State of Play for Circular Built Environment in North America

Countries considered: United States of America

Author: Naomi Keena and Anna Dyson
Organisation: Yale Center for Ecosystems in Architecture, Yale University

Reviewed by: Emily Walport, Senior Engineer, Materials, Advanced Technology + Research, Arup, USA
Prof Usha Iyer-Raniga, RMIT University, Australia

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One planet build with care

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One Planet Network

The One Planet network has been formed to implement the 10-Year Framework of Programmes on Sustainable Consumption and Production (SCP), which supports the global shift to SCP and the achievement of SDG 12. The One Planet Network acts as an enabler bringing actors from all regions to pool their expertise, resources, innovation and commitment towards a shift to more sustainable modes of production and consumption. The network comprises of six programmes: Sustainable Public Procurement, Sustainable Buildings and Construction, Sustainable Tourism, Sustainable Food Systems Programme, Consumer Information for SCP, Sustainable Lifestyles and Education.

Sustainable Buildings and Construction Programme

The Sustainable Buildings and Construction Programme (SBC) aims at improving the knowledge of sustainable construction and to support and mainstream sustainable building solutions. Through the programme, all major sustainable construction activities can be brought together under the same umbrella. The work involves sharing good practices, launching implementation projects, creating cooperation networks and committing actors around the world to sustainable construction. The goal of the programme is to promote resource efficiency, mitigation and adaptation efforts, and the shift to SCP patterns in the buildings and construction sector.

State of Play Reports

The Sustainable Buildings and Construction Programme has been preparing regional reports on the state of play for circular built environment in Africa, Asia, Europe, Gulf Cooperation Council countries, Latin America and the Caribbean, North America and Oceania. In addition to regional outlooks, a global report has been produced to summarise and compare the state of play regarding circularity in different regions. A crucial part of the reports are to not just provide a benchmark but also recommendations on how to move forward towards a sustainable and circular built environment.

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List of acronyms

AGC	Associated General Contractors of America
AIA	American Institute of Architects
AMP	Advanced Manufacturing Partnership
BD+C	Building Design and Construction
BEA	Bureau of Economic Analysis
BIM	Building Information Modeling
C&D	Construction and demolition
CORR	Certification of Recycling Rates
COTE	Committee on the Environment
CRI	Carpet and Rug Institute
EIE	Energy Information Administration
EMF	Ellen MacArthur Foundation
EPA	Environmental Protection Agency
EPD	Environmental Product Declarations
FSC	Forest Stewardship Council
GHG	Greenhouse gas
GND	Green New Deal
ID+C	Interior Design and Construction
IPCC	Intergovernmental Panel on Climate Change
IRC	Internal Revenue Code
IRP	International Resource Panel
LCA	Lifecycle Analysis
LEED	Leadership in Energy and Environmental Design
MMBTU	Millions of British Thermal Units
MMTCO2E	Million metric tons of carbon dioxide equivalents
MR	Materials and Resources
MSW	Municipal solid waste
MTCE	Metric tons of carbon equivalent
MTCO2E	Metric tons of carbon dioxide equivalent
NIST	National Institute of Standards and Technology
NYC	New York City
NYCEDC	New York City Economic Development Corporation
O+M	Operations and Maintenance
OECD	Organisation for Economic Co-operation and Development
PBT	Persistent Bioaccumulative and Toxic
PPA	Purchase agreements
RCRA	Resource Conservation and Recovery Act
REI	Recycling Economic Information
SAN	Sustainable Agricultural Network
SMM	Sustainable Materials Management
UN	United Nations
US	United States
US OMB	UA Office of Management and Budget
USGBC	US Green Building Council
USGCRP	US Global Change Research Program
USGS	US Geological Survey
VOCs	Volatile organic compounds
WARM	Waste Reduction Model

Executive Summary

Approximately 80% of US human-caused GHG emissions are associated with urban areas where the majority of the US population lives and most consumption occurs, despite only occupying 1–5% of the US land area. Future prospects for increased urbanisation within the US, implies both new construction and renovation to existing urban fabric. Such development relies on the use of construction materials. The US has an entrenched linear material throughput economy with a long-established process of material extraction, manufacturing, transportation, construction, building maintenance and material waste during deconstruction. Material consumption and associated waste are growing. In terms of material extraction, in 2012 construction materials represented 73% of all U.S. raw materials (excluding fuel or food). And in recent years, the US has been the 2nd highest global producer of municipal solid waste – more than half of which goes to landfill. Transitioning away from a linear throughput economy to a circular one offers an alternative where material efficiencies are improved primarily by closing the resource loop.

Circular thinking is evident in the US. The US Environmental Protection Agency adopted ‘Sustainable Materials Management’ as a regulatory framework for managing materials where a strong preference for resource conservation over disposal is established. In addition, federal legislation, such as the *Revitalize American Manufacturing and Innovation Act* (RAMI Act), promotes innovative circular manufacturing and implementation, helping to bridge the gap between academic research and established industry partners.

A number of key enablers towards circular built environments in the US are offered. Evidence suggested that building certification programmes act as cross-cutting policy instruments. US Green Building Council’s ‘Leadership in Energy and Environmental Design’ programme has been adopted and promoted by state and local governments across the US. Design and life cycle thinking is encouraged by the American Institute of Architects’ ‘Framework for Design Excellence’ which offers circular design measures, high-impact strategies and case studies.

Transitioning to a circular built environment requires the design of multi-beneficial policies that take a whole building life cycle and systems-thinking approach. Such policies would enable multi-stakeholder engagement and cross-industry collaboration. Technology and big data have a role to play in helping to establish collaborative networks with efficient construction practices which track material flows across the building life cycle. As climate pressures increase and material scarcity is imminent, systems thinking and innovation in material recovery will be critical to helping ensure the built environments of North America embrace a circular future.

1. Introduction

Given global projections for increased urbanisation and economic development, the overloading of our geo-biosphere upon which such development depends is increasingly at the forefront of international dialogue. In order for economic growth to continue without compromising human health and the environment, the International Resource Panel (IRP, 2020) points out that material use must be decoupled from economic growth and the management of material across its entire lifecycle must be reconsidered.

Within the United States (US) built environment sector, construction materials account for 73% of all raw materials used in the US (not including fuel or food) (Matos, 2017) and construction and demolition (C&D) waste accounts for 25–45% of the country's solid waste stream by weight (Miflin et al., 2017).

This report provides an overview of the current state of play of circular economy in regard to material use in the built environment in the US, North American region. It identifies frameworks, programmes, policies and incentives that encourage a shift from the current status quo linear throughput material economy, to a more circular approach where the use of materials throughout their lifecycle is re-evaluated. The research presented is based on a detailed literature review, including grey literature; reports from building sector professional bodies; as well as key global, federal, state and local government data sources.

The report begins by outlining the environmental and logistical challenges posed by increased urbanisation and the need for greater volumes of materials for construction and maintenance. Within this context it highlights the significance of a circular economy approach. Section 3 looks at the impact of the built environment on the environment and the linkages between economic development, material use and construction activities. Section 4 explains current waste management strategies, especially in regard to C&D waste. Section 5 outlines policies at play within the US in regard to waste management; among others, it highlights the role of the US Environmental Protection Agency (EPA) in establishing the Sustainable Materials Management (SMM) regulatory framework. Section 6 examines various incentives from the government to the local level, as well as incentives provided through rating and certification programmes, such as Leadership in Energy and Environmental Design (LEED) developed by the US Green Building Council (USGBC), which encourages a shift towards the use of biomaterials. Section 7 looks to the role of design in helping to promote a more circular approach, and introduces the Framework for Design Excellence developed by the American Institute of Architects (AIA), comprising 10 identified measures, among them 'Designing for Economy' and 'Designing for Resources'. It considers the trade-offs of retrofitting versus new construction in this region. Section 7 also considers new construction materials and methodologies that can lead to a more overall circular built environment process, including the role of technology and digitalisation in enabling circular economies (sharing mechanisms for materials and urban digitalisation) as well as digitalisation for productivity and waste reduction in aspects of the built environment process such as the construction sector.

The aim of presenting this research review is to set a baseline for the current state of play in the US in regard to circularity within the built environment. Ideally, it will be used as a springboard for further research and development of roadmaps towards reducing unsustainable material use in the building sector. It is also a means to share new concepts and methodologies that enable sustainable material management to be realised.

2. Significance of this work

Referencing the Special Report on Global Warming of 1.5 ºC produced by the Intergovernmental Panel on Climate Change (IPCC, 2018) and the national climate assessment of the US Global Change Research Program (USGCRP, 2018), the US Green New Deal (GND) highlights that the US economy could lose billions of dollars by the end of the century due to climate change effects. It states that, in 2018, carbon emissions rose by 3.4% in the US and 2.7% globally. It advocates for dramatically reducing greenhouse gas (GHG) emissions; creating high-paying jobs related to green technologies and resources; ensuring that clean air, clean water and healthy food are basic human rights; and eradicating all forms of oppression (Ocasio-Cortez, 2019). The goals of the GND require systemic change across environmental, economic and social systems. Section 2.2 explains how circular economy can foster systemic change, especially within the built environment, where such change would have large significance across natural, built and social systems.

2.1 Growing urbanisation increases the demand for construction materials

Urban areas are built environments that fundamentally rely on materials for their initial creation and subsequent maintenance and operation. The lifecycle of current building practices involves a chain of events from raw material extraction to building deconstruction, which fall within a throughput linear material economy. This linear lifecycle is unsustainable and contributes to prevailing environmental impacts. Business as usual simply cannot continue if we are to reverse the effects of climate change, especially in the face of rapid urbanisation. The United Nations 2018 Revision of World Urbanisation Prospects (UN, 2018) explains that the gradual shift in residence of the human population from rural to urban areas known as urbanisation, in conjunction with the overall growth of the world population, could add another 2.5 billion people to urban areas by 2050. That is equivalent to 68% of the global population living in cities by 2050 (UN, 2018). Based on the US Census 'Projected Population Size Figures for 2017-2060' (Colby and Ortman, 2015), the US population is expected to grow from 328 million to 404 million people between 2018 and 2060, an increase of 23%. The Census report also indicates that a significant proportion of this 23% are projected to live in urban areas. In the US alone, urban projections show that between 425 and 696 million people will be living in metropolitan and micropolitan areas combined by 2100 (USGCRP, 2018).

We can anticipate that, with growing urbanisation, there will be an increased need for construction materials. Many have raised concern regarding the development of buildings and supply of materials for new urban areas, given the current role of the building sector in exacerbating climate change effects. Globally, the building sector consumes 40% of the earth's natural resources, 40% of energy and 25% of water, and contributes to a third of global GHG emissions (IRP, 2017). Current linear, throughput material processes of extraction, manufacture, use and disposal cannot continue without significant environmental consequences. A circular built environment raises questions about the value of traditional throughput linear material economies, replacing them with a cyclical approach whereby material sourcing, design and use are all reimagined. The significance of the work outlined in this report lies in the fact that in order to avoid further destruction to our planet, new built developments in the face of rapid urbanisation must avoid unsustainable (often linear) material and construction practices, and a circular built environment offers a viable alternative approach. A circular economy, which decouples growth from the use of scarce and linear resource inputs (such as virgin materials and non-renewables), represents a solution that heeds environmental concerns and at the same time allows for healthy economic growth. The next section defines circular economy in the context of the built environment.

2.2 The potential of circular economy for the built environment

A circular economy, when applied to the built environment, seeks to improve material efficiency primarily by closing the resource loop and reducing material waste at the end of life of a material, component or building. Achieving circularity involves following a set of principles. The first principle, according to the Ellen MacArthur Foundation (EMF), is to 'design out waste and pollution'. The second is to 'keep materials and products in use'. Haas et al. (2015) describe these two principles, respectively, as 'reducing material use for the same service, more intensive use of existing products (e.g., sharing or selling the service instead of individual ownership), longer life, more repair, more reuse and improved material efficiency in the production process'; and as 'end-of-life recycling'. The third principle, per the EMF, is to 'regenerate natural systems'.

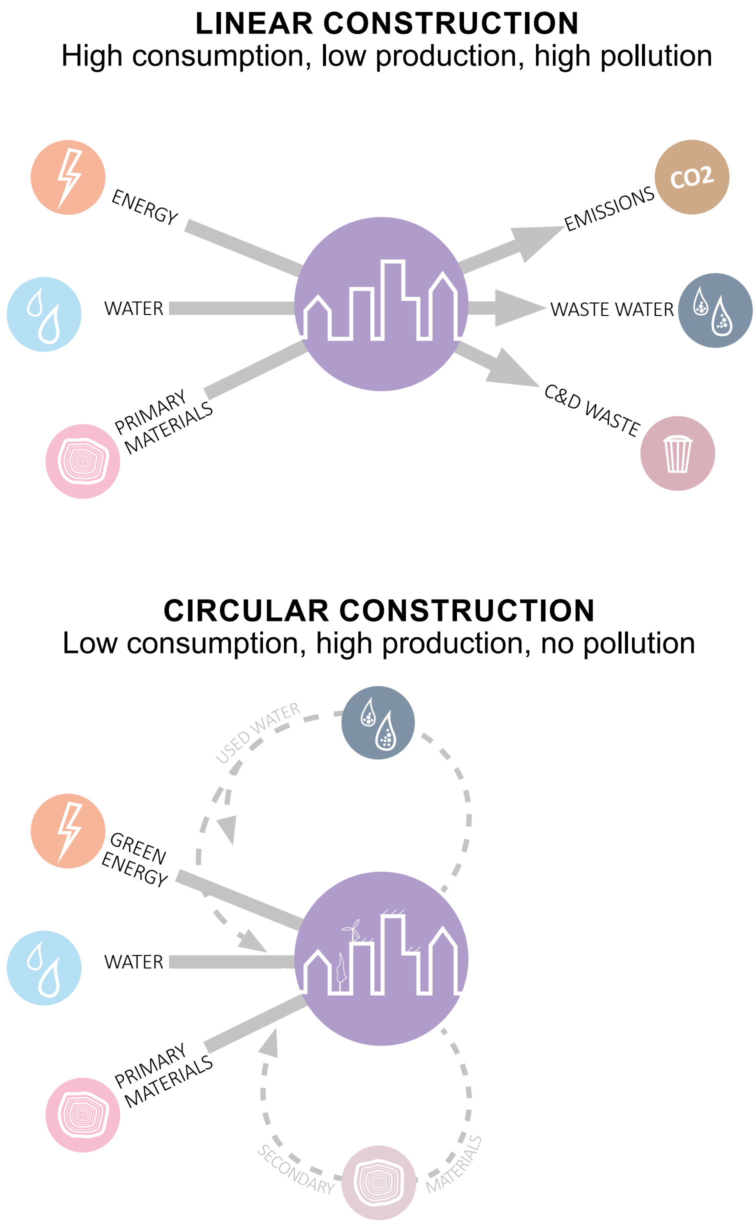

Figure 1: Difference between linear and circular economy construction

Source: Ninni Westerholm
Graphics: Ninni Westerholm

Failing to fundamentally challenge unsustainable mainstream approaches to the production and consumption of materials, and other integral supply chains in our built environment, hampers the capability to foster systemic change. The key to circular economy is that it takes a systemic approach in aiming to redesign an economy. Haas et al. (2015) point out that implementing circular economy principles, as outlined above, across the economy implies an extensive overhaul of the basic structure of industrial systems. In this regard, individual or incremental improvements to material efficiency, which are often environmentally ineffective and produce little economic savings, are surpassed by transformative and sustainable interventions that foster systemic change while still supporting economic growth. Along these lines, a circular economy approach to the built environment allows for a more networked or systems-thinking methodology, which helps in understanding relationships and the interaction and interconnection between various entities and associated impacts. Such a methodology is useful for considering an expanding scope or lifecycle of the built environment process – that is, pre-building, building use and post-building – in order to support the decoupling of material resources from economic growth towards reducing the building sector's environmental impacts. It is to be noted here that the 'built environment process' is a concept that has been introduced and defined by the authors elsewhere (Keena, 2017) and is used extensively throughout this report. In short, the built environment process refers to the pre-building, building and post-building life span of a built environment. It entails the flow of events that encompasses the extraction of materials, the manufacturing of materials, the construction process, the operational life of a building and the end of life of a building.

The next section discusses the US national approach to employing circular economy and why the circular economy rhetoric is not widespread in the US. It highlights areas where this approach is more dominant as well as areas where it is not, and explores the reasons in each case.

2.3 Why a circular economy approach is not prevalent in the US: an EMF perspective

In an interview published on the website *Medium* (Iles, 2018), Joss Bleriot of the EMF points out that it is difficult to motivate circular economy implementation within the US. The reasons for this, he suggests, involve the US context prior to the arrival of COVID-19, when economic growth was good and the unemployment rate was very low. In terms of energy production, the US is projected to become a net exporter by 2022. *The Annual Energy Outlook* 2018 (US EIA, 2018) report by the US Energy Information Administration (EIA) predicts that this move to exports will be primarily driven by changes in petroleum and natural gas markets, in particular the increased production of crude oil and natural gas production in the US. In terms of material flows, the expansive land mass of the US greatly facilitates the disposal in landfill of the unwanted by-products and waste associated with a linear economy. In contrast to other countries, such as many in Europe or Japan, where the lack of available resources and of space is a driver of moves towards a circular economy, these are not issues in the US, making the shift away from a linear economy less enticing. It is worth noting that, historically in the US, national environmental awareness is often associated with the 1973 Arab Oil Embargo, which resulted in an energy crisis in the US. This event led to a shift in built environment design thinking as well as greater awareness of the importance of resources efficiency. In terms of architecture, it spurred a movement towards 'ecological' and environmental design. Today, at the state and local government levels, in cities like New York and Phoenix and states like California, Colorado and Washington, there is an environmental consciousness and a move towards more sustainable practices to address the problems of the built environment, including circular economy activities, often driven by building certification systems, as outlined in section 7.

3. Impact of the built environment

This section investigates the structure of urban areas in the US, where the greatest proportion of the population lives. It highlights that, although US metropolises are responsible for the highest percentage of US GDP, being hubs for financial growth they are also the largest contributors to GHG emissions and environmental impacts in the country. The section continues by examining the built environment process in terms of the strong links between economic development, construction activity and demand for construction materials (Organisation for Economic Co-operation and Development [OECD], 2019).

3.1 Environmental consequences of urbanisation trends

Approximately 80% of US human-caused GHG emissions are associated with urban areas, despite only occupying 1–5% of the US land mass (USGCRP, 2018). As of March 2020, the population of the US was estimated at 331 million people, with 85% of the population living in metropolitan areas, according to the Worldometer algorithm that processes data collected from the United Nations Population Division (Worldometer, 2020). Los Angeles is the nation's densest urban area, at 6999 people per square mile (2702 people per square kilometre). The 2010 US census data revealed that the densest urban areas in the US, starting with the densest, were Los Angeles, San Francisco, San Jose, New York and Las Vegas. Forty-one urban areas in the US have an average density of 3245 people per square mile (1253 per square kilometre) (US Census Bureau, 2010; Cox, 2012). Urban projections for the US show that between 425 and 696 million people will be living in metropolitan and micropolitan areas (these classifications are discussed in section 3.2) combined by 2100. Many factors affect how urban areas are currently responding to climate change and how they plan to respond in the future.

Understanding of the relationship between growing urbanisation and human-caused GHG emissions is vital given that climate change effects are leading to extreme weather phenomena. Estimates indicate that the impact of a global temperature increase of 2 °C by 2055 would exacerbate extreme weather, rising sea levels and loss of ecosystems, among other impacts. A 1.5 °C temperature increase target is possible, according to the IPCC report of 2018; however, even with global warming of 1.5 °C there would be increased risks to health, livelihoods, food security, water supply, human security and economic growth. Furthermore, pathways limiting global warming to 1.5 °C require rapid and far-reaching transitions in, among other sectors, urban infrastructure including buildings, towards deep reductions in harmful GHG emissions, according to the IPCC report (2018). This forecast makes considering resiliency in the design of our built environment and new urban development even more pressing and highlights the value of a circular built environment. One aspect of resilient design and a circular approach involves reducing our reliance on the extraction of natural resources and intensive energy usage for the manufacture, transportation and construction of materials and buildings, which ultimately increase carbon emissions and exacerbate climate change effects. *The 2018 Fourth National Climate Assessment: Volume II: Impacts, Risks, and Adaptation in the United States report* (USGCRP, 2018), in which US federal scientists assess the effects of climate change, states that carbon emissions rose by 3.4% in the US in 2018, compared to 2.7% globally in the same year. This report reinforces that changes to urban activities with respect to construction materials and the built environment process can have significant effects on US GHG emissions, which could catalyse support for a circular economy approach to the built environment.

3.2 Relationship between economic development, urbanisation and the construction sector

An OECD report on the *Global Material Resources Outlook to 2060* (OECD, 2019) identifies a link between economic development, investment, construction activity and demand for construction materials. It states that 90% of global construction is for investment purposes and that the sector is projected to double in size between 2017 and 2060. This growth will primarily be to meet the demand for housing and infrastructure in the expanding cities of emerging economies, but also to address the maintenance demands of existing infrastructure in both OECD and non-OECD economies (OECD, 2019). Hence, although up to 90% of the global increase in urbanisation is set to occur in Asia and Africa, throughout the US urbanisation is also predicted to grow, as outlined in section 3.1, with current cities continuously changing, being retrofitted, upgraded and extended.

Within the US, cities house much of the population and account for a large proportion of the country's economic development. As stated above, current urbanisation statistics show that 85% of the US population lives in metropolitan areas, with 8% living in smaller micropolitan areas. The US Office of Management and Budget (US OMB) defines metropolitan (statistical) areas as standardised county-based areas that have at least one urbanised area with a minimum population of 50,000 and an adjacent region that consists of surrounding communities that are linked to the urban centre by social and economic factors (Baumgardner, Hinson and Panek, 2016). Micropolitan statistical areas follow the same concept as metropolitan areas, yet they consist of at least one urban core and have a population of between 10,000 (minimum) and 50,000 (maximum). Metropolitan areas are the centres of US economic growth, with land valued at trillions of dollars, accounting for approximately 91% of US GDP in 2015, despite only occupying 1–5% of the US land mass (USGCRP, 2018). Of the total US GDP, 23% comes from the five largest cities (Baumgardner, Hinson and Panek, 2016).

The built environment process is a key contributor to the US GDP, from mining and extractive processes for raw materials and energy resources, to the construction industry. GDP varies considerably across the US and is often classified by county size. The Bureau of Economic Analysis (BEA) highlights that the real GDP for 2018 ranged from USD18.4 million in Issaquena County, MS, to USD710.9 billion in Los Angeles County, CA. Due to this wide range, GDP is computed by county where results are grouped by county size, with large counties representing 141 counties with populations greater than 500,000 in 2018, medium counties representing 464 counties with populations between 100,000 and 500,000 in 2018, and small counties representing 2508 counties with populations less than 100,000 in 2018 (BEA, 2018, 2019). Across all three scales, the built environment sector contributes to national GDP, from the extraction of raw materials through mining to the activities of the construction industry (BEA, 2018, 2019). According to the US Geological Survey (USGS) Mineral Commodity Summaries (2020), the total value of industrial minerals production was USD58.2 billion in 2019, and 48% of this total value was attributed to construction aggregates production (that is, construction sand, gravel and crushed stone), of which 22% was crushed stone. This made crushed stone the leading nonfuel mineral commodity in the country in 2019. The USGS reported that an increase in construction activity in 2019 led to increased prices and production of some industrial minerals. Hence, the demand for construction materials and construction activities is a key driver of the US economy, and it can be anticipated that, with urbanisation growth, this demand will continue to rise.

Studies show that rising populations and economic growth are both key drivers of resource demand (Accenture, 2014). In terms of the built environment, research also reveals that there is a strong link between economic development and demand for construction materials

(OECD, 2019). As cities continue to grow globally and as the buildings and infrastructure in existing US cities continue to require maintenance, a greater demand is placed on construction materials. Business-as-usual manufacturing of construction materials, such as concrete and steel, typically relies on raw mineral extraction and energy-intensive processes. This is a problem as our capacity to use raw material resources is not infinite, our disposal culture leads to mounting waste and our current built environment processes are intrinsically linked to unfavourable environmental impacts and climate change effects.

The next section looks at the state of play of the global construction industry, and specifically at the challenges and opportunities facing the US construction sector. The construction sector in the US, which contributed 4.1% of US GDP in 2018, has much potential for greater productivity coupled with reduced environmental impacts. It is primed for change and circular economy approaches offer much opportunity for a potential way forward.

3.2.1 Construction sector: productivity, employment and environmental impacts

A 2017 McKinsey report by Barbosa et al. (2017) indicates that the construction sector is one of the largest in the world economy, accounting for 13% of the world's GDP. However, as the report points out, the sector's annual productivity growth has trailed that of other sectors for decades, having only increased by 1% over the past 20 years. Nevertheless, Barbosa et al. (2017) highlight an opportunity to close the gap, citing the potential for the industry's value-add to rise by USD1.6 trillion a year (Barbosa et al., 2017). Value-add involves an industry enhancing its products or services in order to increase their value. Barbosa et al. propose that this could be achieved by higher productivity within the sector, raising the possibility of meeting half the world's infrastructure needs and increasing global GDP by 2%. According to the McKinsey report, one-third of this opportunity is in the US, where up to 1500% growth in productivity has been observed in sectors such as manufacturing, retail and agriculture since 1945; but within the construction sector little or no productivity has been recorded. According to data from the online portal Statista, the construction sector in the US is one of the largest in the world, employing approximately 10.69 million people. The Statista data sources, US Census Bureau data, the BEA, and data from the Fails Management Institute (Bowman, J. and Strawberry, B. 2019) all show that, in 2018, construction spending in the US reached USD992 billion and is expected to total USD1526 billion by 2022. If global projections as outlined by the McKinsey report are correct, this figure could increase if productivity within the sector were improved.

The construction industry faces many challenges including external forces such as the state of the US economy as well as internal pressures such as productivity within the sector. A survey jointly conducted by the Associated General Contractors of America (AGC) and the software company Autodesk reported a shortage of skilled labour in the US (AGC and Autodesk, 2018). There is evidence of a decline in labour productivity within the construction sector since 1968, according to Barbosa et al. (2017). They deduce that, unlike other sectors, which have reported an increase in productivity, the construction sector has failed to develop in terms of technological capabilities, production methods and scale. Current sustainability requirements within the sector are further highlighting the benefits of pre-production, which could go hand-in-hand with a shift to digitalisation for enhanced productivity and waste reduction. The construction sector, which has been historically sluggish in incorporating new advancements and technology, will have to rethink, in the face of higher sustainability demands, how it designs and builds projects to meet new requirements around waste reduction, abatement of carbon emissions and more sustainable practices. In this regard, there is much potential for the principles of circular economy to help with this transition and these are discussed further in section 7.6.

4. Waste streams and trends in materials management

The following section outlines the waste stream in the US. It starts by explaining the generation and disposal of municipal solid waste (MSW) and then reports on C&D waste and debris. Overall quantities of MSW and C&D are reported separately; however, it is deemed important to look at both streams, as from a circular perspective waste streams from a number of different sectors could become the 'raw material' for a new building material or product.

4.1 Background on MSW in the US

OECD data reports that the US was the second-highest producer of municipal waste in kilograms per capita from 2008 to 2016, with only Denmark scoring higher (OECD, 2020). The US EPA has collected data on MSW waste streams in the US for 30 years. This data collection is a key component of the EPA's SMM programme, aimed at understanding the end of life of a material's lifecycle. This regulatory framework is described in detail in section 5. Data on US MSW and C&D published in a 2019 EPA report shows that, in 2017, MSW generation amounted to approximately 268 million tons[1]. Of this MSW generation, approximately 67 million tons were recycled, 27 million tons were composted, 34 million tons were combusted with energy recovery, and 140 million tons were landfilled. Figures 2 and 3 show this breakdown by weight and percentage of total MSW generation.

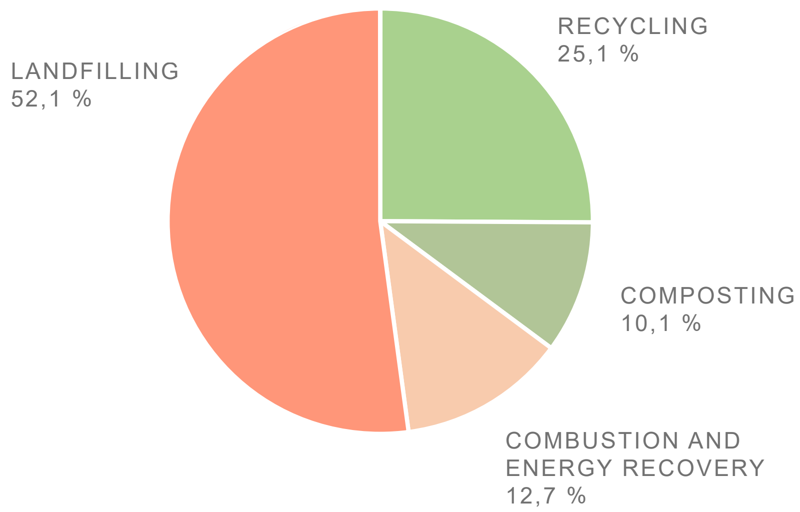

Figure 2: Management of MSW (in percentages) in the US in 2017

Data source: EPA (2019)

Graphics: Ninni Westerholm

1. Note: section 4 uses US short tons as the unit of measurement unless specified.

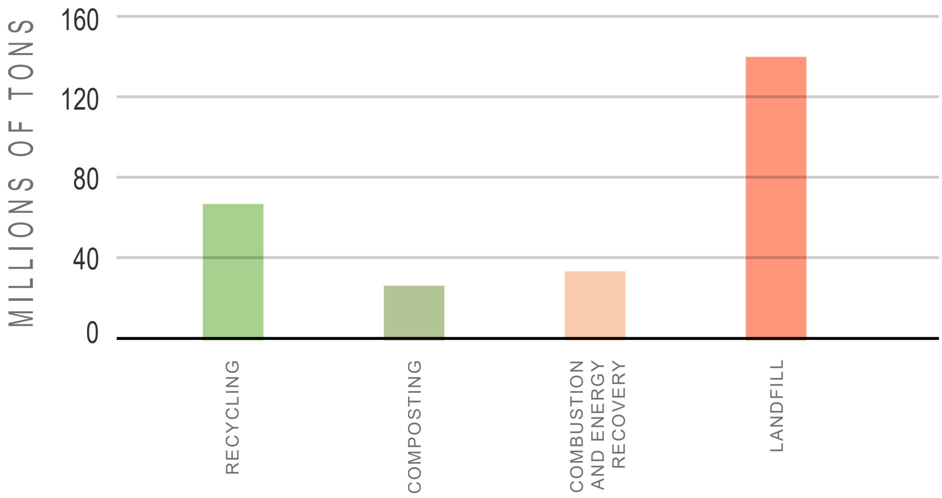

Figure 3: Management of MSW (in millions of tons) in the US in 2017

Data source: EPA (2019)
Graphics: Ninni Westerholm

The materials associated with the total MSW generation are shown in Figure 4 and the percentage of each material that is recycled, composted, combusted for energy recovery or put into landfill are shown in Figure 5.

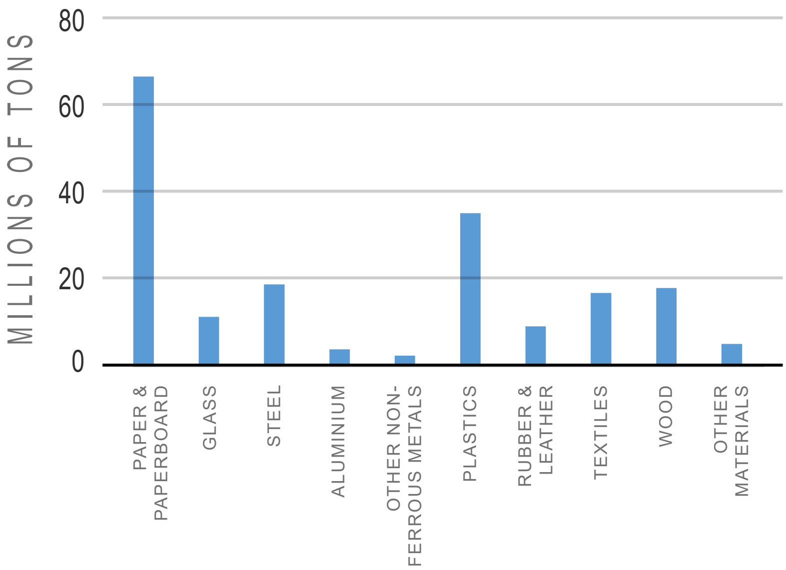

Figure 4: Generation of materials of MSW in the US in 2017 (in millions of tons)

Data source: EPA (2019)
Graphics: Ninni Westerholm

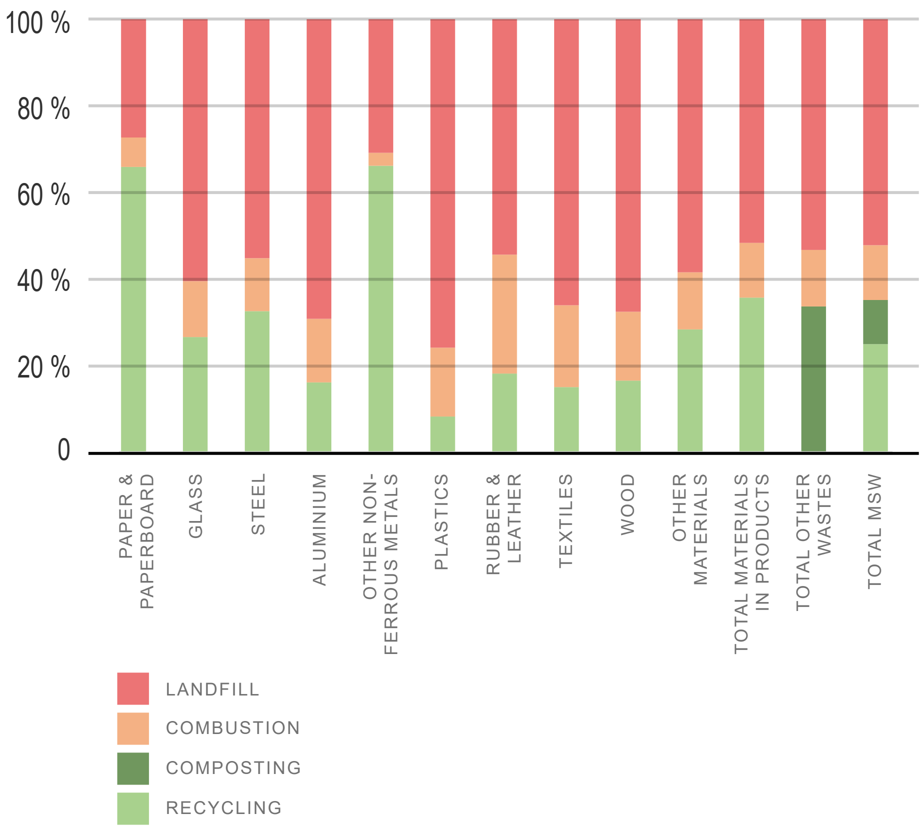

Figure 5: Recycling, composting, combustion with energy recovery, and landfilling of materials of MSW in the US in 2017 (percentage of generation of each material)

Source: EPA (2019)
Graphics: Ninni Westerholm

4.1.1 Per-capita MSW generation

The sources of MSW taken into account by the EPA (2019) report include residential waste, such as that from multi-family housing; and commercial and institutional waste, including waste from businesses, schools and hospitals. Generation of MSW per person was 2.7 pounds per person per day in 1960 and rose to 4.5 pounds per person per day in 2017. To put this in perspective, on a global scale, according to the World Bank (2018) projections, the average generation of MSW globally per day is 1.7 pounds per person, based on the assumption that 2.1 Gt of MSW is currently generated worldwide.

In 1960, 0.2 pounds per person per day of MSW was recycled in the US, whereas in 2017 1.1 pounds per person per day was recycled. In terms of landfill, in the US, 2.5 pounds per person per day of MSW was landfilled in 1960 versus 2.3 pounds per person per day in 2017. It is worth noting that there has been a significant population increase in the country over this period, from 180 million in 1960 to 325.1 million in 2017. However, since 1990 the total amount of MSW put into landfill each year has decreased by 5.7 million tons, from 145.3 million tons in 1990 to 136.9 million tons in 2017. Therefore, from 1990 to 2017, the net per-capita landfilling rate decreased by 0.9 pounds per day. The composting of food continued to rise every year between 1960 and 2017 (EPA, 2019).

4.1.2 Recovery of MSW for recycling

Paper and paperboard, along with food, are the largest components of MSW generated, accounting for 25% and 15.2%, respectively. Paper and paperboard together also constitute the most recycled material, representing 65.7% of total MSW recycling in 2017, followed by metals, which accounted for 12.4% of recycled MSW in the same year. Food (22% of total MSW landfilled) and plastics (19.2% of total MSW landfilled) are the materials most commonly found in landfill in the US (EPA, 2019). The environmental concerns around plastic recovery are growing. The US was one of the largest exporters of plastic waste to China for recycling. However, since China's 2017 ban on the import of most plastic waste apart from high-quality plastics, other countries such as Vietnam, Turkey and Malaysia have assumed the burden of importing plastic waste for recycling purposes. Since China's ban, most plastic waste in the US is now being dealt with domestically, leaving municipalities struggling with the volume of plastic to be recycled, much of which cannot be recycled. Many local recycling programmes have collapsed (Statista, 2020). Another aspect of recycling in the US is that single-stream recycling is commonly used by material recovery facilities. This recycling is having a positive impact as it results in increased recycling rates due to its ease of use. However, it also has a negative impact, in that the mixing of products tends to lead to deterioration, meaning that the quality of end product recycled materials is lower than it could be (Statista, 2020).

4.1.3 Environmental benefits of recycling and composting MSW

The EPA report of 2019 states that the environmental benefits of recycling and composting over 94 million tons of MSW in the US in 2017 included saving over 184 million metric tons of carbon dioxide equivalents (MMTCO2E). The EPA report compares these GHG benefits from recycling and composting to the equivalent reduction in emissions of taking over 39 million cars off the road in one year (EPA, 2019). These calculations and the data summarised in the report (EPA, 2019) are based on a materials flow methodology that relies on a mass balance approach and uses the EPA Waste Reduction Model (WARM) tool (WARM, 2019), which is described in more detail in section 5.1.

4.1.4 Economic benefits of recycling and composting

The 2019 EPA report outlines the benefits of creating an economy from waste products. It indicates that global competition for finite resources is expected to continue to grow and yet it cautions that the use of materials is intrinsically linked to the future of the US economy and environment. It highlights that opportunities lie in the use of waste materials as valuable raw materials, thereby reducing environmental impacts and increasing the nation's economic competitiveness. The EPA report states that building a prosperous environmental and economic future can be achieved through creating recycling jobs and building more competitive manufacturing industries.

The EPA Recycling Economic Information (REI) Study (2001) and updated Report (EPA, 2016) assessed the economic implications of material reuse and recycling based on the quantity of recycling jobs, wages and tax revenue data. The 2016 report showed that, based on the most recent data at the time (from 2007), recycling and reuse activities accounted for 757,000 jobs, USD36.6 billion in wages, and USD6.7 billion in tax revenues (local and state). It equated this to 1.57 jobs for every 1000 tons of materials recycled. It also reported that C&D waste recycling was responsible for the largest portion of all three categories (jobs, wages and tax revenues).

4.2 C&D waste

A 2017 IRP report on *Accessing Global Resource Use* states that 40% of solid waste streams in 'developed' countries are attributed to the construction, renovation and deconstruction of buildings. Aside from the hazardous portions, the report claims that much of this waste has the potential to be reused (IRP, 2017). C&D waste accounts for between 25% and 45% of the US solid waste stream by weight (Miflin et al., 2017). C&D waste, classified as 'debris' by the EPA, is waste that is not included in MSW, yet accounts for a significant portion of the nation's non-hazardous solid waste stream. It includes waste related to the built environment process such as steel, wood, drywall and plaster, brick and clay tile, asphalt shingles, concrete and asphalt concrete. These materials are used in the construction, deconstruction and renovation of buildings but also in civil engineering construction of roads, bridges and other infrastructure.

The EPA's 'Advanced Sustainable Material Management 2017 Fact Sheet', published in 2019 (US EPA, 2019), estimated that, in 2017, 569 million tons of C&D waste was generated. Figure 5 outlines the total C&D waste breakdown per material by source of waste and activity, thus comparing the waste generated during construction with the waste attributed to deconstruction. Concrete was the largest contributor at 69.7%, followed by asphalt concrete at 15% and wood at 7.1%, with all other products combined accounting for 8.1%. It is worth noting that the EPA reported that 90% of all C&D waste was attributed to deconstruction, with construction representing the other 10%. Of the total C&D waste generated in 2017, 184.3 million tons, or 32%, was attributed to buildings, with roads and bridges accounting for substantially more at 250.2 million tons, or 44%. Of the total C&D waste, 135 million tons (24%) was associated with 'other structures' categorised by the EPA as C&D waste generated from communication, power, transportation, sewer and waste disposal, water supply, conservation and development, and the manufacturing infrastructure. In all three categories of buildings, roads and bridges, and other structures, concrete was the number one source of C&D waste. However, as is highlighted by notes for Figure 7, there are gaps in the EPA data and therefore concerns regarding its veracity. It is also worth noting that plastic, glass, cardboard, organics, C&D fines and carpet estimates are excluded from this C&D waste breakdown. The EPA (US EPA, 2020) indicates that the exclusion of these materials is intended to avoid duplication, as these are routinely estimated for in the MSW stream. The EPA acknowledges that further assessment and estimate reconciliation is necessary with regard to the inclusion of these materials in C&D

waste accounting. Future recommendations involve making more data available and allowing for greater accountability across built environment sectors in collecting and reporting C&D waste data.

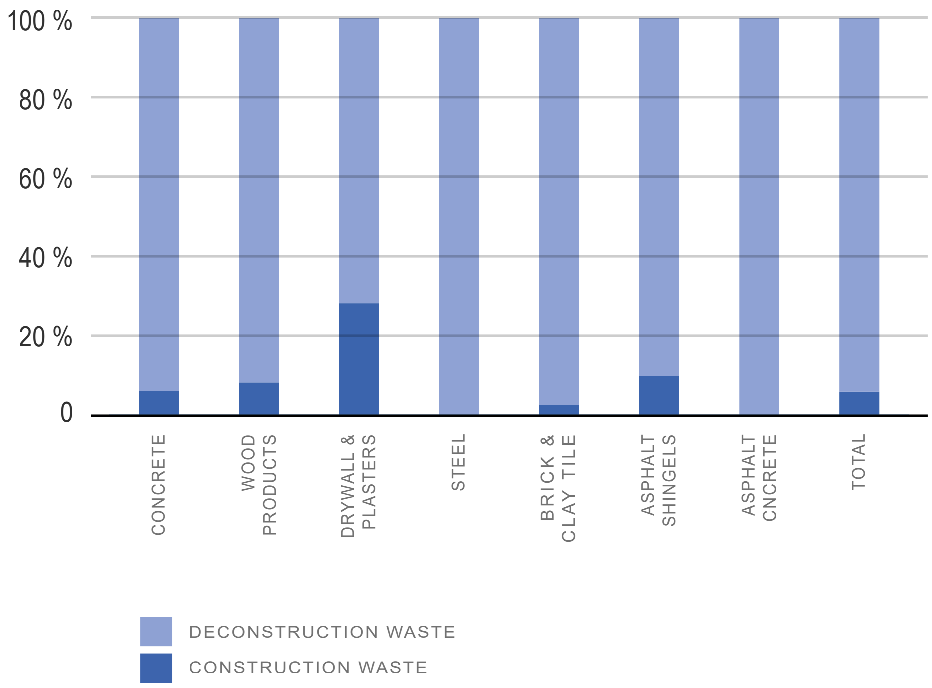

Figure 6: Share of construction and deconstruction waste of total C&D waste per material in 2017

Source: US 2019 EPA data
Graphics: Ninni Westerholm

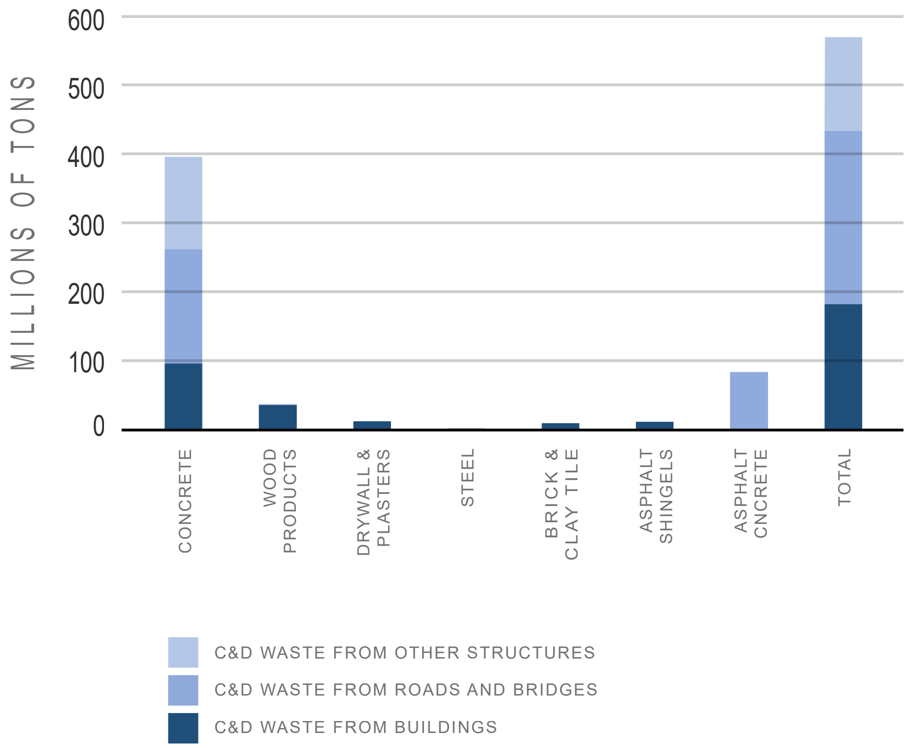

Figure 7: C&D waste generation by source and by material (in millions of tons) in 2017

NOTE: The EPA 2019 report outlines that the wood consumed in buildings is often used in other structures. Data here only includes railroad ties as lumber consumption between buildings and other structures; data on all other lumber consumption for such scenarios was not available. Therefore, the lumber associated with buildings is that consumed after railroad ties have been subtracted.
NOTE: The EPA 2019 report explains that steel consumption for buildings includes steel consumed for the construction of roads and bridges. Data was not available to split steel accurately across the three categories; therefore, the assumption here is that most steel consumption is allocated to building construction.
NOTE: In the case of C&D waste from buildings no data was available for Asphalt concrete. In the case of C&D waste from roads and bridges no data is available for Wood products, Drywall & plasters, Steel, Brick & clay tile, and Asphalt shingles. In the case of C&D waste from other structures no data was available for Drywall & plasters, Steel, Brick & clay tile, Asphalt shingles and Asphalt concrete.

Source: US 2019 EPA data
Graphics: Ninni Westerholm

Studies at the city level show a higher percentage of C&D waste is produced in cities when compared to national averages, as outlined in the *Zero Waste Design Guidelines*, a collaborative effort by architects (Kiss + Cathcart Architects), circular economy experts (Closed Loop Partners) and waste management experts (Foodprint Group) in association with the AIA New York, and a number of New York City (NYC) government agencies with support from the Rockefeller Foundation (Miflin et al., 2017). These guidelines indicate that although C&D waste is expected to be higher in NYC compared to nationwide values, the data is unreliable because transfer stations self-report to the City of New York Department of Sanitation. However, based on the data available, in 2016, quarterly reports outlined an average volume of 7500 tons of C&D waste per day. *The Zero Waste Design Guidelines*, directed primarily at architects, highlight the role design can play in reducing waste, including incorporating circular waste management principles during the building design phase when the flow of waste streams for the building is being decided upon, prioritising for waste reduction during the construction phase and proposing potential end-of-life designs. The guidelines point out that for commercial buildings, C&D waste is almost a daily stream given that large buildings are constantly undergoing refurbishment. Referencing a 2015 EMF report on circular economy in Europe, *the Zero Waste Design Guidelines* estimate that 10–15% of waste occurs during construction with the remaining 85–90% occurring during deconstruction or replacement. These figures are relatively in line with the EPA (2019) figures on C&D waste per activity, outlined in Figure 5.

As already discussed in section 3.2.1, there is an opportunity for the construction sector to greatly reduce the waste it generates and increase productivity through a reimagining and restructuring of how the sector functions. This is explored further in section 7.5.

5 Policies

5.1 SMM: Policies, legislation, strategic plans and practices in the built environment

The US EPA has adopted the SMM regulatory framework for managing materials. In 2009, the EPA published a report titled *Sustainable Materials Management: The Road Ahead 2009–2020* which outlines a strategy for implementing SMM in the US. In this report, the EPA defines SMM as:

> an approach to serving human needs by using/reusing resources productively and sustainably throughout their life cycles, generally minimizing the amount of materials involved and all associated environmental impacts. (US EPA, 2009)

The Resource Conservation and Recovery Act (RCRA) gives the EPA authority to manage SMM from a legislative perspective, and to establish a strong preference for resource conservation over disposal. Although responsibility for managing materials and waste is primarily at the state and local levels, the EPA facilitates by providing national consistency and co-implementing the RCRA with US states. Co-implementation involves providing states, businesses and other stakeholders with national standards, guidelines and technical support on better practices for conserving materials, reducing waste and increasing the efficient and sustainable use of resources (US EPA, 2015).

The US EPA Sustainable Materials Management (SMM) Program Strategic Plan (US EPA, 2015), covers a five-year period from fiscal year 2017 to 2022. This five-year plan focuses on three strategic initiatives around the following: 1) the built environment, 2) organics recycling, and 3) reduction in packaging. Each of these three areas is described under the SMM programme objectives:

1. Decrease the disposal rate, which includes **source reduction, reuse, recycling and prevention;**
2. Reduce the environmental impacts of materials across their life cycle;
3. Increase socio-economic benefits; and
4. Increase the capacity of state and local governments, communities and key stakeholders to adopt and implement SMM policies, practices, and incentives.

These objectives are very similar to and align with a circular economy approach. As noted in the OECD's *Global Material Resources Outlook to 2060* (2019) report, the EPA SMM Program Strategic Plan is similar, though differently named, to circular economy roadmaps that now exist in China (2013), the European Union (2015), Finland, France, the Netherlands, and Scotland (2016), as well as Slovenia and Portugal (2017). Hence, although not classified as circular economy, the 2015 EPA SMM Program Strategic Plan promotes a transition to a more resource-efficient economy, and makes reference to circular economy articles such as Accenture's 'Circular Advantage: Innovative Business Models and Technologies to Create Value in a World without Limits to Growth' (Accenture, 2014). The following sections look specifically at the SMM programme's objectives with regard to the strategic priority area of the built environment and it highlights a number of action areas.

5.1.1 Action Area 1: Incorporate lifecycle SMM concepts into the built environment marketplace

The EPA encourages collaboration between building design marketplace entities (such as architects, engineers, product designers, educators and students) and federal, state and community stakeholders towards adopting SMM policies, practices and incentives, in every aspect of the built environment lifecycle from initial design, to material extraction, manufacturing, building operation and end-of-life design including renovation, recycling, reusing and/or deconstruction.

For this first action area, the EPA outlines anticipated outcomes by 2022, which include increasing the safe reuse and recycling of C&D materials as well as increasing the safe reuse of high-priority industrial byproduct materials (US EPA, 2015).

5.1.2 Action Area 2: Advance climate adaptation and community resilience efforts

The EPA strategic plan outlines that natural disasters in the US have been a source of copious debris, citing Hurricane Andrew as an example that generated 20 million cubic yards of debris, equivalent to filling a football pitch a mile high. It therefore explains the second action area as promoting sustainable and resilient construction techniques and disaster debris planning and management, to protect communities from the impacts of natural disasters associated with climate change.

The second action area sets the following anticipated outcomes by 2022: 1) a national data tracking approach to begin to measure amounts of debris generated and how it is managed; 2) decreased disposal of debris (measured by a new national tracking system); 3) improved disaster debris management plans in communities to enhance resilience to disasters; and 4) improved building codes and ordinances in communities to reduce disaster debris (US EPA, 2015).

5.1.3 Action Area 3: Improve and enhance data & measurement of C&D and industrial byproduct materials

The EPA report emphasises the requirement for high-quality scientific information and data, as well as tools for monitoring and quantifying the environmental and socioeconomic benefits of following the SMM approach.

The anticipated outcomes by 2022 for this third action area include: 1) national baseline and trend data for the generation, reuse, recycling and disposal of C&D materials; 2) a national, replicable methodology to provide baseline and trend data for the generation, reuse, recycling and disposal of high-priority industrial byproduct materials; and 3) improved and expanded the Waste Reduction Model also known as WARM (WARM, 2019) and other tools and calculators to allow quantification of environmental and economic benefits and impacts related to C&D materials management and industrial byproduct materials (US EPA, 2015).

The EPA has developed WARM to calculate GHG emissions, energy and economic impacts for baseline and alternative waste management practices, including source reduction, recycling, combustion, composting and landfilling. The goal of WARM is to assist solid waste planners and organisations to design waste management practices that reduce GHG emissions while allowing for healthy economic growth. It does this through comparative analysis by calculating GHG emissions, energy and economic impacts for baseline and alternative waste management practices, including source reduction, recycling, combustion, composting and landfilling. In this way, building sector decision-makers can obtain estimates of end of life design environmental and economic impacts at the early design stages and throughout the lifecycle. This allows built environment stakeholders to design for end of life by understanding through quantitative calculation the environmental impact reduction associated with decreased disposal rates. The model calculates emissions in metric tons of carbon dioxide equivalent (MTCO2E) and metric tons of carbon equivalent (MTCE), energy in millions of British Thermal Units (MMBTU), wage impacts, tax impacts, and labour hours supported across a wide range of material types commonly found in both MSW and C&D debris. The GHG emission factors used in WARM are based on a lifecycle perspective. The use of WARM and other similar tools is encouraged by the EPA as a means to improve and enhance data on and measurement of C&D and industrial byproduct materials (US EPA, 2015).

At a government level, the Green New Deal is also important to mention in regard to environmental security. Although circular economy is not specifically advocated in the Green New Deal, many of its goals are in line with a circular way of thinking (Ocasio-Cortez, 2019). As well as the EPA and Green New Deal, professional organisations in the US such as the AIA, as well as rating systems such as the USGBC's LEED and the Living Building Challenge have set out standards, guidelines and certifications (many of which are influenced by the EPA's regulatory frameworks) for how best to achieve sustainable and resilient design. Section 6.2 looks at these rating systems, focusing particularly on the LEED certification and its approach to materials and resources and its use at the federal, state and local levels.

5.2 Approaches to CE through federal legislation supporting advanced innovation in manufacturing

At the federal level, under the Obama administration, the idea of circular economy was considered from the perspective of vehicle remanufacturing but also in relation to transforming and reinvigorating advanced manufacturing in the US in general (Report to the President on Capturing Domestic Competitive Advantage in AM, 2012). The Presidents' Council of Advisors on Science and Technology recommended the formation of the Advanced Manufacturing Partnership (AMP), with a final report published in 2014. The AMP 2.0 report focused on bringing together industry, academia and federal partners to secure US leadership around the emerging technologies that will create high-quality manufacturing jobs and enhance the country's global competitiveness (AMP 2.0, 2014). In December 2014, Congress passed the *Revitalize American Manufacturing and Innovation Act* (RAMI Act), which sets the legislative basis for the establishment of manufacturing innovation institutes in the US, giving Congressional authorisation to the Advanced Manufacturing National Program Office.

Manufacturing USA was founded in 2014 as the National Network for Manufacturing Innovation within the National Institute of Standards and Technology (NIST). Under the umbrella of NIST, grants are established and awarded to institutes of manufacturing innovation forming a national network of linked manufacturing institutes. Within this national network, one of the institute members that champions circular economy is the Reducing Embodied-Energy and Decreasing Emissions (REMADE) Institute. The REMADE Institute was an initial collaboration between academic institute Rochester Institute of Technology and the Sustainable Manufacturing Innovation Alliance, which received funding from the US Department of Energy to lead the

REMADE Institute. In 2018, the Trump administration continued to approve funding for this alliance. The REMADE Institute takes a circular economy approach by focusing on technical and economic knowledge gaps that present challenges in achieving material recycling, recovery, remanufacturing and reuse. It enables early stage design and applied research and development around rethinking how material manufacturing processes can work towards a more circular approach that dramatically reduces embodied energy and carbon emissions (REMADE, 2020). Although examples of the work coming out of the REMADE Institute are more focused on product-based manufacturing than on construction materials, the work of the institute does demonstrate the capabilities needed to develop this area of advancement within the built environment using a circular economy model.

6 Incentives

6.1 Financial and structural incentives from municipalities and government

Typically, financial and structural incentives are provided by municipalities, aimed at incentivising the market in order to encourage sustainable and green building practices. Although not classified as ‘circular’, these incentives are driven by a desire to encourage sustainable design and built environment practices, many of which can be considered as steps towards a circular built environment. According to the USGBC, by choosing sustainable practices, building developers and homeowners help to stimulate innovation and growth in the environmental building technologies market (USGBC, 2014, 2015). Section 6.1 outlines the incentives provided by municipalities and government, while section 6.2 highlights the role of the USGBC’s LEED rating system in driving circular practices for material and resource selection and use as well as waste management.

6.1.1 Structural incentives

Examples of structural incentives offered by municipalities include expedited permitting processes and density and height bonuses.

6.1.1.1 Expedited permitting processes

These incentives typically incur little or no cost to the municipality. For example, for permitting processes the municipality offers an expedited review in cases where the developer has employed sustainable building standards. This provides a financial incentive to the developer, as jurisdiction wait times for permitting processes can otherwise be up to 1.5 years. However, from the perspective of the municipality this requires no financial investment but rather a reorganisation of the permitting priority.

6.1.1.2 Deconstruction (demolition) permit process

In terms of end-of-life design, an opportunity arises to salvage furniture and finish materials for reuse or recycling before deconstruction begins. In many cities in the US most projects require a demolition permit; hence, there is a period of time before the deconstruction process begins during which reuse, recycling and salvaging of existing interiors could be officially sanctioned, as has been suggested by the *AIA’s Zero Waste Design Guidelines* (Miflin et al., 2017). For example, in New York City asbestos testing is required before deconstruction may begin, so during this time interiors could be salvaged.

6.1.1.3 Density and height bonuses

Another incentive offered by municipalities involves percentage increases in Floor Area Ratio or other metrics of density in exchange for certification such as a LEED certification or proof of meeting sustainable building standards (USGBC, 2014).

6.1.2 Financial incentives

These incentives involve tax credits and reductions, fee reductions, grants or revolving load funds offered by municipalities to developers and homeowners who choose to adopt sustainable practices. Again, in theory, similar to the structural incentives, these direct incentives should not affect the municipality's revenue as many of the proposed sustainable developments should increase the property value in the jurisdiction. According to a 2019 USGBC report, LEED buildings 'sell at higher prices and faster' (USGBC, 2019e).

6.1.2.1 Tax credits and tax deductions

Tax credits and tax deductions are given by many municipalities as a means of encouraging sustainable goals for the built environment.

- **Internal Revenue Code (IRC) Section 179D Energy Efficient Commercial Buildings Deduction:** The IRC Section 179D covers the Energy Efficient Commercial Buildings Deduction (IRS, 2018). According to the US Energy Star, a programme run by the EPA and the Department of Energy to promote energy efficiency, the Energy Efficient Commercial Buildings Deduction provides the following:
  'A tax deduction of up to $1.80 per square foot is available to owners or designers of commercial buildings or systems that save at least 50% of the heating and cooling energy as compared to ASHRAE Standard 90.1-2007 (or 90.1-2001 for buildings or systems placed in service before January 1, 2018)… Partial deductions of up to $.60 per square foot can be taken for measures affecting any one of three building systems: the building envelope, lighting, or heating and cooling systems.' (Energy Star, 2020)
- **IRC Section 45L Energy Efficient Home Credit:** In 2005, under the Energy Policy Act, the Energy Efficient Home Credit was established, codified under the IRC as 45L. It allows developers to claim a USD2000 tax credit per unit on all new residences (since 2005) constructed or reconstructed and/or rehabilitated that meet the following conditions: 1) residences are built within the US, 2) each unit must be three stories or less, 3) construction meets certain energy saving requirements, and 4) units are sold or leased for use as a residence. The energy saving requirements involve a 50% reduction in heating and cooling demands compared to a 'comparable dwelling unit', and one-fifth of the 50% energy savings must be attributed to reduced energy losses at the building envelope. The comparable dwelling unit refers to the building construction, which must abide by the 2006 International Energy Conservation Code and the heating and cooling equipment efficiencies must align with the minimum allowed by the Department of Energy regulations under the *National Appliance Conservation Act of 1987.*
- **IRC Section 48 Investment Tax Credit** is another incentive provided in the form of an investment tax credit to encourage businesses to invest in renewable energy equipment and to help lower the costs of procurement and operation via a 10–30% tax credit on costs (CTI, 2019).

6.1.2.2 Fee reduction or waiver

Another incentive provided by municipalities is a **fee reduction or waiver** for permit review and processing charges when a developer demonstrates sustainable building standards. This often works in conjunction with the structural incentive on expedited permitting described in section 6.1.1 above.

6.1.2.3 Grants

Grants are typically provided by cities. Grant awardees can be homeowners and/or developers who receive funding for perusing green building certification or to help cover the costs associated with achieving sustainable building development.

6.1.2.4 Revolving loan funds

Another incentive to encourage sustainable development and investment in green solutions is in the form of revolving loan funds. These are typically low-interest loans from an allocated fund available to those seeking to adopt green building standards in a proposed development or renovation. The aim is to help cover the upfront costs often associated with green building technologies and practices and to encourage investment in same, in a context in which a return on investment may take a number of years. This is achieved by offering loan repayments to the allocated fund that are at a lower rate than the savings associated with operational costs. The continuous fund repayments allow for additional loans to be provided from the fund (USGBC, 2014).

Many of the structural and financial incentives discussed in this section are created to encourage the employment of green or sustainable practices in the construction of buildings, often with a primary focus on energy reduction and a transition to renewable sources of energy. From a building lifecycle perspective, these incentives can be seen as focusing primarily on the operational phase of the building. However, the choice of construction materials and assemblies in the design and construction phase determines whether the energy requirements for the building's operation will be met, by employing sustainable practices, particularly energy reduction, through the building envelope. Typically, reducing energy consumption involves a review of the building envelope where adjustments to construction materials and assemblies can help reduce heating and cooling losses through the envelope, thereby reducing the need for supplemental heating or cooling as well as the need for artificial lighting if adequate daylighting is provided through the building envelope. From a circular economy approach, considering how these materials are produced and obtained is important. Taking this broader viewpoint, by considering the built environment as a process, including how it sources energy to meet the lighting, heating, cooling and equipment operational loads of buildings, is also crucial. Therefore, incentives to use renewable energy will also help in achieving a circular built environment. In the next section we focus on the end of life aspects of the building lifecycle and consider how the management of C&D waste is being addressed through incentives, ordinance and specific programmes.

7. Design issues, policies and regulation

7.1 Building certification programmes as cross-cutting policy instruments and drivers of increased recovery of C&D materials

The adoption, support or promotion of the USGBC's LEED building certification programme by state and local governments has occurred across the US. *The IRP's Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future* (2020) characterises the government use of building certification systems as a cross-cutting policy instrument. Stating that 'building certification provides potential leverage to increase uptake of many material efficiency strategies related to building design and end-of-life management'. Information on policies relating to green building and LEED at the federal, state and local levels is outlined in the USGBC's Public Policy Library web-based platform (USGBC, 2020c).

Driven by certification programmes such as the USGBC's LEED v4.1's inclusion of credits for the recycling of C&D waste, more states and municipalities are implementing programmes and laws in order to increase the recovery of C&D materials. For example, the City of Hayward located in the San Francisco Bay Area of California has updated its C&D ordinance to include more project types that require increased diversion. California Building and Standards Codes (CALGreen) states that 65% of non-hazardous C&D waste must be recovered or recycled from projects. To monitor this, CALGreen requires the use of a qualified third party organisation such as a C&D recycling facility and a verification certificate must be reported (CALGreen, 2019).

7.1.1 Certification of Recycling Rates (CORR) programme

The Recycling Certification Institute developed a national standard programme titled the Certification of Recycling Rates (CORR) programme. It provides an ISO-level third-party certification of the recycling rates of C&D facilities as well as meeting the LEED V4.1 Waste Management credits (MRpc87) criteria for recycling.

7.2 LEED and its approach to material and resource use in the built environment including environmental and human health impacts

The USGBC's most recent LEED v4.1 has introduced a number of additional materials and resources prerequisites and credits, outlined in a series of guides for beta participants, which are referenced in Tables 1-5 below (USGBC, 2019a, 2019b, 2019c, 2019d, 2020a, 2020b). According to the USGBC, LEED v4.1 offers an expanded focus on materials to include not only the use of materials in buildings but also their impact on human health and the environment. Many of the material practices outlined in the materials and resources (MR) credit category foster circular economy through recycling, adaptive reuse, rewarding embodied carbon and the use of renewable bio-based materials, as well as reducing material use through efficiency. These MR credits include, among others, a Building-Life-Cycle Impact Reduction credit and a Building Product Disclosure and Optimization – Sourcing of Raw Materials credit that encourages best practice in materials extraction and responsible sourcing of raw materials. LEED defines five different rating systems – 1) Building Design and Construction (BD+C), 2) Interior Design and Construction (ID+C), 3) Building Operations and Maintenance (O+M), 4) Residential, and 5) Cities and Communities – and indicates different prerequisites and credits for a number of 'performance' or 'credit category' areas. The LEED v4.1 MR credit category aligns with the strategies outlined in the SMM regulatory framework, discussed in section 5.1, which strives to decrease the waste disposal rate through source reduction, reuse, recycling and prevention. In Tables 1-5 below, each rating system is outlined in terms of its prerequisites and credits for the MR credit category area.

7.2.1 Building Design and Construction (BD+C)

Table 1 shows the MR credits that are available for the BD+C rating system. Storage and collection of recyclables along with C&D waste management planning are set as prerequisites. This implies that, at a minimum, consideration is to be given to the end of life of construction materials and the recycling of materials used within buildings. In terms of human health and wellbeing, a number of prerequisites and credits are given for reducing the release of Persistent Bioaccumulative and Toxic (PBT) chemicals associated with the lifecycle of building materials within such buildings. This includes reducing the use of mercury-containing products and devices as well as mercury release through product substitution, capture and recycling (USGBC, 2020a). Similar credits are given for substituting materials manufactured with lead and cadmium, as well as for reducing or eliminating joint-related sources of copper corrosion. All building types are credited for considering an environmental reduction in lifecycle impacts as well as for providing Environmental Product Declarations (EPD) for specified material and building products.

Table 1: Overview of LEED v4.1 MR credit category breakdown and explanation for BD+C, referencing LEED guidelines per USGBC, 2020a, LEED v4.1 Building Design and Construction

Source: USGBC, 2019a, 2019b, 2019c, 2019d, 2020a, 2020b
Graphics: Ninni Westerholm

LEED v4.1 for BD+C				
Credit Category Area:		**New Construction, Schools, Retail, Data Centres, Warehouses & Distribution Centres, and Hospitality** (total possible credits)	**Core & Shell** (total possible credits)	**Healthcare** (total possible credits)
MR		**13**	**14**	**19**
Prereq.	Storage and Collection of Recyclables	Required	Required	Required
Prereq.	C&D Waste Management Planning	Required	Required	Required
Prereq.	PBT Source Reduction – Mercury	-	-	Required
Credit	Building Lifecycle Impact Reduction	5	6	5
Credit	Building Product Disclosure and Optimisation – EPDs	2	2	2

Credit	Building Product Disclosure and Optimisation – Sourcing of Raw Materials	2	2	2
Credit	Building Product Disclosure and Optimisation – Material Ingredients	2	2	2
Credit	PBT Source Reduction – Mercury	-	-	1
Credit	PBT Source Reduction – Lead, Cadmium and Copper	-	-	2
Credit	Furniture and Medical Furnishings	-	-	2
Credit	Design for Flexibility	-	-	1
Credit	C&D Waste Management	2	2	2

7.2.2 Interior Design and Construction (ID+C)

Table 2 outlines the MR credits that are available for the ID+C rating system. The LEED v4.1 makes reference to many federal and international guidelines, codes and standards. In terms of recycled materials and products, it references the US EPA's Comprehensive Procurement Guidelines. For bio-based products it advocates products that meet the Sustainable Agriculture Network's Sustainable Agriculture Standard. Bio-based raw materials must be tested using ASTM Test Method D6866 and be legally harvested. Paper and wood products must be certified by the Forest Stewardship Council or an USGBC-approved equivalent. LEED v4.1 also recommends products that have been cradle-to-cradle certified; products with a Health Product Declaration indicating any hazards associated with the product and its use; and products with an EPD that conform to specific ISO standards, having at least a cradle-to-gate scope. It also takes into account the indoor air quality and human health and wellbeing aspects of materials, recommending low formaldehyde for composite wood and low emissions of volatile organic compounds (VOCs) for products other than furniture, such as insulation, as well as floor, ceiling and wall materials and finishes.

Table 2: Overview of LEED v4.1 MR credit category breakdown and explanation for ID+C, referencing LEED guidelines per USGBC, 2019a, LEED v4.1 Interior Design and Construction

Source: USGBC, 2019a, 2019b, 2019c, 2019d, 2020a, 2020b
Graphics: Ninni Westerholm

LEED v4.1 for ID+C					
Credit Category Area		**New construction** (total possible credits)	**Retail** (total possible credits)	**Hospitality** (total possible credits)	**Notes**
MR		**13**	**14**	**13**	Greater emphasis on embodied carbon reductions via building reuse, salvage, whole building LCA and EPDs.
Prereq.	Storage and Collection of Recyclables	Required	Required	Required	Intent: To reduce the waste generated by building occupants and hauled to and disposed of in landfills.

Prereq.	C&D Waste Management Planning	Required	Required	Required	Intent: To reduce C&D waste disposed of in landfills and incineration facilities by recovering, reusing and recycling materials.
Credit	Long-Term Commitment	1	1	1	Intent: To encourage choices that conserve resources and reduce environmental harm from materials manufacturing and transport for tenants' relocation.
Credit	Interiors Lifecycle Impact Reduction	4	5	4	Intent: To encourage adaptive reuse and optimise the environmental performance of products and materials.
Credit	Building Product Disclosure and Optimisation – EPD	2	2	2	Intent: To encourage the use of products and materials for which lifecycle information is available and that have environmentally, economically and socially preferable lifecycle impacts.
Credit	Building Product Disclosure and Optimisation – Sourcing of Raw Materials	2	2	2	Intent: Same as for EPD. To reward project teams for selecting products verified to have been extracted or sourced in a responsible manner.
Credit	Building Product Disclosure and Optimisation – Material Ingredients	2	2	2	Intent: Same as for EPD. To reward project teams and raw material manufacturers for selecting or producing products for which the chemical ingredients in the product are inventoried using an accepted methodology and for selecting products verified to minimise the use and generation of harmful substances.
Credit	C&D Waste Management	2	2	2	Intent: To reduce C&D waste disposed of in landfills and incineration facilities by recovering, reusing and recycling materials.

7.2.3 Building operations and maintenance (O+M)

Table 3 indicates the MR credits that are available for the O+M rating system. This section deals primarily with waste management during the life of a building, including MSW. It also considers waste associated with the maintenance of the building during its operation.

Table 3: Overview of LEED v4.1 MR credit category breakdown and explanation for building O+M, referencing LEED guidelines per USGBC, 2019b, LEED V4.1 Operations and Maintenance

Source: USGBC, 2019a, 2019b, 2019c, 2019d, 2020a, 2020b
Graphics: Ninni Westerholm

LEED v4.1 for Building O+M				
Credit Category Area:		**Existing buildings** (total possible credits)	**Interiors** (total possible credits)	Notes
MR		**9**	**12**	
Prerequisite	Purchasing Policy	Required	Required	Changed title was 'Ongoing Purchasing and Waste Policy'. Solid waste management policy is now a strategy for the waste performance score.
Prerequisite	Facility Maintenance and Renovations Policy	Required	Required	
Prerequisite	Waste Performance	8	8	Waste must be tracked in weight. A minimum waste performance score of 40 is required.
Credit	Purchasing	1	4	Intent: To reduce environmental harm from materials and products purchased, used, installed and disposed of during the operations and maintenance of buildings. Options: 1) Ongoing Consumables, 2) Building Materials, 3) Electronic Equipment, and 4) Food and Beverage.

7.2.4 Residential

Table 4 outlines the MR credits that are available for the residential rating system, for both single-family and multi-family homes. This is similar to the Building Design and Construction (BD+C) rating system guidelines but with a focus on durability management.

Table 4: Overview of LEED v4.1 MR credit category breakdown and explanation for residential, referencing LEED guidelines per USGBC, 2020b, LEED v4.1 residential single-family homes; USGBC, 2019c, LEED V4.1 Residential BD+C Multifamily Homes

Source: USGBC, 2019a, 2019b, 2019c, 2019d, 2020a, 2020b
Graphics: Ninni Westerholm

LEED v4.1 for residential				
Credit Category Area:		**Single-family homes** (total possible credits)	**Multi-family homes** (total possible credits)	**Notes**
MR		**12**	**13**	
Prerequisite	Storage and collection of recyclables	-	Required	Intent: To reduce the waste generated by building occupants and hauled to and disposed of in landfills.
Prerequisite	C&D Waste Management Planning	-	Required	Intent: To reduce C&D waste disposed of in landfills and incineration facilities by recovering, reusing and recycling materials.
Prerequisite	Certified tropical wood	Required	-	Intent: To encourage environmentally responsible forest management.
Prerequisite	Durability management	Required	-	Intent: To promote durability and performance of the building enclosure and its components and systems through appropriate design, materials selection and construction practices.
Credit	Durability Management Verification	3	-	Intent: To promote enhanced durability and high performance of the building enclosure and its components and systems through appropriate design, materials selection and construction practices.
Credit	Building Lifecycle Impact Reduction	-	5	Intent: To encourage adaptive reuse and optimise the environmental performance of products and materials.
Credit	Environmentally Preferable Products	5	6	Intent: To increase demand for products or building components that minimise material consumption through recycled and recyclable content, reclamation or overall reduced lifecycle impacts.
Credit	C&D Waste Management	2	2	Intent: To reduce construction waste generation and to reuse and recycle debris.

7.2.5 Cities and communities: plan and design

Table 5 indicates the MR credits that are available for the cities and communities rating system. This section focuses specifically on MSW management and explores options around designing for recycling, composting and reuse. It also addresses responsible sourcing for urban infrastructure.

Table 5: Overview of LEED v4.1 MR credit category breakdown and explanation for cities and communities: plan and design, referencing LEED guidelines per USGBC, 2019d, LEED V4.1 Cities and Communities: Plan and Design

Source: USGBC, 2019a, 2019b, 2019c, 2019d, 2020a, 2020b
Graphics: Ninni Westerholm

LEED v4.1 for cities and communities				
Credit Category Area		**Cities** (total possible credits)	**Communities** (total possible credits)	Notes
MR		11	11	
Prerequisite	C&D Waste Management	Required	Required	Intent: To reduce C&D waste disposed of in landfills and incineration facilities by recovering, reusing and recycling materials.
Prerequisite	Solid Waste Management	Required	Required	Intent: To move towards a zero-waste city and reduce environmental and economic harms associated with waste generation.
Credit	Organic Waste Treatment	2	2	Intent: To encourage diversion of organic matter away from landfill and move towards the creation of valuable nutrient-rich soil and clean power.
Credit	Recycling Infrastructure	5	5	Intent: To encourage waste diversion of inorganic matter away from landfill and move towards 100% diversion from landfill.
Credit	Responsible Sourcing for Infrastructure	2	2	Intent: To encourage the use of products and materials for which lifecycle information is available and that have environmentally, economically and socially preferable lifecycle impacts. To reward cities for selecting products verified to have been extracted or sourced in a responsible manner.
Credit	Smart Waste Management Systems	2	2	Intent: To improve efficiency of the waste management system.

7.3 Reverse design/design for disassembly and future proofing

The AIA's Committee on the Environment (COTE) Top Ten Measures, more recently titled the Framework for Design Excellence, sets targets and goals for climate action. In order to meet these goals, each measure in the framework is presented in terms of best practice, high-impact strategies, resources and case studies (AIA, 2020).

The 10 measures of the AIA Framework for Design Excellence are presented in Table 6.

Table 6: AIA Framework for Design Excellence

Source: AIA (2020)
Graphics: Ninni Westerholm

1. DESIGN FOR INTEGRATION
2. DESIGNING FOR EQUITABLE COMMUNITIES
3. DESIGNING FOR ECOLOGY
4. DESIGNING FOR WATER
5. *DESIGNING FOR ECONOMY*
6. DESIGNING FOR ENERGY
7. DESIGNING FOR WELLNESS
8. *DESIGNING FOR RESOURCES*
9. DESIGNING FOR CHANGE
10. DESIGNING FOR DISCOVERY

Although the entire AIA framework could be seen as promoting a more circular approach to the built environment, two goals in particular are deemed intrinsically linked to the concept of a circular built environment and are therefore analysed in more detail below. They are 'Designing for Economy' and 'Designing for Resources'.

7.4 'Designing for Economy': space design, material lifecycle, the operational phase, financing and incentives, and linking communities

The designing for economy measure stipulates the best practices presented in Table 7.

Table 7: The Designing for Economy measure stipulates the following key best practices

Source: AIA (2020)
Graphics: Ninni Westerholm

BUILDING SIZE	Many aspects are considered here including conserving space and promoting economical design. Planning and programming of building space is highlighted to reduce programme redundancies. A building efficiency ratio is determined to act as a guideline measure for the good use of space for specific programmes. Designing for flexibility of space use is recommended. In the scenario of budget cuts, it is preferable to reduce scope rather than downgrading material quality. Existing buildings should be reused where possible.
MATERIAL USE	In terms of materials, the guidelines recommend re-ducing the material palette used in a building design. The use of materials should be minimised and those that are multi-functional should be prioritised. Reducing redundancy in material finish – such as floor, ceiling or wall coverings – can lead to reduced waste at the end-of-life phase. Materials' lifecycle and return on investment should be considered, where greater upfront costs for certain materials may pay back in the long run in terms of energy savings, durability and environmental impacts, for example. Lifecycle Analysis (LCA) during design can greatly inform the selection of material and efficient material use. The AIA has published guides for architects to introduce LCA into practice such as the AIA 2010 Guideline to Building Lifecycle Assessment in Practice.
OPERATIONAL REQUIREMENTS	When considering the operational and maintenance phase of a building's lifecycle, design strategies for improved water and energy performance coupled with optimised upfront and operational costs are recommended. The goal is to design affordable yet better performing water and energy systems that reduce operational costs. In terms of material selection, durable, low-maintenance and self-cleaning materials, as well as those with longer replacement cycles, are encouraged.
FINANCING & INCENTIVES	The measure encompasses advice on maximising the use of local, state and national incentives, as well as grants and financing options that recognise long-term investments towards better overall performance, such as energy-cost payback, water savings, measured productivity gains and third-party purchase agreements. This measure encourages equitable economic solutions that can support disadvantaged economies.
COMMUNITY LINKS	This section encourages sourcing materials locally and from local craftspeople, thereby supporting sustainable practices and local employment. Research workforce training is needed to support new skills and experience opportunities during the construction phase. Local and global scale impacts must be considered when making economic decisions, such as the choice of material. For example, wood that is certified by the Forest Stewardship Council (FSC) may be more expensive, but alternatives could have devastating effects on the local communities where the lumber is being harvested.

7.4.1 Space design, building use and reuse, and building less

Referencing the AIA's COTE Top Ten measure 'Designing for Economy', Miflin (2019) suggests that a circular design means addressing space as a resource to be conserved or efficiently used, just like water or energy. She states that spaces should be designed to be used more, that is, by more people and more of the time. Miflin (2019) explains that this is often at odds with the requirements for achieving net zero energy or many green certification rating systems, such as LEED. In these cases, buildings are to be used only when needed to conserve energy, limit occupancy and outsource as many impacts as possible. Miflin questions how we might eliminate the need for new buildings, suggesting that this may be achieved by making efficient use of existing spaces, such as creating multi-functional spaces that facilitate a variety of activities. Eliminating new construction and making existing space more efficient, she claims, would help in reducing embodied energy and carbon.

Miflin further points out that when measuring embodied carbon there is no credit for designing better use of space or reducing the size of a building. Along these lines, the Regional Plan Association's Fourth Regional Plan (Regional Plan Association, 2017) presents guidelines for achieving affordable housing in the New York–New Jersey–Connecticut Metropolitan Area without the need to build any new structures. Based on the association's calculations, 300,000 new units region-wide could be created without any new construction by changing zoning laws to allow for accessory dwellings. By locating multi-family developments within walking distance of transit stations, the regional plan suggests that the need for parking lots could be reduced and that existing parking lots could thereby yield a quarter of a million new homes in walkable, mixed-income communities without constructing one new building (Regional Plan Association, 2017). In a similar way, the United Kingdom's 2013 HM Treasury Infrastructure Carbon Review suggests that the potential for carbon reduction can be tackled early in the design process by '*Building nothing'* that involves *'challenging the root cause of the need; [and] exploring alternative approaches to achieve the desired outcome'*. In other words, a recommendation is made to question whether a new building is the correct solution to meeting a particular demand and to investigate what alternative options are appropriate. It also outlines an approach of *'Building less',* which includes '*maximizing the use of existing assets; [and] optimiz[ing] asset operation and management to reduce the extent of new construction required'*. The concept of building less is appropriate in developed countries like the US where, although urbanisation continues to increase, there is an existing urban fabric that can be developed, renovated, readapted and reused.

7.4.2 Sharing

Miflin (2019) also points to the value of the circular economy practice of sharing as outlined in the EMF's ReSOLVE framework, which states that the average office is used only 35–40% of working hours. Co-working spaces, such as those provided by the company WeWork, are now commonplace in many US cities. Some of these spaces are multifunctional, such as restaurants that only open in the evening and function as co-working spaces during the day, reporting utilisation rates 2.5 times higher than the average office space of 35–40% (Miflin, 2019). Services such as Airbnb also follow this model where residential properties are shared and are therefore always in use. Such activities create income and allow for the maximum use of spaces.

7.5 'Designing for Resources': sourcing, safety, environmental impacts and end-of-life design

Table 8: The Designing for Resources measure stipulates the following key best practices

Source: Miflin (2019)
Graphics: Ninni Westerholm

SAFER MATERIAL SELECTION	'Chemicals of concern' should be excluded from building projects. This measure recommends the ILFI Living Building Challenge Red List (Living Building Challenge is a green rating certification programme). The chemical makeup of specified materials must be understood. The AIA measure encourages the setting of goals regarding material selection criteria around health and that the contractor is fully aware of and compliant with these criteria.
MATERIAL SOURCING	Material impact tracking during the construction process, via EPDs or similar, is recommended. The material sourcing measure states that products should be extracted and sourced in a 'responsible manner' and that the implications of material extraction and sourcing are to be understood. Lumber that is FSC-certified should only be used. The use of bio-based (organic) materials is encouraged whenever possible. The examples of wood, linoleum, cotton and bio-plastics are given. Such products should meet the Sustainable Agricultural Network (SAN) Standard. Material reuse, such as salvaging and high recycled content, is encouraged. Identify products where the entire lifecycle is considered, such as those that have an extended producer responsibility via a manufacturer take-back programme. The use of materials that are locally sourced should be considered. Ethically sourced materials that support fair trade, equitable labour practices and respect for manufacturing communities should be prioritised.
EMBODIED CARBON	A whole building LCA is encouraged to understand the environmental impacts of material and design choices. The use of wood, bio-based, regional, recycled and salvaged materials is encouraged in this measure for their potentially low embodied carbon properties. In terms of concrete, this measure recommends specifying concrete mixes with high percentages of supplementary cementitious materials in order to minimise the use of Portland cement due to its high-embodied carbon.
CONSTRUCTION WASTE DIVERSION	This aspect of the Designing for Resources measure recommends reducing C&D waste by recovering, reusing and recycling C&D debris. It suggests setting goals and developing strategies with the contractor. It also recommends that these goals be reviewed on a monthly basis during payment review, by asking the contractor to present waste-tracking data throughout the construction and deconstruction periods.

7.6 The role of data and technology in reducing waste generation in the built environment process

As discussed in section 3.2.1, a 2017 McKinsey report (Barbosa et al., 2017) explores productivity in the construction sector and proposes many new ways to reinvent the built environment process, specifically in regard to the construction sector or construction phase of this process. Although not classified as such, the suggested improvements, which incorporate systems thinking, are in line with circular economy methodologies such as designing out waste and pollution and keeping products and materials in use. Some examples include incorporating digitalisation techniques and providing pre-production and fabrication in offsite facilities. Such improvements involve redesigning construction practices to provide additional control over the project during fabrication within a measured environment. This potentially facilitates more sustainable practices such as reducing material use and waste during the construction process and more digitalisation of files in the construction workflow, which reduces the need for a paper trail of drawings and increases productivity by relying more heavily on digital design processes like Building Information Modeling (BIM) and/or Big Data connected to Internet Of Things (IoT). In such scenarios, overall productivity should increase as less time is spent onsite and more time is spent in the manufacturing or controlled fabrication environments. These changes in themselves involve systems thinking and an overhaul of existing construction practices. Such circular economy underpinnings could lead to enhanced productivity, a reduction in waste and the abatement of associated carbon emissions and climate change effects.

Arup's report *Circular Economy in the Built Environment* (Zimmann et al., 2016) examines a number of such technological advancements in more detail. Subsequently, a report by Arup in collaboration with EMF, 3XN architects and GXN Innovation *From Principles to Practices: First Steps towards a Circular Built Environment* (Acharya et al., 2018) outlines a vision in which data-driven models are used to consider the economic, environmental and social outcomes of a circular built environment. The AIA's *Zero Waste Design Guidelines* (Miflin et al., 2017) suggest technical interventions such as the use of data, material passports and ID tags that allow for the encoding of materials with information with the aim of greatly lowering waste creation. Such information, it recommends, could be useful for deconstructing a building and repurposing materials. Modelling a building in BIM and including such material data and information allows the building, or 'material bank', to be tracked and accessed via the virtual model over its lifecycle, from the operational and maintenance phase, to the end-of-life phase. The Carpet and Rug Institute (CRI), which represents 95% of the US carpet industry, provides a more low-tech example of encoding materials with data through its carpet labelling implementation. CRI members unanimously decided to label the underside of carpets with a list of the material makeup of the carpet, thereby making it much easier to decide upon the correct recycling procedure.

7.7 Regulations at the state and city levels towards creating awareness of a circular built environment

As has been eluded to in this report thus far, one challenge the US faces in relation to achieving a circular built environment is the lack of consistency in approaches at the city, state and federal levels and the lack of effective policy to drive change. Despite these challenges, some positive changes, driven by incentives and regulations, have taken place at the state and city levels. This section highlights a few of these.

7.7.1 San Francisco: cradle-to-cradle carpets

The City of San Francisco passed legislation in 2018 stipulating that all carpets installed in city department buildings should achieve, at a minimum, a 'silver' rating by the Cradle to Cradle Certification programme. Currently, 80% of discarded carpets are sent to landfill in the US. Coupled with this, traditional carpets often contain toxins and chemicals of concern that off-gas, among others, VOCs, which are believed to negatively impact human health and wellbeing by altering the indoor air chemistry (Katsoyiannis, Leva and Kotzias, 2008). As stated by Haines et al. (2020), 'Overall, it is clear that carpet can influence our exposures to particles and volatile compounds in the indoor environment by acting as a direct source, as a reservoir of environmental contaminants, and as a surface supporting chemical and biological transformations.' Hence, environmental and human health impacts became two key drivers of the cradle-to-cradle carpet initiative undertaken by the City of San Francisco.

In this case, the city's goal with regard to the use of materials in city buildings that benefit the environment and human health and wellbeing was achieved by focusing on shifting the built environment supply chain and creating new opportunities for suppliers to win city contracts. Under the legislation, carpets used in city buildings must not contain antimicrobials, fluorinated compounds, flame-retardant chemicals, or other chemicals of concern. Similar requirements apply to carpet adhesives. To avoid waste and ease replacement costs carpet tiles are used. Additionally, both the carpet fibres and backing materials must contain minimum amounts of recycled materials, and ultimately be recyclable at end of use. The initiative encouraged material and business innovation that was circular in its thinking and also facilitated a competitive bid process. Much research and stakeholder engagement took place for almost two years prior to the legislation being passed. Carpet specifications and requirements were developed under the leadership of the San Francisco Department of Environment with support from the elected mayoral leadership and Board of Supervisors in the city, and under the mandate of two ordinances: 1) the Environmentally Preferable Purchasing Ordinance, and 2) the Green Building Requirements for City Buildings Ordinance. This initiative is a case study as part of the EMF's 'Circular Economy in Cities' suite of online resources (EMF, 2019).

7.7.2 New York State: Low Embodied Carbon Concrete Leadership Act

In 2019, New York State implemented The New York State Low Embodied Carbon Concrete Leadership Act, which relates to state procurement policies that require low embodied carbon concrete to be used in state projects. It sets a preferential standard for concrete implementing CO2 capture and utilisation technologies. It also establishes the environmental product declaration tax credit (State of New York, 2019).

7.7.3 New York City: building emissions Local Law 97 of 2019

The legislation passed by the New York City Council in 2019 known as 'Local Law 97 of 2019' is globally one of the most ambitious pieces of climate legislation for buildings enacted by any city. It aims to cap GHG emissions for many types of buildings starting from 2024 (buildings of greater than 25,000 square feet), in order to meet the city's goal of achieving an 80% overall reduction in GHG emissions by 2050. Prior to then, the law states that a 40% reduction in citywide GHG emissions is to be achieved by 2030. Buildings that do not meet the caps could face fines. Currently buildings produce nearly 70% of total GHG emissions within the city (City of New York, 2019). This law impacts approximately 50,000 buildings, covering close to 60% of the city's built fabric, of which 59% are residential and 41% are commercial. An advisory board will help refine emissions metrics and limits (Urban Green, 2020). This law highlights the willingness and drive within certain cities in the US to move to a more environmentally progressive future.

7.7.4 Circular economy programmes and events at the city level

The New York City Economic Development Corporation (NYCEDC) and New Lab (a multi-disciplinary technology centre based in Brooklyn, NY) have launched the 2020 edition of the Circular City programme. The aim is to design and test solutions that address the grand challenges that cities face. The partnership between New Lab and NYCEDC in 2017 resulted in the creation of the Urban Tech Hub. The goal of the Urban Tech Hub is to connect the City of New York with New Lab's multidisciplinary innovative technology-driven community to create and implement significant tech-based solutions in addressing the growing environmental challenges facing cities. The Circular City is a key outcome of this partnership, which aims to position New York City as a global leader in urban innovation. The focus for 2020 is to transition the city to a circular economy and to consider the future of energy efficiency in the built environment. The expanded edition of the Circular City programme encourages startups to test technological innovations for reusing and recycling resources, eliminating waste, and improving energy efficiency through pilots in real-world urban environments across New York City.

Each year, New York City has hosted a Circular City Week since 2019 (Circular City Week, 2020). Organised by the Danish Cleanteach Hub, it aims to be a platform and event for knowledge sharing around circular economy practices and agendas. The week is intended to 'inspire industry professionals across sectors, showcase international pioneers, highlight local change makers and engage students to be the future of circularity'. The support it receives from local government entities and renowned international public and private organisations highlights the growing support and interest in circular economy in the built environment in New York City, which bodes well for such an approach becoming more relevant and mainstream in other US cities.

8. Analysis and evaluation

In the US, the dominant protagonists seeking to percolate a circular approach in the built environment (although often using alternative names and not classifying their approach as 'circular economy') are the EPA with its SMM framework (US EPA, 2015); the USGBC with the building certification systems of LEED (USGBC, 2019, 2020), which has been adopted, supported or promoted by federal, state and local governments; and the AIA through the Framework for Resilience (AIA, 2020). The key challenges to achieving circularity in the built environment in the US include the building and construction industry's continued reliance on raw materials extraction, with construction materials accounting for 73% of all US raw materials (not including fuel or food) (Matos, 2012); the increasingly inefficient use of materials and associated waste generation, with C&D waste accounting for 25–45% of the US solid waste stream by weight (Miflin et al., 2017), despite the awareness of reuse and recycling alternatives; and the lack of change and productivity within the construction sector, as discussed in section 3. According to the EMF, as presented in section 2.3, the US has no major incentive to move to a circular approach apart from its environmental benefits, due to the availability of ample land for landfill, extensive national resources for energy production, and long-established linear, throughput material economies and practices. More incentives need to be provided at the federal, state and local level to encourage and enable building sector stakeholders to shift from a linear, throughput economic model to a circular one. The federal government's RAMI Act was a step towards such a transformation. This allowed for the establishment of the Network for Manufacturing Innovation programme within NIST and Manufacturing USA, as outlined in section 5. This creation of a legislative basis for manufacturing innovation institutes within the US helps fill the gap between academic research in this area and established industry partners, thereby facilitating a shift towards a more circular approach. This has been successful in product manufacturing and has much potential in terms of rethinking the built environment process, which has a similar lifecycle to product manufacturing, despite the longer life span of a building.

9 Conclusion

The information presented in this report highlights the interconnected nature of all phases in the built environment process, from material extraction, building design, product manufacturing, and construction, to building operation and maintenance, and finally to end-of-life processes. This process consists of multiple phases that are increasingly transboundary, involving multiple built environment stakeholders. Studies (IRP, 2017; USGCRP, 2018) indicate that focusing on a single system, be it natural, built or societal, will not achieve a collective vision such as that of the UN Sustainable Development Goals (UN, 2020), but rather may cause unanticipated negative cascading impacts, if the interactions between each of the systems are not considered. Consequently, such systems are vulnerable in the face of climate change. The NCA's 2018 *Fourth National Climate Assessment: Volume II – Impacts, Risks, and Adaptation in the United States (USGCRP, 2018)* highlights the interconnected impacts of climate change by stating that *'The full extent of climate change risks to interconnected systems, many of which span regional and national boundaries, is often greater than the sum of risks to individual sectors.'*

Linking the way natural resources are used in the economy to their environmental and societal impacts across time can be achieved by employing a systems approach. Circular economy offers a systems thinking approach by connecting the material flows – from material extraction to building component dismantle or disposal – with their associated impacts on economies, societies and the environment at each stage of a building's lifecycle. As the IRP (2017) states, such an approach *'can be used to identify key leverage points; develop resource targets; design multi-beneficial policies that take into account trade offs and synergies; and steer a transition toward sustainable consumption and production and infrastructure systems'*. Hence, taking a systems thinking approach in decoupling material consumption from economic growth and reducing our reliance on the extraction of natural resources, while also reducing material waste, may offer vast environment, social and economic benefits. This also points to the role of built environment stakeholders in collaboratively working together and recognising their contribution at each stage of the overall building lifecycle. Technology and big data also have a role to play in enabling these connections and collaborative networks to be easily accessible and allowing for material and information flows to be tracked across the building lifecycle. Multi-stakeholder engagement across government, industry and academia could greatly facilitate the development of circular economy strategies, amendments to policy and building codes, and further incentives for cross-industry collaboration. A systems approach that connects building sector stakeholders, material use and new technologies with data and circular economy policies can play a significant role in the move towards a more sustainable, cost-effective and progressive built environment. Table 9 considers different lifecycle phases and potential impacts of buildings.

Table 9: Considerations for different lifecycle phases of the built environment

Source: Authors
Graphics: Ninni Westerholm

CAPITAL COSTS

MANUFACTURE	Cost benefits of the use of waste and byproducts, circular product development.
DESIGN	Lifecycle design; higher value for USGBC LEED certified buildings.
CONSTRUCTION	Productivity and economic benefits of circular building materials and activities in the construction process.
OPERATION AND USE	Lifecycle cost savings, increased value.
RENOVATION	Reusability and replaceability of building products and systems.
DECONSTRUCTION END OF LIFE	Value of recovered building products, upcycling.

OPERATIONAL COSTS

MANUFACTURE	Service life planning.
DESIGN	Design for multi-use, flexibility and adaptability per the AIA's Framework for Design Excellence, including measures for Designing for Economy and Designing for Resources.
CONSTRUCTION	Reduced waste, LEED v4.1 Waste Management credits CORR for C&D waste, a National Standard programme, named) programme, that provides ISO-level third-party certification of the recycling rates of C&D facilities.
OPERATION AND USE	Better maintainability, design and material choices contributing to energy efficiency, i.e. lower energy and other utility expenses, better return on investments.
RENOVATION	De-mountability and reusability of building products, design for disassembly and reassembly – these areas need further development.
DECONSTRUCTION END OF LIFE	As above – LEED v4.1 Waste Management credits for C&D waste. Value of recovered building products, upcycling.

ENVIRONMENTAL IMPACTS

MANUFACTURE	Reduced emissions and waste.
DESIGN	LCA design for multi-use and flexibility, design for disassembly, USGBC LEED certified buildings, net zero energy, the AIA's Framework for Design Excellence, encouraging the use of biomaterials including higher rise timber construction.
CONSTRUCTION	Reduced emissions and waste.
OPERATION AND USE	Reduced emissions and waste.
RENOVATION	Reduced emissions and waste.
DECONSTRUCTION END OF LIFE	Reduced emissions and waste, also in second life.

NEW BUSINESSES

MANUFACTURE	Digital marketplace, upcycling product development.
DESIGN	LCA design for multi-use and flexibility, design for disassembly, green design services, green certification (e.g. LEED) and valuation services, including those for net zero energy.
CONSTRUCTION	Green building business – affordable housing, higher value of real estate, green construction services driven by certification programmes such as the USGBC's LEED.
OPERATION AND USE	Next-generation building systems maintenance and servicing, space sharing platforms, rental and shared ownership models.
RENOVATION	Assessment for high-value recovery of building products.
DECONSTRUCTION END OF LIFE	High-value recovery of building products and systems.

GREEN JOBS AND SKILLS

MANUFACTURE	Developing quality products from waste streams.
DESIGN	Quality assurance of recycled products, certification and rating consultants, green design skills.
CONSTRUCTION	Green construction skills, C&D waste recovery certification and processing.
OPERATION AND USE	Retrofitting and repair artisans.
RENOVATION	High-value recovery in circular renovation.
DECONSTRUCTION END OF LIFE	High-value recovery in circular deconstruction, recyclers and assembly workforce.

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