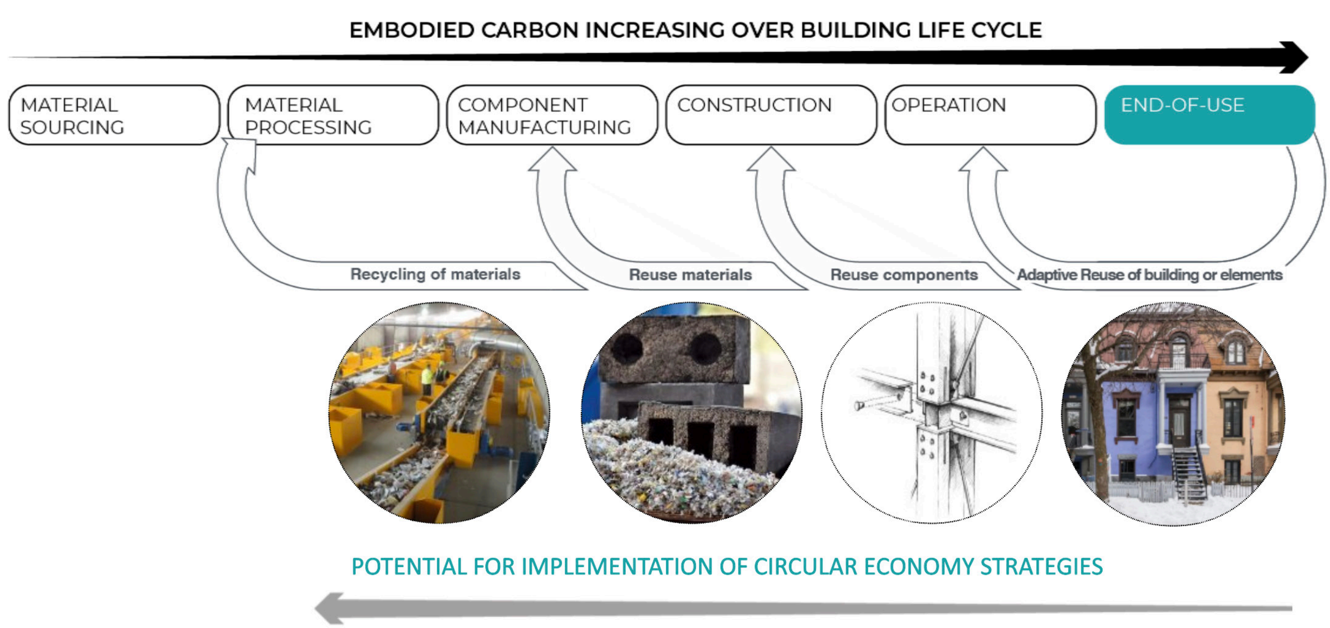

Figure 4. Compiling research and precedents on novel circular methods used in the building sector to tackle crd material recovery. Detailed analysis of potential circular economy strategies and methods for use in the building sector to tackle CRD material recovery and level of environmental preservation or life extension. Image courtesy of authors.

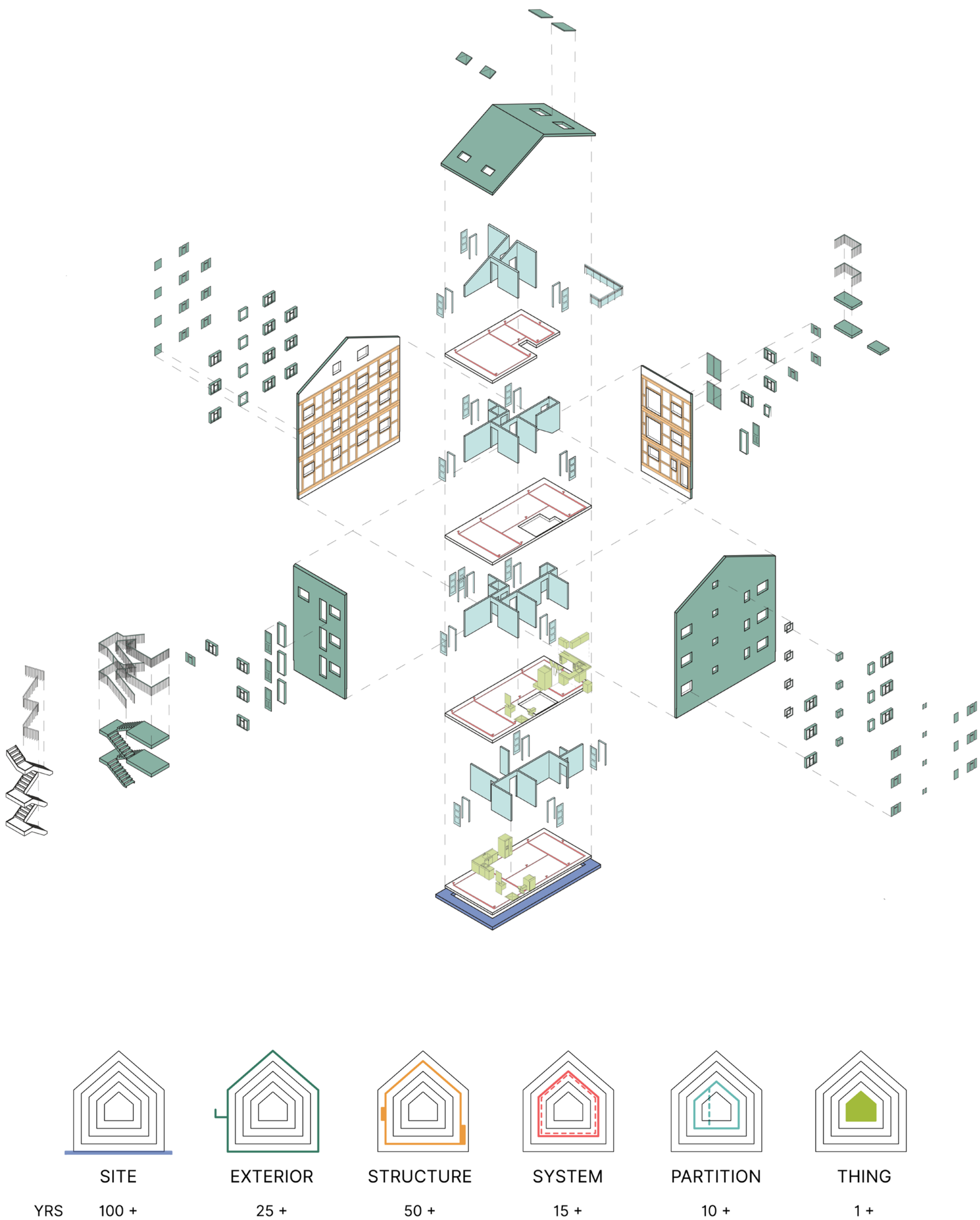

Figure 5. Image caption. Image courtesy of authors..

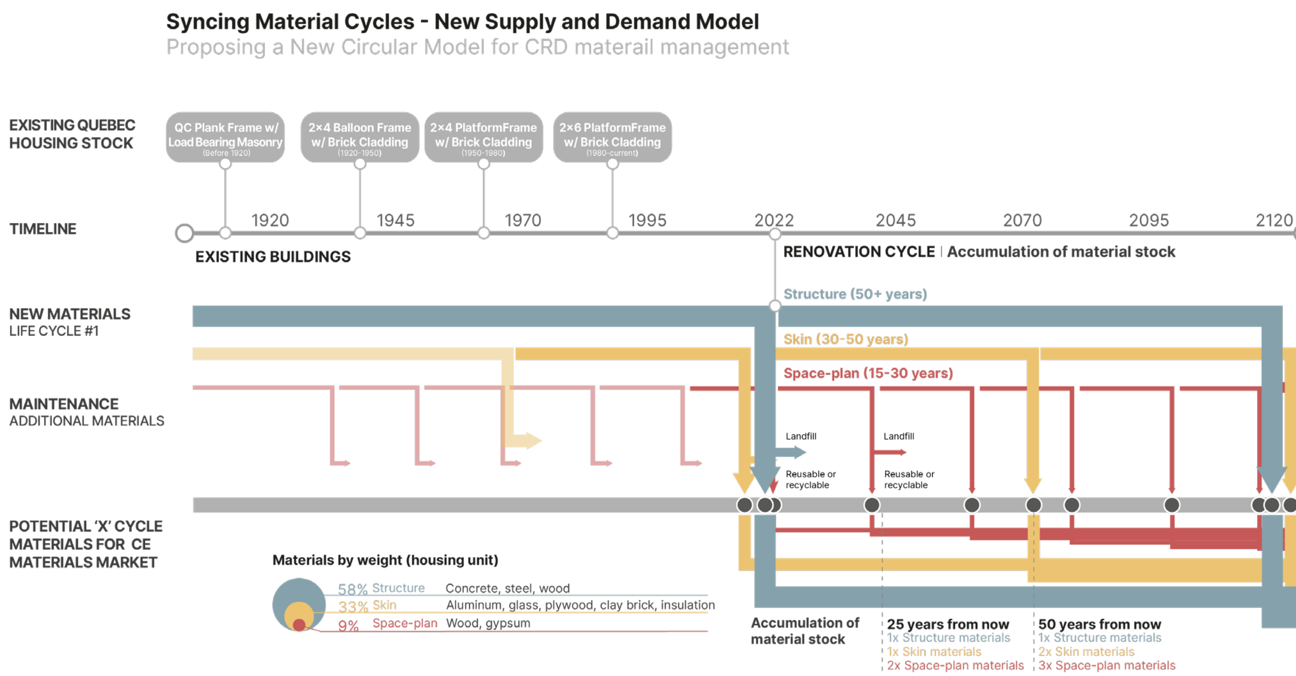

Figure 6. Syncing material cycles – a new supply and demand model. Proposing a new circular model for CRD material management. Image courtesy of authors.

1950-1980	2 x 4 Platform Frame w/ Brick Cladding
1980-current	2 x 6 Platform Frame w/ Brick Cladding

As illustrated in Figure 6, in order for circular thinking to occur a rethinking of the supply and demand model for materials and components needs to be considered where there is a syncing of material cycles. This will take the work of governments and policy-makers to create policies which stimulate and catalyse major increase in the reuse of construction products and materials. Along with improved high-quality recycling, optimizing building material standards and legislation for how to deal with materials on the construction site and at the end-of-use phase is vital. Such policies can support measures to stimulate market demand so that reusable and secondary materials are easily accessible and accepted by clients. Having a major increase in the number of conveniently located reuse and recycling facilities with state of the art technologies will be an important first step.

CONTRIBUTIONS

Advancing towards zero CRD waste in Montréal will require the input of multiple stakeholders. This research paper is part of a larger research effort which works to deliver an initial but vital first step in the collection, integration, and dissemination of data towards a circular, more resilient built environment. The work strives to help in identifying the key circular measures and the range of stakeholders necessary to advance towards zero CRD waste. It outlines where is best for these measures to take place along the building life cycle.

Key research contributions and future work involve a decision-making framework with web-presence piloted for the city of Montréal. The goal is to help mobilize key stakeholder engagement and shed light on opportunities for new research, industry, or knowledge sharing partnerships, that may not yet exist.

The second contribution is to the emerging field of circularity in the built environment. Although piloted for the city of Montréal, the new proposed methodology to integrate and visualize CRD data in a holistic way that makes it useful and actionable, is intended to be widely applicable to the field.

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