A circular design process for material selection in site design

by

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A REPORT

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Abstract

2020 is the first year that all mass embedded in human-made products has surpassed the amount of biomass on our planet (Oxman 2020). Even so, the demands for raw materials are still increasing, when almost one fourth of the materials extracted worldwide end up as waste (OECD 2015). While there is a call for sustainably reusing site design materials, it is difficult for landscape architects to respond to the call without having a material selection process that optimizes reusing and recycling materials. However, this need for a material selection process for landscape architects can be realized through "circular design". Circular design has successfully been used in architecture and product design to help reduce project costs, emissions, waste and pollution. Yet in landscape architecture, the use of circular design is not wide spread.

To answer the question "how can a circular design process guide material selection in site design, and what are the tradeoffs when it is compared to existing linear and sustainable processes," this research proposed a circular design process for material selection in site design and applied it to the plaza design of MLK Jr. Square Park in Kansas City, Missouri. The proposed circular design process was generated from a comparative study of the existing best practices of circular design in other disciplines and from existing guidelines for sustainable materials selection. By applying the linear, sustainable, and circular design processes, three material palettes and plaza designs were created to illustrate the tradeoffs between each material selection process.

The results reveal both the benefits and shortcomings of the proposed circular design process for material selection in site design. The proposed circular design process requires more time and effort during project management, design, and construction phases than the linear and sustainable processes do. While the sustainable process addresses a wide range of environmental impacts such as reducing waste, stormwater runoff, urban heat island effect, and volatile organic compounds, the circular design process prioritizes waste reduction and resource conservation. Although the application of the circular design process for material selection in site design is challenging, due to the uncertainty of available recycled materials and the limited tolerance of irregular design elements, it performs best in reducing waste, energy and resource consumption. And because circular design prioritizes the use of recycled, reused, and repurposed materials, it also has a strong potential to reduce environmental impacts associated with material extraction, processing, manufacturing, and disposal.

Acknowledgments

I would like to express my special gratitude to my major professor Jessica Canfield for her meaningful guidance and support which helped me to proceed and reflect on the project. I also sincerely thank my committee members Kirby Barrett and Katie Loughmiller for their thoughtful comments within every meeting and review. I would not have been able to develop this report without their collaboration and input.

Big thanks to my parents and family who always selflessly support, encourage, help and love me. I would not have been able to pursue this degree without you. Also, thanks to my best friends who always give me trust and care.

Preface

In the fall 2020 semester, my Master's Project Studio focused on Martin Luther King Jr. Square Park in Kansas City, MO. As a studio, our collective efforts result in a site master plan, an activation strategy, event programming, and a funding and management strategy. Through those efforts my particular topic on material selection for site design emerged.

The motivation for this research stems from the concerns of waste and resources scarcity due to materials used in construction of the built environment. Landscape architects design with both natural and manmade materials, making materiality decisions for extraction methods, pre-consumer manufacturing, transportation distance, construction practices, use, maintenance, and post-consumer recycling and repurposing. I am driven to investigate how landscape architects can make material selection that saves the existing resources and reduces environmental damage.

This research was inspired by reading about the concept of circular design and from the book "Materials for Sustainable Sites" by Meg Calkins. While sustainable materials considerations address the environmental and human-health impacts resulting from all stages of a materials' life-cycle, circular design considerations focus on extending a materials' end-of-life by reusing and recycling. This research investigates the potential of using circular design to guide material selection in site design and its relative merits.

A Circular Design Process for Material Selection in Site Design

2021 Spring
Submitted for Master of Landscape Architecture

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Abstract

2020 is the first year that all mass embedded in human-made products has surpassed the amount of biomass on our planet (Oxman 2020). Even so, the demands for raw materials are still increasing, when almost one fourth of the materials extracted worldwide end up as waste (OECD 2015). While there is a call for sustainably reusing site design materials, it is difficult for landscape architects to respond to the call without having a material selection process that optimizes reusing and recycling materials. However, this need for a material selection process for landscape architects can be realized through “circular design”. Circular design has successfully been used in architecture and product design to help reduce project costs, emissions, waste and pollution. Yet in landscape architecture, the use of circular design is not wide spread.

To answer the question “how can a circular design process guide material selection in site design, and what are the tradeoffs when it is compared to existing linear and sustainable processes,” this research proposed a circular design process for material selection in site design and applied it to the plaza design of MLK Jr. Square Park in Kansas City, Missouri. The proposed circular design process was generated from a comparative study of the existing best practices of circular design in other disciplines and from existing guidelines for sustainable materials selection. By applying the linear, sustainable, and circular design processes, three material palettes and plaza designs were created to illustrate the tradeoffs between each material selection process.

The results reveal both the benefits and shortcomings of the proposed circular design process for material selection in site design. The proposed circular design process requires more time and effort during project management, design, and construction phases than the linear and sustainable processes do. While the sustainable process addresses a wide range of environmental impacts such as reducing waste, stormwater runoff, urban heat island effect, and volatile organic compounds, the circular design process prioritizes waste reduction and resource conservation. Although the application of the circular design process for material selection in site design is challenging, due to the uncertainty of available recycled materials and the limited tolerance of irregular design elements, it performs best in reducing waste, energy and resource consumption. And because circular design prioritizes the use of recycled, reused, and repurposed materials, it also has a strong potential to reduce environmental impacts associated with material extraction, processing, manufacturing, and disposal.

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List of Key Terms

Biomimicry: a concept that inspires design solutions from nature, demonstrating how ecological concepts can create strong, durable and intelligent materials with no waste and less energy.

Circular Design: circular design is not formally defined due to its high adaptability to various design disciplines. It is part of the circular economy thinking. The general principle of circular design is design of a closed-loop system where resources are continuously cycled in various forms. The core principle of circular design and circular economy is material recycling, reusing, and repurposing.

Circular Economy: an idea of using resources based on a circular model of production and growth instead of a highly consumptive and wasteful linear model. This is a fundamentally new way of looking at resources; a way that enable the uncoupling growth from the use of new resources by extending the life-cycle of existing resources – either by keeping them in their first use phase or by bringing them back into circulation in a new way.

Closed-Loop System: a system with continuously cycling activities where the outputs feedback into inputs in a constant cycle.

Cradle to Cradle (C2C): a holistic concept that maintains resources by reusing and recycling them after in the future.

Composite Materials: a material produced from two or more constituent materials with different chemical or physical properties. For example, concrete is a composite material, and its components are sand, aggregates, water, and cement**.**

Deconstruction: dismantling buildings/structures with the goal of maximizing material reuse potential by preserving the demolished fragments.

Demolition: knocking down buildings/structures.

DFD (Design for Disassembly): a design concept that facilitate future dismantle, deconstruction, and recovery of the used materials and components. DFD involves making provisions for the reusing and recycling of its parts.

Feedstock Selection: selecting materials based on where they come from, or how they are sourced.

Finite/Technical Material: materials that are usually man-made and not renewable in nature. Examples include glass, plastic and brick.

Homogeneous Material: having a uniform composition and in theory not able to be separated mechanically into distinct materials. For instance, plastic that is dyed contains just one homogeneous material because it is made of a combination of polymer and dye materials that are microscopically intertwined, thus making mechanical separation impossible.

Industrial Ecology: an industrial system that is designed like an ecosystem, where the wastes of a species can be resource to another species.

Man-made Material: a material that has been heavily processed in a scientific lab. Examples include plastic, polyester, steel and rayon.

Material: substances of something composed or made; both living and non-living matter that can be categorized by their use, structure, or properties.

Material Life-cycle: include raw material acquisition, primary processing and refining, manufacturing, product delivery, construction, use, and maintenance, final disposition.

MSDS (Material Safety Data Sheet): required by the U.S. Occupational Safety and Health Administration (OSHA) for all products, and sometimes used globally, and is designed to address occupational safety only and provide an incomplete assessment of the chemical hazards in a product.

Raw Material: material sourced from nature. Examples include stone, cotton, soil, and wood.

Regenerative Design: a process to restore, renew and regenerate their own sources of energy and materials in a continuous feedback loop.

Renewable/Organic Material: usually biomass or materials that are naturally renewable, examples include trees, crops and water.

Spheres of the Circle: referring to the renewable/organic material sphere and the finite/technical material sphere that make up the circle of circular design.

VOCs: violatile organic compounds

INTRODUCTION

Ch. 1

1. INTRODUCTION

1.1 The Dilemma of Construction Materials

Materials used to construct sites, buildings, and infrastructure typically include: concrete, asphalt, wood, metal, plastic, stone, gravel, sand, glass, brick, and, soil. The extraction, production, processing, and transportation of construction materials lead to numerous environmental and human health issues. The construction material industry consumes over 50% of natural resources worldwide (Horvath 2004), while material transportation and manufacturing contributed to 50% of total U.S. greenhouse gas emission in 2018 (EPA 2020). As urbanization continues to expand, the construction material industry is estimated to consume one-sixth of the worldwide freshwater reserve, two fifths of global energy, and generate 30% of the total waste worldwide (Hanafi et al. 2020). The following is a list of the major environmental and human health concerns and their linkages to the construction material industries (Calkins 2009):

1. Global Climate Change

Linkages to construction materials: greenhouse gas emissions from energy use, non-fossil fuel emissions from material manufacture (e.g., cement production, iron and steel processing), transportation of materials, landfill gases.

2. Fossil Fuel Depletion

Linkages to construction materials: electricity and direct fossil fuel usage (e.g., power and heating requirements), feedstock for plastics, asphalt cement, and sealants, solvents, and adhesives.

3. Stratospheric ozone depletion

Linkage to Construction Materials: emissions of CFCs, HCFCs, halons, nitrous oxides (e.g., cooling requirements, cleaning methods, use of fluorine compounds, aluminum production, steel production).

4. Air Pollution

Linkage to construction materials: fossil fuel combustion, mining material processing, manufacturing processes, transportation, construction, and demolition.

5. Smog

Linkage to Construction Materials: fossil fuel combustion, mining material processing, manufacturing processes, transportation, construction, and demolition.

6. Acidification

Linkage to construction materials: sulfur and NOx emissions from fossil fuel combustion, smelting, acid leaching, acid mine drainage and cleaning.

7. Eutrophication

Linkage to construction materials: manufacturing effluents, nutrients from fossil fuel combustion, smelting, acid leaching, acid mine drainage and cleaning.

8. Deforestation, desertification, and soil erosion

Linkage to construction materials: commercial forestry and agriculture, resource extraction, mining, and dredging.

9. Habitat Alteration

Linkage to construction materials: land appropriated for mining, excavating, and harvesting materials. Growing of bio-materials, manufacturing, waste disposal.

10. Loss of Biodiversity

Linkage to construction materials: resource extraction, water usage, acid deposition, and thermal pollution.

11. Water Resource Depletion

Linkage to construction materials: water usage and effluent discharges of processing and manufacturing.

12. Ecological Toxicity

Linkage to construction materials: solid waste and emissions from mining and manufacturing, use, maintenance and disposal of construction materials.

One of the leading causes of the aforementioned issues is that the construction industry typically engages in the linear process for material selection and use. The linear process for material selection and use is based on a ‘take-make-dispose’ process (IGI 2021). This process involves collecting raw materials as resources, transforming them into goods, distributing and using them as products, and disposing them as waste (IGI 2021). Each phase in the linear process leads to multiple environmental and human health impacts, and consumes a significant amount of fossil fuels, water and raw materials [1.11].

Figure 1.11 Material in a linear life. Informed by McDonough et al. 2002 and OECD 2015.

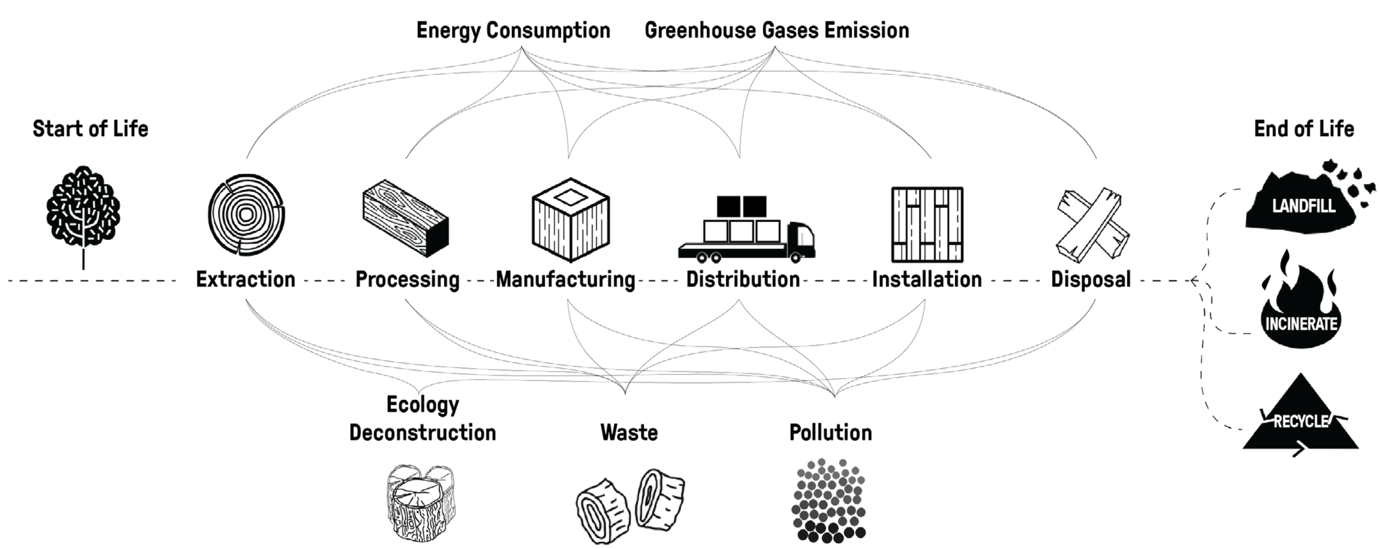


Figure 1.12 explains each phase of a material's life-cycle in the linear process and related environmental and human health impacts.

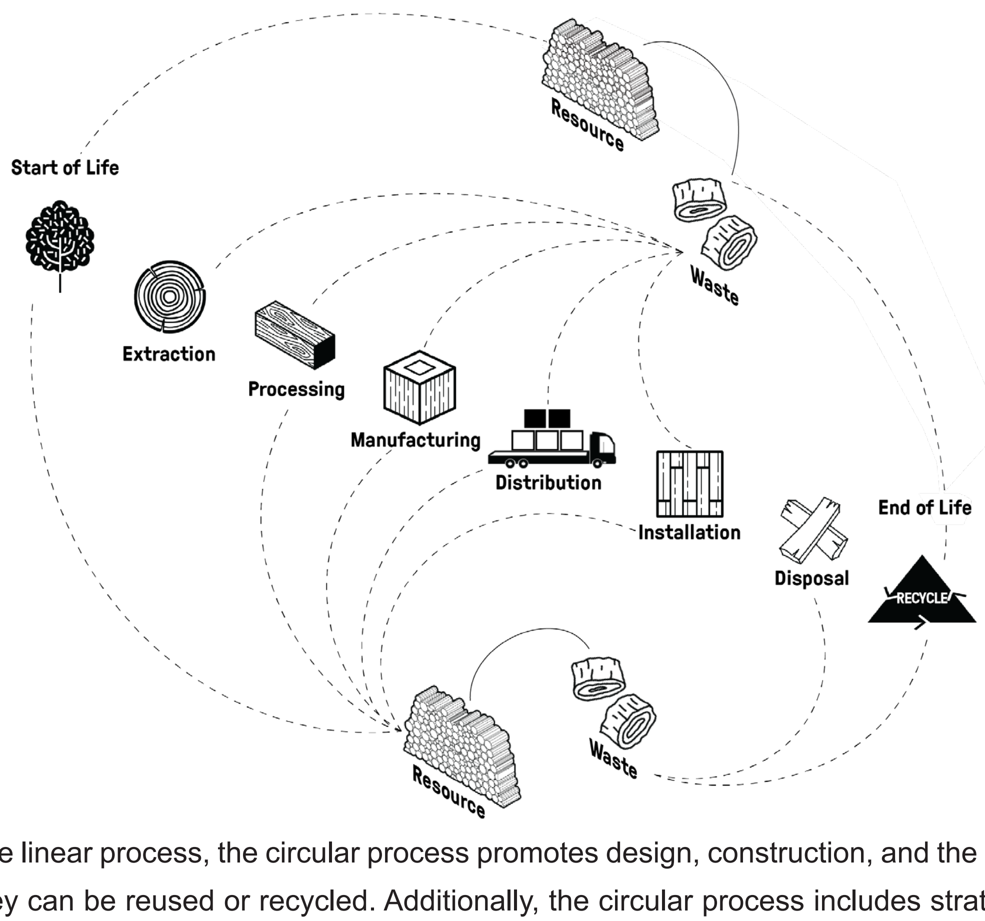
Figure 1.12 Phase of material's linear life-cycle and related environmental and human health impacts. Adapted from Calkins 2009 p.25-27 Table 2-6.

Phase of Materials' Life-cycle	Introduction	Environmental and Human Health Impacts
Extraction Raw Material Acquisition 'Start of Life'	Raw materials that are available for immediately use without additional processing and are rarely found in nature. Acquiring raw materials involves removing layers of earth and drilling which requires enormous amounts of water and energy (Gesimondo 2011). A common example of raw material acquisition is stone extracted from the earth by subsurface mining and quarrying.	The process of raw material acquisition, if not managed properly, can destroy physical and ecological systems, and can release emission and waste into the air, land and water.
Processing Primary Processing and Refining	Most raw materials require some degree of milling, cutting or curing prior to manufacturing.	This process is energy and waste intensive. For example, the waste to metals ratios during the iron and aluminum primary processing is 3:1 (Dalquist et al. 2004). Moreover, to produce 1kg usable aluminum from the raw material uses 12kg input materials and release about 15kg CO2 (Duflou et al. 2012).
Manufacturing Secondary Fabrication, Assembly and Finishing	Manufacturing includes any secondary processing such as fabrication, assembly and finishing. This process has fewer impacts partially because a lesser amount of materials is being handled. Manufacturing uses additional materials such as solvents for bonding, finishing and coating.	Some of these additional materials might contain toxic constituents and release volatile organic compounds (VOCs). The result from this process directly affects human safety and wellness.
Distribution Product Packaging & Delivery	Product delivery includes packaging and transportation among extraction point, manufacturer, distributor, site and disposal point.	This process contributes to a large amount of greenhouse gases (VOCs, CO2, CO, particulates and sulfur and nitrogen compounds) emission and fossil fuel consumption (EPA 2009). Freight emission accounted for 53% of the total global greenhouse gases emission in 2005 (EPA 2009).
Installation Construction, Use and Maintenance	This phase is also when most designers start interacting with the materials. Designers are recommended to have a plan for the expected life-time, quality, assembly and disassembly methods, and re-usability of the 'product'.	This phase is highly exposed to users for a long period of time, thus it is critical to consider its environmental and human health impacts.
Disposition 'End of Life'	The final disposal points of materials include landfills, incinerators, and manufactory of material reuse, reprocessing or recycling.	Waste ends up in landfills and incinerators release CO2 and methane, which are both greenhouse gases. Landfills that contain harmful non-degradable particles pollute water and soil.

Most significantly, the ‘end of life’ for materials in the linear process is that they end up as waste, to be managed primarily by landfilling or incineration, which furthers pollution. The primary concern for materials in the linear process is that they are not designed or constructed in ways that allow them to be reused or recycled in the future (a concept sometimes referred to as design for disassembly). Materials in the linear process can be difficult to recycled, or sometimes they can’t be recycled at all (Green 2020). Therefore, it is critical for the construction industry and related design professionals to adapt a better alternative to the linear process.

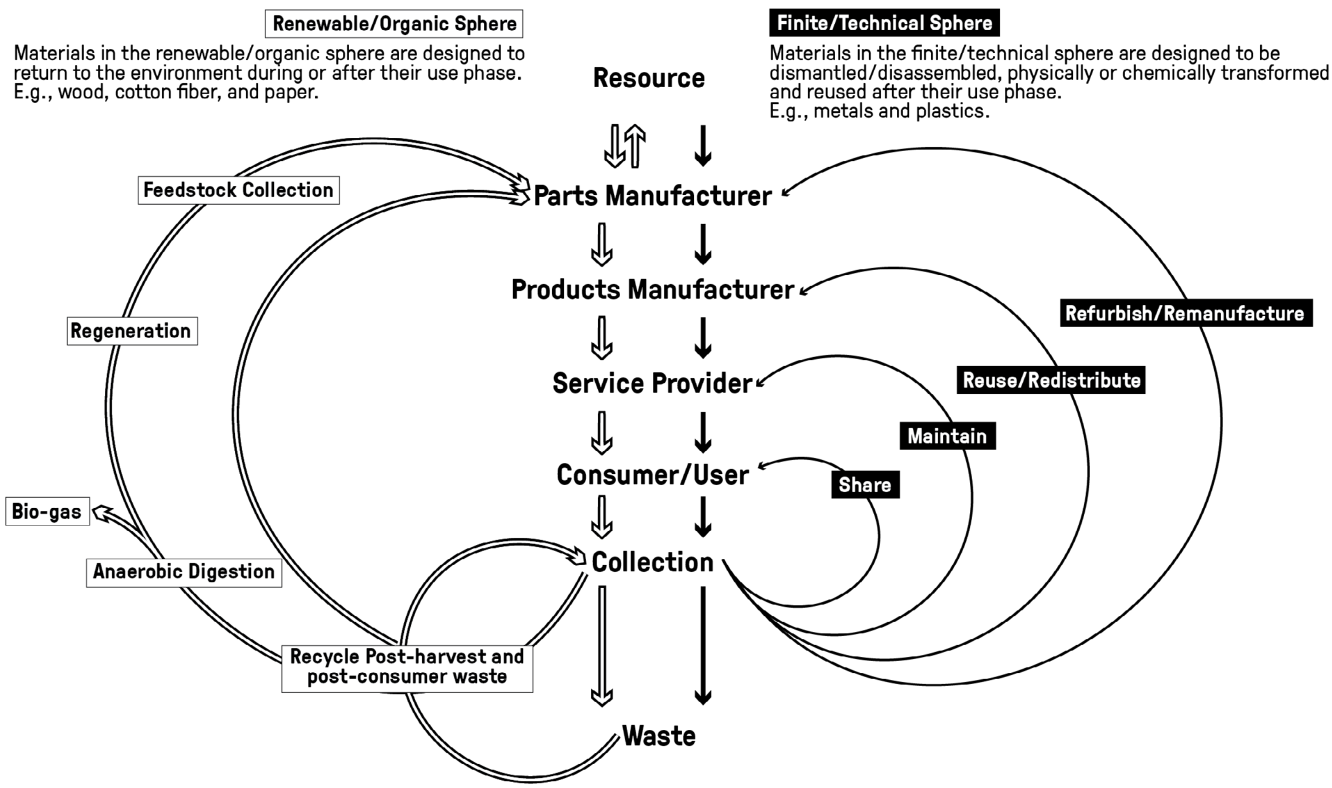
To find an alternative to the linear process of selecting and using construction materials, designers have started to establish theories and practices that examine materials in all stages of their ‘life-cycle’ to identify and reduce negative environmental impacts. As a result, a circular process that turns waste (the output) into the resources (the input) for another use emerged [1.13]. In the circular process, a material’s life extends in a continuous cycle [1.13].

Figure 1.13 Material in a Circular life. Informed by McDonough et al. 2002, OECD 2015, and Vind 2019.



Compared to the linear process, the circular process promotes design, construction, and the use of materials in ways that they can be reused or recycled. Additionally, the circular process includes strategies to reduce waste and pollution in all phases of a material’s life-cycle (Vind 2019). This idea of reducing waste, cost, pollution and other environmental impacts by handling materials in a circular process has become a fundamental concept of the circular economy [1.14]. According to the Ellen MacArthur Foundation, a circular economy is a concept of utilizing resources in which the resources can be used for as long as possible–either by keeping them in their first use or by bringing them back into the cycle as a new form (Ellen MacArthur Foundation 2013). This circular economy concept has been developed into a circular design approach that centers on material reusing and recycling (London Design Festival 2020). In otherwords, circular design is a design process that prioritizes the use of recycled materials, and optimizes materials' capacity to be reused or recycled at their 'end of life'.

Figure 1.14 Circular Economy Diagram. Adapted from McDonough et al. 2002, Ellen MacArthur Foundation 2013.



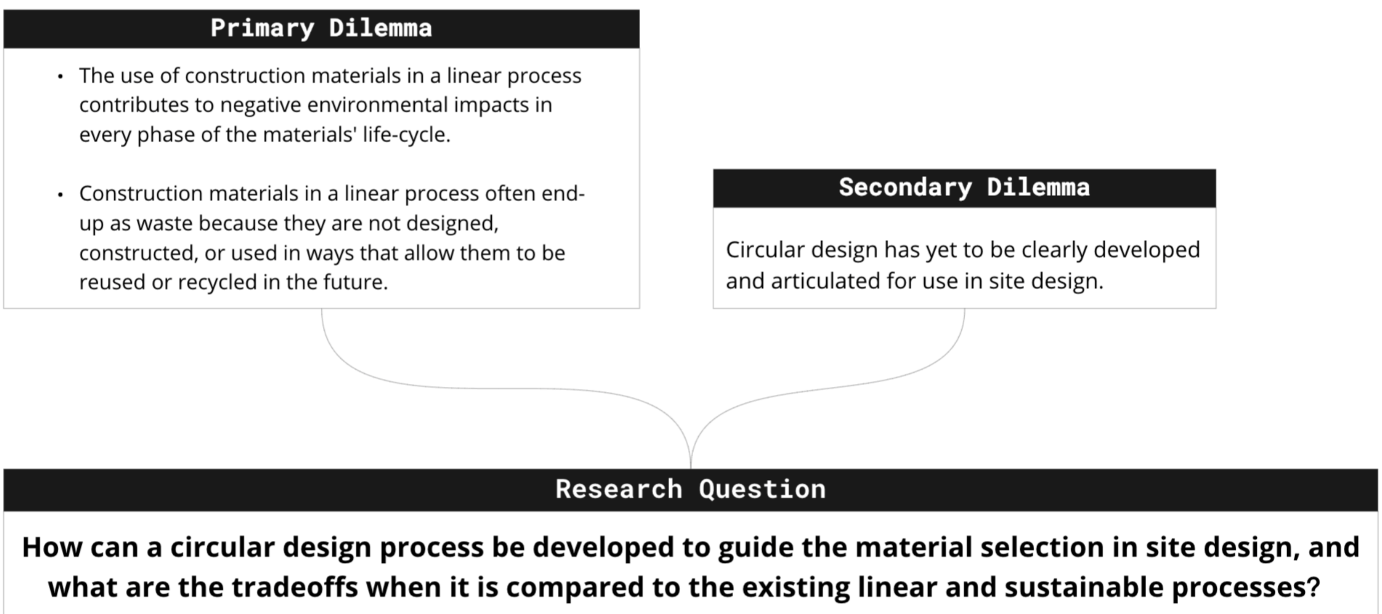
According to the "Circular Economy in Cities and Regions: Synthesis Report" by OECD, the principles of circular design and circular economy have been successfully used in multi-disciplinary design industries to reduce the costs, emissions, waste, and pollution (OECD 2020). The principles of circular economy have been well adopted in frameworks and best practices for material selection in architecture and product design, such as "A Changemaker's Guide to the Future," "Circular City," and "Building a Circular Future," for their strength in reusing available materials and reducing energy and carbon footprints. These frameworks and best practices can be used for landscape architects to establish a circular design process for material selection of their own. However, in landscape architecture there is little literature and few project examples that focus on a circular design process for material selection. Similar to a sustainable process, a circular design process has the potential to reduce negative environmental impacts from construction materials; however, a circular design process has yet to be clearly developed and articulated for use in site design. Thus, this research project examines the potential to create and apply a circular design process to guide material selection in site design, as means to prioritize the reuse and recycling of materials.

1.2 Project Significance

It is significant for landscape architects to explore the potential of a circular design process to material selection because they design with both natural and manmade materials, making materiality decisions for: extraction methods, pre-consumer manufacturing, transportation distance, construction practices, use, maintenance, and post-consumer recycling and repurposing (Calkins 2009). While construction materials in the linear process often end-up as waste because they are not designed, constructed, or used in ways that allow them to be reused or recycled after their useful lifespan, the concept of circular design aims to reduce waste and other negative environmental impacts by increasing the rate of reusing and recycling materials after their useful lifespan. The concept of circular design has a potential to be developed to guide material selection in site design. Material selection directly impacts the use and design of construction materials. Additionally, materials selection can influence the social and ecological performance of the design.

1.3 Research Question and Goals

Figure 1.31 Dilemma and research question



To address the aforementioned dilemmas [1.31], the research question is raised: “how can a circular design process be developed to guide material selection in site design, and what are the tradeoffs when it is compared to the existing linear and sustainable processes?” To answer the research question, this project consists of the following major efforts: 1. a synthesis of existing linear and sustainable processes for material selection; 2. the development of a circular design process for material selection in site design; 3. an application of the proposed circular design process for material selection in site design; 4. a comparison between the application of linear, sustainable, and circular design processes for material selection.

To illustrate the use of the proposed circular design process for material selection, it will be applied in a projective design for a plaza at Martin Luther King Jr. Square Park in Kansas City, MO. This site was chosen due to it being the focus of the concurrent Master’s Project Studio. Both the linear and sustainable processes will also be applied in projective designs for the plaza as means to compare and identify tradeoffs between all three material selection processes.

To conclude, the primary goal of this project is to create a circular design process for material selection in site design, and to explore its applicability in a projective site design.

BACKGROUND

Ch. 2

2. BACKGROUND

2.1 Why Materials Matter

Merriam-Webster defines materials as “the elements, constituents, or substances of something composed or can be made; matters that has qualities which give it individuality and by which it may be categorized” (Merriam Webster 2020). In otherwords, materials can be living or non-living, and they can be categorized by their use, structure, or properties.

Materials matter because people live in a physical world of materials. The food, clothes, houses, and streets are all made from and embody massive quantities of materials. Materials are either directly sourced from nature (raw materials) like stone, cotton, soil, and wood, or they are made through scientific processes (man-made materials) like plastic, polyester, steel, and rayon. Although man-made materials have gone through processing, their original materials have been derived from nature (OECD 2015).

The development and use of materials have come a long way since the Industrial Revolution, with both positive and negative impacts. The development of synthetic material technologies, nanotech materials, and high-performance composite materials have helped technology to advance (Gesimondo 2011). However, mass production has led to the rapid consumption of raw materials and has created tremendous economic and technological benefits, but the major concerns are the environmental impacts. The global consumption of materials was 31 Gt, or gigatonne (1Gt=1x10^12kg) in 1980, and is projected to reach 100 Gt by 2030, due to increasing population and economic growth (OECD 2015). With the increased consumption of raw materials, resource scarcity has become an urgent issue. The reproduction of natural materials occurs at much lower rates than rates of material extraction.

The depletion of natural material resources is also exacerbated by climate change. Evidence shows that increasingly natural catastrophes, such as cloudbursts, hurricanes, floods, droughts, wildfire and famines are negatively impacting cities, crops, forests, water, and animal species worldwide (Berlemann 2017). These catastrophes directly impact sources of materials, like the direct loss of available wood and plants in the forests. On the other hand, the construction recovery efforts after climate catastrophes, like the rebuilding of seawalls, results in added consumption of materials and further depletion of resources.

However, while the construction industry is consuming more and more raw materials, the used materials that end up as waste are accumulating. In 2008, along with 62 Gt of raw materials that were extracted and entered into the global economy, an additional 44 Gt of materials were extracted but not used in production processes, resulting in about a fifth of the materials extracted worldwide ending up as waste (OECD 2015). Facing these challenges, the construction industry and related professions are changing the existing linear process of material selection and use to a more sustainable alternative.

2.2 The relationship between Closed-Loop System, Sustainable Design, and Circular Design

In the past few decades, a sustainable alternative to the linear process for material selection and use has emerged–called a closed-loop system. In this process, all stages of material's life are sought to be less harmful to human and environmental health by using strategies of renewing, recycling, remanufacturing, reusing, and composting (EPA 2009). In "The Sustainable Sites Handbook: a Complete Guide to the Principles, Strategies, and Practives for Sustainable Landscsape," Calkins states that an ideal material life is a closed-loop cycle, where waste from one process can become feedstock or resource for another process and none is released to the environment (Calkins 2012).

The term 'closed-loop' is an adjective, used to describe a process, a system, or a cycle where the outputs feedback into inputs in a continual way (McDonough 2002). In the last two decades, the term has gained popularity in the design industry after the book "Cradle to Cradle: Remaking the Way We Make Things" established the idea by integrating the eco-efficiency concepts, and proposed a sustainable design approach to manage materials in a closed-loop (McDonough 2002). This approach of creating closed-loop material systems is mentioned in "Materials for Sustainable Sites" as one of the sustainable strategies to reduce and eliminate waste and pollution (Calkins 2019).

The closed-loop system has been incorporated into many sustainable design philosophies, concepts, and frameworks, like circular economy and design, industrial ecology, biomimicry, cradle to cradle design, and regenerative design. Figure 2.21 shows the relationship of a closed-loop system to other associated design philosophies, concepts, and frameworks.

Figure 2.21 The relationship between closed-loop system, sustainable design, circular design and related design concepts

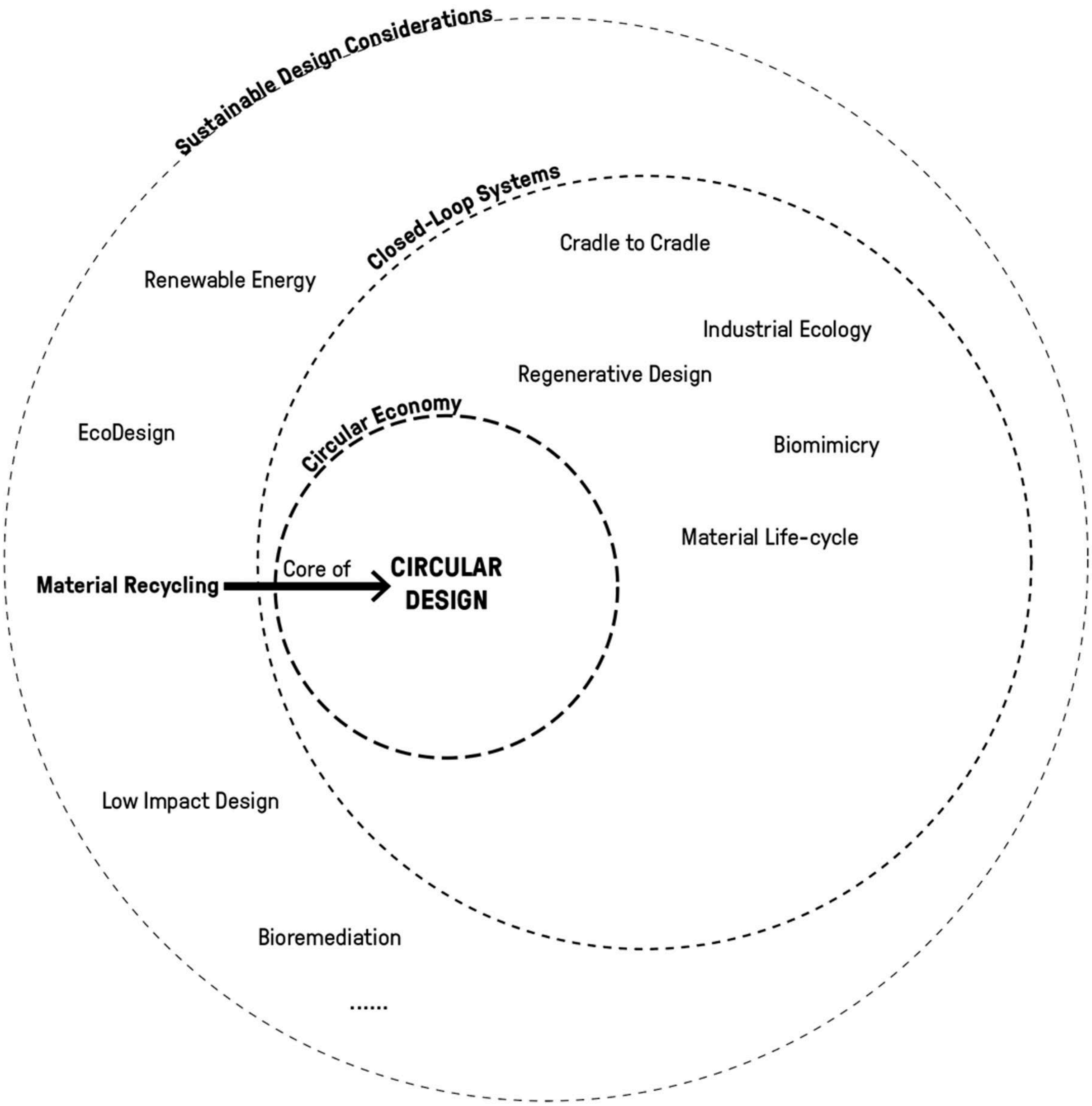


Figure 2.22 (on the next page) explores similar sustainable concepts (including: closed-loop system, industrial ecology, regenerative design, cradle to cradle, biomimicry, circular design and economy) in relation with their current status in architecture and landscape architectue, and their considerations for materials.

Figure 2.22 Closed-loop system, circular design and other related concepts.

IDEAS	Introduction	Current Status in Architecture and Landscape Architecture	Consideration for Materials
Closed-Loop System	A system with continuously cycling activities. In the last two decades, there is a shift from linear material production and consumption to a closed-loop system with recycling activities (Calkins 2009)	It is a general term that has been incorporated into many design philosophies, concepts and frameworks such as circular design, regenerative design, and cradle to cradle. In "The Materials for Sustainable Sites", Meg Calkins advocates for a closed-loop system for materials in landscape design practices with comprehensive design considerations encouraging resources reuse (Calkins 2009).	Closed-loop system is a broad and general term to describe any cyclic or circular system. The life-cycle thinking of materials is a closed-loop system; and all the ideas discussed in the table is built on a closed-loop system
Industrial Ecology	In a 1989 "Scientific American" article, Robert Frosch and Nicholas E. Gallopoulos argued that industrial systems should behave like an ecosystem where the wastes of a species may be a resource to another species (Frosch 1989). Industrial ecology as a field of scientific research has grown quickly in various disciplines such as design, engineering, and politics (Wong 2004).	No established framework or best practices in landscape design. Although industrial ecology is less mentioned in landscape design, it's principles can be found in many existing practices, and it has influenced later models in architecture and landscape architecture such as circular design (Wong 2004).	Life-cycle thinking of materials is an important part of industrial ecology (Frosch 1989). A well-known example is Kalundborg Eco-industrial Park in Denmark, where the large power plant, oil refinery, pharmaceutical plant, and other industrial entities reuse byproducts and waste heat from one another (CADDET 1999).
Regenerative Design	In 1994, John Tillman Lyle published "Regenerative Design for Sustainable Development." which is the first book to establish regenerative design framework in the built environment (Lyle 1994). The major concept of regenerative design framework is a process to restore, renew and regenerate their own sources of energy and materials in a continuous feedback loop (Lyle 1994). This framework is most recently used in agriculture, architecture, urban design, and landscape design.	The most well-known one is developed by Perkins+Will in 2008 with the University of British Columbia (Cole et al. 2012). From the recent publication such as "Regenerative Design Techniques: Practical Applications in Landscape Design" by Pete Melby and Tom Cathcart, "Regenerative Urban Design and Ecosystem Biomimicry: by Maibritt Pedersen Zari, and the "Regenerative Design for Creating an Autarkadian Energy Landscape" by Tang Y, the regenerative design in landscape architecture is developing towards food production, renewable energy, ecological habitat and biodiversity restoration, and climate resilient design.	Consideration for materials is not the major focus and less discussed. No established framework or best practices about materials in landscape design.

IDEAS	Introduction	Current Status in Architecture and Landscape Architecture	Consideration for Materials
Cradle to Cradle (C2C)	In 2002, William McDonough and Michael Braungart published “Cradle to Cradle: Remaking the Way We Make Things” which reiterated much of the concepts developed by Lyle’s regenerative design (McDonough 2002). The difference is, that C2C design is more holistic, which is not only used in design and manufacturing, but also in social model, industry and business (McDonough 2002).	Since it is holistic and highly adaptive to various disciplines, C2C is the “cradle” of other models such as closed-loop systems and circular design (Vind 2019). On the other hand, since it is holistic and broad, it is used more often as a fundamental philosophy or concept (e.g. 2010 ASLA honor award project: Park 20/20 by William McDonough + Partners). There is no established C2C framework specific to landscape design.	Consideration of materials is an essential part of the C2C The current C2C model represent a life-cycle where materials are circulating in healthy, safe and metabolic way (McDonough 2002). Again, due to its broadness, C2C is mostly used as inspiration, philosophy or design concepts where material is one of the layers.
Biomimicry	In “Biomimicry: Innovation Inspired by Nature” by Janine Benyus inspired designers to seek nature’s solutions for their practices (Benyus 2002). Biomimicry demonstrates ecological concepts to create strong, durable and intelligent materials with no waste and less energy in industrial products, architecture and landscape architecture (Calkins 2009).	There is no established framework in architecture or landscape design. Instead, it is considered a principle that is used as fundamental concepts and philosophy, or used as part of sustainable strategies in landscape design. A well-known landscape design example is the Oyster-Tecture by SCAPE.	Biomimicry projects in architecture and landscape design often consider innovative materials and innovative use of materials to create a closed-loop system. These projects often emphasize and showcase the ecological function the materials provide.
Circular Design & Economy (Research Focus)	Circular design is not formally defined because of its high adaptability to various design disciplines. The general principle of circular design is design of a closed-loop where resources are continuously cycled in various forms (Ellen MacArthur Foundation 2013). It is based on the principles of circular economy; thus, it is often discussed as design and the circular economy. Circular economy is well developed into standards, frameworks and best practices in industry, architecture, urban design, agriculture, business, and policy making. It has been practiced and advocated worldwide especially in Europe, where it has made a significant progress in recycling resources and reducing carbon emission in the last fifty years (OECD 2015).	There is no established circular design framework for landscape architecture. However, publications of circular economy frameworks and best practices, such as “A Changemaker’s Guide to the Future”, “Circular City”, and “Building a Circular Future”, often include projects of architecture, urban design and landscape architecture as circular design example that implement the principles of circular economy to reuse, recycle and redesign the flow of materials.	Considerations of material life-cycle is the major part of circular design and economy. The core of circular design and economy is material reuse, repurposing and recycling.

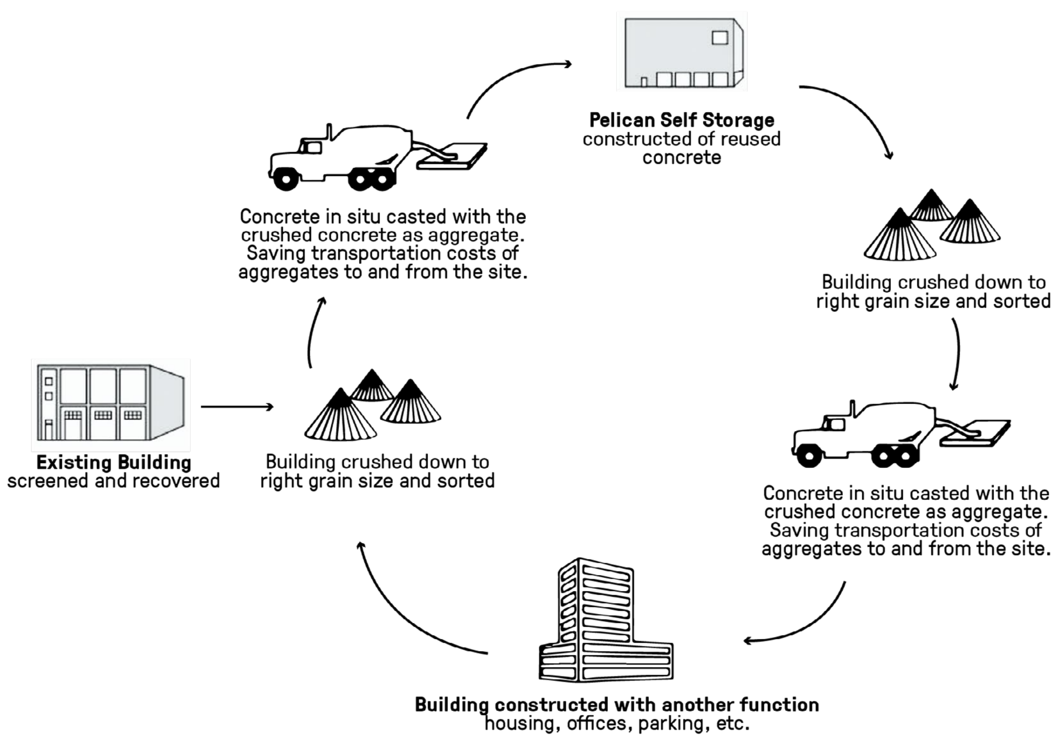
2.3 Circular Design Defined

Circular design is based on the principles of the circular economy. Circular economy is a fundamentally new way of looking at resources: a way that enables us to uncouple growth from the use of new resources and materials by extending the life-cycle of existing resources – either by keeping them in their first use or by bringing them back into circulation in a new way (Vind 2019). It was initiated as an economic system aimed at eliminating waste and the continual use of resources. Circular systems employ reuse, sharing, repair, refurbishment, remanufacturing and recycling to create a closed-loop system, minimizing the use of resource inputs and the creation of waste, pollution and carbon emissions (Geissdoerfer et al. 2017).

Circular economy and design promote a closed-loop system for handling materials. Materials as resources can be understood as the 'currency' of circular economy and design, and this 'currency' is exchangeable for different 'rates' or 'tradeoffs' depending on the serving project and region. The core of circular design and economy is material recycling (London Design Festival 2020).

In a circular design process, strategies that optimize the material reusing, repurposing, and recycling opportunity are incorporated in multiple phases of a materials' life-cycle. An example of circular design process in architecture is the Upcycle Studio project by the Lendager Group, which illustrates the reusing and recycling of concrete [2.31]. The Upcycle Studio recycles concrete in various forms such as the crushed aggregate for road base, the alternative for mixing new concrete walls, and the up-cycled concrete with crushed bricks as aggregate (Vind 2019). In this way, the concrete kept stays in use by continuously being recycled and transformed into a new form of resource.

Figure 2.31 Circular Design example of using concrete. Adapted from Upcycle Studio Project by Lendager Group (Vind 2009).



2.31 Historical Development of Circular Economy and Design

The following timeline shows the major development of circular design and economy:

1966 (approximately)

The American economist Kenneth E. Boulding described the contrast between an “open economy” with infinite input and a “closed economy” where a certain amount of input “remains forever a part of the concerns of the economy” (Geissdoerfer et al. 2017). This is most likely the origin of circular economy concept.

1976

Walter Stahel (an architect, economist, and a founding father of industrial sustainability), and Genevieve Reday sketched the vision of an economy in loops, or circular economy, and its impact on job creation, economic competitiveness, resource savings and waste prevention (Reday et al. 1976). This concept had gained attention after Walter Stahel won the third prize in the Mitchell Prize on sustainable business models (Clift et al. 2011).

1989

British environmental economists David W. Pearce and R. Kerry Turner further modelled the circular economy concept. In “Economics of Natural Resources and the Environment,” they pointed out that a traditional open-ended economy was developed with no built-in tendency to recycle, which was reflected by treating the environment as a waste reservoir (Pearce et al. 1990).

1990

Tim Jacksons, the author of “Post Growth,” moves industrial production away from an extractive linear system through a circular economy by a new approach of clean production strategies that addresses material concerns with scientific basis (Jackson 1996).

2002

William McDonough and Michael Braungart published “Cradle to Cradle: Remaking the Way We Make Things” which reiterated many of the concepts developed by Lyle’s regenerative design (McDonough 2002). The difference is, that C2C design is more holistic, which is not only used in design and manufacturing, but also in the social model, industry and business (McDonough 2002). Since it is holistic and highly adaptive to various disciplines, C2C is the “cradle” of other models such as closed-loop systems and circular design (Vind 2019).

2006

The Ellen MacArthur Foundation, one of the largest players in circular design and economy, has outlined the economic opportunity in a circular system and has brought together thoughts from complementary fields/schools to create a coherent framework (Ellen MacArthur Foundation 2006). This has given the concept of circular economy and design wide exposure and appeal.

2013

The Ellen MacArthur Foundation released “Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition,” which detailed the significant benefits, calling a net materials cost savings up to $360 billions annually towards 2025 (Geissdoerfer et al. 2017).

2017

The British Standards Institution (BSI) developed and launched the first circular economy standard “BS 8001:2017 Framework for implementing the principles of the circular economy in organizations.” It contains a comprehensive list of CE terms and definitions, describes the core CE principles, and presents a flexible management framework for implementing CE strategies in organizations (British Standards Institution 2017).

2018

The PACE (Platform for Accelerating Circular Economy) was launched by the World Economic Forum, World Resources Institute, Philips, Ellen MacArthur Foundation, United Nations Environment Programme, and over 40 other partners. PACE members include global corporations like IKEA, Coca-Cola, Alphabet Inc., and DSM (company), along with governmental partners and development institutions from Denmark, The Netherlands, Finland, Rwanda, UAE, China, and beyond (Weetman 2017).

2019

PACE released “A New Circular Vision for Electronics: Time for a Global Reboot” (in support of the United Nations E-waste Coalition (PACE 2019).

2020

The Ellen MacArthur Foundation and London Design Festival curated and promoted a selection of stories and supporting resources to empower and equip the design and creative community to seize the opportunity of the circular economy as a framework for positive global impact.

2.32 Current Status of Circular Economy and Design

Circular design still needs to be developed and integrated into various design processes and systems. Additionally, its development can be slow, even for a large corporation like Google. Google has a form for designers to record at every level of the design process including what material choice could they could make, or not make and why (London Design Festival 2020). This record helps material engineers, scientists and designers to see if and how those challenges can be overcome and how. The gradual development of circular design helps to inform the work focus moving forward.

The principles of circular economy and design have been adopted in the design standards, frameworks and best practices in product design, architecture, urban planning, agriculture, business, and policy making. It has been practiced and advocated worldwide especially in Europe, who have made significant progress in recycling resources and reducing carbon emission in the last fifty years (OECD 2015). Circular economy is found to play a critical role for European economic growth. The research and innovation of a circular economy is supported and financed by the "European Environmental Research and Innovation Policy" and the program "Horizon 2020" (Cristoni et al. 2018).

On the other hand, in the United States, the biggest players of circular design and economy are large manufacturers, waste management services and technology corporations such as Dell, Google and Republic Services (Ranta et al. 2018). The major barriers for the circular design and economy in the United States is the abundance of products and materials, and the highly product/market-oriented atmosphere (Ranta et al. 2018). The circular design challenges the current manufacturing and market culture. In "Construction Ecology", the authors point out five major challenges to a circular material system: 1. the materials of products and construction components are not all recyclable; 2. products and structures are often not designed for disassembly; 3. demolition is more common than deconstruction; 4. in the U.S. there is no requirement for manufacturers or producers to take back packaging or product; and 5.recycled and reclaimed products need to compete with newly made products (Sendzimir et al. 2002). As a result, although the idea is widespread, little speficic guidance on circular design, its monitoring, or its assessment is formed within architecture and site design in the United States.

2.33 Challenges and Gaps in Applying Circular Design to Material Selection in Site Design

Circular design encourages material recycling, however, not all materials can be reused, recycled, or repurposed. The challenges of maximizing recycling opportunities in landscape architecture can include: 1. many salvaged materials are not shared (Vind 2019); 2. the inventory of recyclable materials always change, varying by the scale of the inventory and the quantities of any given material available (Calkins 2012); and 3. there are hidden costs in reusing certain types of reclaimed materials-refurbishing, storage, disassembly, and installation for irregularities (Calkins 2012).

There is a lack of consideration for the finite/technical aspect of material selection within the few published circular design precedents in landscape architecture projects. The precedents of landscape architecture projects are far less than those of architecture and product design in the well-known publications on circular design and economy, like “A Changemaker’s Guide to the Future,” “Circular City,” “Circular Boulder,” and “Building a Circular Future.” Though most of the landscape architecture precedents in these resources showcase the regenerative design concept, which focuses on renewable energy, water and climate resiliency, and ecology habitat regeneration [2.22]. Examples of these landscape architecture projects are: “The Courtyard of the Future” by Lendager Group, “Smart Forest City” by Stefano Boeri, and “Circular City Blocks” by Jolma Architects. On the other hand, the circular design examples in architecture are a good example fi material selection and management.

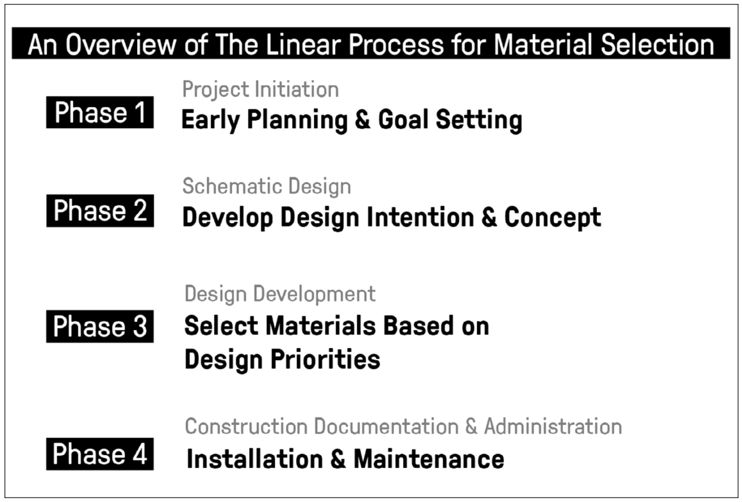
There is no established circular design process for material selection in landscape architecture projects. However, such a ‘process’ can be incubated based on the principle of circular economy, best practices for site design material sourcing, and the existing circular design frameworks from other disciplines. The dilemma is how to move from a visionary idea to tangible results, or from innovation to implementation. While no one understands the entire picture of how to truly create a regenerative, prosperous future where climate change is mitigated and the global population is thriving, many people know smaller components regarding how to achieve these goals. There is much innovation that still needs to happen, and more connections between neighboring and existing circular design based frameworks.

2.4 Approaches to Material Selection

2.41 The Linear Process for Material Selection

As discussed, the selection and use of materials in a linear system does not prioritize reduction of environmental impacts. The linear process of material selection is based on a ‘take-make-dispose’ process (IGI 2021). This process involves collecting the raw materials as resources, transforming them into goods, distributing and using them as products, and then disposing of them as waste (IGI 2021). Figure 2.41 shows an overview of the linear process typically used for material selection in site design.

Figure 2.41 An overview of the linear process for material selection



The phases were developed from the "LEED Material Selection Guidelines" (U.S. Green Building Council 2013) and "Material Selection in Interior Construction" (Geissdoerfer et al. 2017). LEED, a globally recognized certification organization for green and sustainable building development, has published material selection guidelines for building construction. The "LEED Material Selection Guidelines" provides considerations for the material selection process and a list of sustainable design considerations (extracted out from the linear process). "Material Selection in Interior Construction" establishes a linear process for material selection in interior construction with comprehensive details and examples. Following is a step-by-step linear process for material selection with a purpose and an example to explain each phase:

Phase 1: Early Planning & Goal Setting

Purpose: During project initiation, understand project priorities, opportunities, and constraints, and identify design goals that will influence selection and use of materials.

Step 1. Understand Project's Impact Priorities

Work with clients, stakeholders, community, or city to understand the project's impact priorities such as: design goals and scope; opportunity and limitation; conditions and budget.

Step 2. Establish Design Goals

According to client need and the project's impact priority, establish design goals that influence the material selection.

Example: A residential complex in a college town needed a small garden that would strengthen community and increase opportunities for informal interactions.

Phase 2: Develop Design Intention & Concept

Purpose: In schematic design, site analysis is conducted to address the design priorities, and design intention and concept are consequently developed to further identify the performance requirement of the materials.

Step 1. Site Analysis and Design Concept

Conduct site analysis and develop design concept based on project priorities. These priorities might be economic, social, aesthetic, or environmental depending on the projects and clients.

Step 2. Identify Material's Performance Requirement

Develop design intention and concept that inform material's performance requirements. These requirements may include: perception and behavior; visual characteristics; haptic sensation; health, safety, and welfare.

Example: The design priorities are safety, and the client has strong opinions about color and costs.The design included a winding path that needed to look classic and respond to the facade of the residential complex.

Phase 3: Select Materials Based on Design Priorities

Purpose: The linear process prioritizes design priorities. During design development, gain insight on how materials can be expected to perform and make decisions regarding the material selection and its detail resolution.

Step 1. Consider Materials' Attributes

Consider material's attribute along with the environmental and structural conditions of the space in which it will be installed. These considerations may include: aging and weathering; compressive and tensile strength; workability and joinery; moisture resistance; human health and safety.

Example: The proposed path needed to be made from materials that are slip-resistant, water resistant, long-lasting and low-maintenance. To meet aesthetic goals and budget, as a result, granite from another country was chosen over local options.

Phase 4: Installation & Maintenance

Purpose: During construction documentation and administration, design or select the appropriate installation method by considering how material will be maintained, repaired, and serviced throughout its lifespan.

Step 1. Review with Manufacturer or Contractor

Review manufacturer and contractor recommendations for installation and fabrication.

Step 2. Define Construction and Installation Methods

Define how materials will be constructed and installed based on materials' properties and performance characteristics, the existing site conditions, and the manufacturer and contractor's recommendations.

Step 3. Consider Installation and Maintenance Requirements

Consider how materials will be constructed and installed based on materials' properties and performance characteristics, the existing site conditions, and the manufacturer and contractor's recommendations. These considerations may include: aging and weathering;

compressive and tensile strength; workability & joinery.

Example: Granite cobbles were selected and costum-cut to fit the winding shape. Mortar joints were used for durability and avoid other maintenance in the future. The granite was sourced internationally and shipped to a manufacturer for finishing, then shipped to the project site.

The linear process of material selection will be used in Ch.4 Process Design and Ch.5 Site Design to compare with the sustainable and circular design processes.

2.42 The Sustainable Process for Material Selection

To reduce the negative environmental and human health impacts from every phase of the materials' life-cycle, the construction industry and related professions are integrating sustainable design considerations for material selection. The reduction of negative environmental and human health impacts, in material selection and use, is at the core of sustainable site design (Calkins 2012). Sustainable design considerations for material selection include topics such as design for disassembly and adaptability, design for resources conservation, use of regional materials, water and soil management, sustainability in materials manufacturing, support sustainability in plant production, transparency in reporting, and responsible extraction of raw materials (SITES 2015). The sustainable process for material selection addresses all aspects of negative environmental and human health impacts from construction materials and their uses. Figure 2.42 is an overview of the sustainable process for material selection.

Figure 2.42 An overview of the sustainable process for material selection

An Overview of The Sustainable Process for Material Selection

Project Initiation

Phase 1 **Early Planning & Goal Setting**

Schematic Design

Phase 2 **Regional & Site Assessment Related to Material Selection**

Phase 3 **Inter-exchange with Preliminary Design & Material Selection**

Phase 4 **Specify Sustainable Material**

Design Development

Phase 5 **Establish a Local Sustainable Design Collaborative**

Construction Documentation & Administration

Phase 6 **Design Iterations & Final Material Selection**

Post Construction

Phase 7 **Maintenance, Result Measurement and Post Construction Monitoring**

The sustainable process for material selection was developed from “Materials for Sustainable Sites” (Calkins 2009) and “SITES v2 Rating System for Sustainable Land Design and Development” (SITES 2009). “Materials for Sustainable Sites” is one of the most comprehensive guides to evaluate, select and use materials for site landscape design and construction. SITES is an accredited certification that establishes a rating system for informing the creation of sustainable and resilient landscape site projects.

Phase 1. Early Planning & Goal Setting

Purpose: During project initiation, understand project priorities and identify sustainable design goals that will influence the design and use of materials.

Step 1. Understand Project Impact Priority

Work with clients, stakeholders, the community, or the city to understand the project’s impact priorities that influence the design and selection of materials. Prioritize elements that relate to environmental and human health impacts such as resource conservation, support responsible extraction of raw materials, and eliminate the use of wood from threatened tree species.

Step 2. Establish Sustainable Goals and Practices

Identify sustainable goals and practices with the client, stakeholders, the city and the design team to allow extra time and budget for sustainable design.

Example: The city and stakeholders called for a park with a healthy environment that reduced carbon emission and minimized the consumption of non-renewable resources. The design should use regional materials and support sustainability in materials.

Phase 2. Regional & Site Assessment Related to Material Selection

Purpose: In schematic design, understand the local resources, human health and environmental concerns, economic and social performance requirements related to material sourcing and selection.

Step 1. Bioregional Assessment

Assess the bioregional resources and understand the opportunity and limitation of using native materials.

Step 2. Site Assessment

Following the steps from Figure 2.43-2.45 to understand the environmental concerns, owner and stakeholder priorities, and resources conservation related to the design and use of materials. Figures 2.43-2.45 are sourced from the “Site and Regional Assessment for Site Construction Materials and Products Table” (Calkins 2009) and SITES’s site assessment standards (SITES 2009).

Figure 2.43 Environmental concerns assessment. Adapted from Calkins 2012 pg.54-59.

Environmental Concerns Assessment
1. Identify sensitive ecosystems on or around the site that may be impacted by construction materials or maintenance products and process. **Purpose and Considerations:** Reduce pollution impacts from materials installation an dmaintenance activities, and the materials themselves. An example of negative environmental impacts from construction materials can be: wood with copper-based preservatives can impact adjacent aquatic ecosystems as the copper leaches out of the wood over time.
2. Identify local environmental issues and priorities around the site **Purpose and Considerations:** Avoid local environmental issues from materials installation and maintenance activities, and the materials themselves. For example, the sites located in urban or densely developed suburban areas should be selected to minimize pollution and urban heat island impacts, which means a reduction in pavement areas and high-albedo materials.
3. Identify climate or pollution conditions that may impact materials or products on the site **Purpose and Considerations:** The purpose is to avoid climate or pollution impacts on the construction materials. Climate and pollution conditions can affect the longevity of construction materials. Other examples can be: some metals corrode in environments with acid rain, high pH levels or salty air. Wood use in extremely damp environments tends to be decay without preservative or resistant treating.

Figure 2.44 Owner and stakeholder priority assessment. Adapted from Calkins 2012. Calkins 2012 pg.54-59.

Owner and Stakeholder Priority Assessment
1. Owner and stakeholder priorities **Purpose and Considerations:** Define project priorities with respect to environmental and human health impacts of materials. Some will want o minimize toxicity of materials while resource use will not be as big a concern. Others will want to use as many local material as possible to support the local economy.
2. Understand the expected life of the project **Purpose and Considerations:** Avoid waste of resources by proposing materials and products that match the expected life of the site. Appropriate detailing and connections can maximize durability of materials. More durable materials may have fewer maintenance requirements.
3. Understand the expected maintenance intensity of the site during operation **Purpose and Considerations:** Make the post-construction maintenance doable for the clients. For instance, if an owner does not want to maintain pavements, porous pavements should be avoid. Maintenance priorities of owners will vary widely and can impact choices of materials and products specified for the site construction.

Figure 2.45 Resources conservation assessment. Adapted from Calkins 2012. Calkins 2012 pg.54-59.

Resources Conservation Assessment
1. Identify in situ structure that can be reused on site **Purpose and Considerations:** Identify structure, includes sub-grade ones, on the site that can be refurbished and reused in place. Structure reuse can influence the design of the site so a detailed inventory of all structures must be undertaken prior to preliminary design.
2. Identify on-site reclaimed materials that can be recycled or reused **Purpose and Considerations:** Identify structures, including sub-grade ones, that can be deconstructed and the members reused in whole form. Include a deconstruction contractor can help identify materials for reuse.
3. Identify on-site reclaimed land clearing materials that can be recycled or reused **Purpose and Considerations:** Identify plants, soil, or rocks that can be reclaimed during site preparation and reused in new construction.
4. Identify on-site materials that can be reprocessed to use **Purpose and Considerations:** Identify structures on site that can be removed and reprocessed to use all or part of the materials.
5. Identify on-site land clearing materials that can be reprocessed for another use **Purpose and Considerations:** Identify land-clearing materials on site that can be reprocessed for another use.
6. Identify local deconstruction material outlets **Purpose and Considerations:** Identify local outlets that will recycle the used materials. These facilities should be in close proximity to the project site. Facilities that will take heavy materials should be within 50 miles of the site. A deconstruction contractor can help identify material outlets during the site assessment phase.
7. Identify off-site sources of materials **Purpose and Considerations:** Identify sources of locally manufactured, reclaimed, recycled content, bio-based, and other appropriate construction materials and products. Soils and aggregates should be extracted within 50 miles of the site, plants within 250 miles, and other materials within 500 miles.

Step 3. Defining a Sustainable Boundary for Sourcing Materials

Looking into SITES and "The Sustainable Sites Handbook" by Meg Calkins, a general sustainable distance for sourcing materials is defined [2.46]. Figure 2.46 does not include considerations on specific regional availability, and the distance should be adjusted according to the project location's resources availability.

Figure 2.46 Sustainable distance for sourcing materials. Adapted from SITES 2009 pg.60.

Material Type	Distance Requirements
Soils, compost, and mulch	Extraction, harvest or recovery, and manufacture must occur within 50 miles
Boulders, rocks, and aggregate, brick, concrete	Extraction, harvest or recovery, and manufacture must occur within 50 miles
Plants	All growing facilities and suppliers for the plant must be within 250 miles
All other materials	Extraction, harvest or recovery, and manufacture must occur within 500 miles

Example: The non-fuel mineral resources from the region where the project is located are the river rock, flagstone, limestone, sand and gravels. Other mineral industries include cement, clay and shale. Using these materials would reduce the energy cost and negative environmental impacts for further transportation. The existing stone retaining wall, lighting fixture and concrete bench were reused on site. I will recycle the concrete path and re-purpose it for the future design.

According to the regional availability and SITE's sustainable guideline, materials located further than 50 miles from the site were excluded from the selection.

Phase 3. Inter-exchange with Preliminary Design & Material Selection

Purpose: In schematic design, develop preliminary programs and materials inventory that ensure the sustainable goals and requirements of the project. The sustainable process for material selection prioritizes environmental concerns of construction materials and their design.

Step 1. Preliminary Programming and Materials Inventory

Consider preliminary programs and list out potential materials and selection criteria to ensure the sustainable design result. These considerations may include:

- programs scope
- programs flexibility
- environmental performance requirement
- social performance requirement
- economic performance requirement
- installation technique and requirement
- assembly and disassembly requirement
- social appreciation

Example: The design included a winding path that has a low embodied energy, output low carbon emissions and pose no health risk. To achieve the project priority, the trail needs to be low maintenance, and the transportation and use of materials should release output low carbon emissions during and post construction. It's preferred to be low-cost and less labor intensive.

Phase 4. Specify Sustainable Material

Purpose: In schematic design, specify sustainable materials from the previous material inventory, the sustainable material parameters and considerations that address the human health and environmental impacts throughout the materials life-cycle.

Step 1. Research Sustainable Material Parameters and Specify Sustainable Materials

From the preliminary material inventory, research and understand the sustainable material parameters such as:

- Acquisition
- Transportation & Delivering
- Processing & Refurbishing
- Secondary Processing & Finishing
- Construction, Use & Maintenance
- Post Construction & End of Life
- Ecological and Cultural Benefit

Example:

Compare the following sustainable considerations for each of the potential material:

- **Acquisition**
  - Brick: consume a significant amount of energy by firing in a kiln.
  - Concrete: One of the most energy intensive processes. The amount of carbon dioxide accounts for approximately 5% of the global emission.
  - Gravel: Less than gravel & brick due to less secondary processing.
- **Transportation & Delivering**
  - No significant difference
- **Processing & Refurbishing**
  - Brick: Need
  - Concrete: Need
  - Gravel: Need
- **Secondary Processing & Finishing**
  - Brick: Need
  - Concrete: Need
  - Gravel: Don't Need
- **Construction, Use & Maintenance**
  - Brick: Moderately easy to construct and maintain, moderate level of carbon emission
  - Concrete: Easy to construct and maintain, higher amount of carbon emission.
  - Gravel: Easy to construct and maintain, less carbon emission
- **Post Construction & End of Life**

  All can be recycled, brick and concrete need secondary process.

  Brick and concrete unit paver are easy to disassemble if used without mortar and other chemical coating.

  Gravel can be disassembled easily.

Phase 5. Establish a Local Sustainable Design Collaborative

Purpose: In design development, optimize sustainable materials performance and sustainable use of materials by a collective effort from designers, clients, engineers, contractors, and expertise.

Step 1. Collaborative Design and Material Selection Review

Communicate and get suggestions on materials selection and its implementation from local agents, contractors, engineers, and related sustainable organizations.

Example: A sustainable collaboration was established with engineers and contractors to help inform the material selection and their implementation.

Phase 6. Design Iterations & Final Material Selection

Purpose: In construction documentation and administration, develop the final material palette selection, and seek to implement sustainable practices throughout the construction process.

Step 1. Design Iterations

Co-design with contractors, engineers and other sustainable design agencies to make the final material selection and to produce a design layout that support sustainable use of materials.

Step 2. Construction Documentation

Work with contractors, engineers and other sustainable design agencies to design a construction and maintenance plan that supports the sustainable use of materials.

Example: Working with the sustainable design collaborative, various design iterations were made to faciliate the sustainable use of materials. The collaborative decided to use gravel for the trail with recycled crushed aggregate as the base to reduce carbon emissions and the need for new materials, and to reduce the cost of labor.

Phase 7. Maintenance, Result Measurement and Post Construction Monitoring

Purpose: Promote sustainability awareness and education by monitoring and reporting the sustainable materials performance over time.

Step 1. Plan to monitor and report site performance

Work with contractors and clients to develop a monitoring plan to measure the sustainable design outcomes.

Example: To measure the sustainable result and performance, a post construction monitoring plan with contractor and client input was developed.

The sustainable process of material selection will be used in Ch.4 Process Design and Ch.5 Site Design to compare with the linear and circular design processes.

2.43 Circular Design Considerations for Materials Selection

While the sustainable process for material selection addresses all aspects of environmental and human health impacts from materials' selection and use, circular design prioritizes waste reduction and resource conservation. Circular design emphasizes material recycling and construction for future disassembly and reuse. Section 2.43.1-2.43.2 explores established frameworks and guidelines for material recycling and disassembly. Section 2.43.3 studies the existing circular design guidelines for material selection in other design fields. This information is be used to develop a circular design process for material selection in site design in Ch.4 Process Design.

2.43.1 Design for Material Recycling

Design for material recycling is one of the main principles in circular design considerations for material selection. Figure 2.43.1 provides definitions of key terms related to resource reuse.

Figure 2.43.1 Definitions of key terms related to resource reuse. Adapted from Calkins 2009 pg.79 Table 4-1.

Term	Definition
Deconstruction	The dismantling of a building in such a manner that its component parts can be reused.
Demolition	A term for both the name of he industry and the process of intentional dismantling and reduction of a building or site without necessarily preserving the integrity of its components or materials for the purpose of reuse or recycling.
Recycled and Reclaimed Materials	Materials set aside from the waste stream for future reuse with minimal processing.
Reuse	The use of recycled and reclaimed materials for their original purpose or related purposes.
Reprocessed Materials	Materials that are broken down or size reduced from their unit or standard size. Although down cycled, reprocessing materials uses less energy and produces less emissions than re-manufacturing for recycling.
Recycled-content products	A new product manufactured using recycled and reclaimed materials, scrap, or waste as feedstock. Usually incurs some environmental impacts such as energy use, emissions, and waste. New product is usually substantially different than the recycled product (e.g., milk jugs recycled into plastic lumber). Recycled-content products are made from materials that would otherwise have been discarded. Items in this category are made totally or partially from material destined for disposal or recovered from industrial activities. Recycled-content products also can be items that are rebuilt or re-manufactured from used products.
Recyclable products	Recyclable products can be collected and re-manufactured into new products after they've been used. These products do not necessarily contain recycled materials and only benefit the environment if people recycle them after use.
Precycling	The decision-making process consumers use to judge a purchase based on its waste implications. Criteria include whether a product is reusable, durable, and repairable; made from renewable or nonrenewable resources; over-packaged; or in a reusable container.
Upcycling	Taking a low-grade material and turning it into a higher-grade material, often using human energy.
Downcycling	Taking a high-grade material and turning it into a lower-grade material, often using fuel energy. Reusing a product, component, or material for a purpose with lower performance requirements than it originally produced.
Closed-loop recycling	A recycling process in which a manufactured product is recycled back into the same product without significant deterioration of the quality of the product. Materials that can be recycled in this fashion include steel and other metals, as well as glass and some types of plastics.
Resource recovery	A term describing the extraction and use of materials and energy from the waste stream. The term is sometimes used synonymously with energy recovery.
Scrap	Discarded or rejected industrial waste material often suitable for recycling.

In the “Resource Reuse: Designing with and Specifying Reclaimed, Reprocessed, and Recycled-content Materials” chapter in “Materials for Sustainable Sites”, Meg Calkins provides a list of considerations for using reclaimed materials in site design (Calkins 2009).These considerations are used as reference in the development of the proposed circular design process for material selection in site design in Ch.4 Proposed Circular Design Process.

- Let the materials inspire the design.
- Locate materials early in the design process to avoid major design revisions when materials are found.
- Maintain flexibility in the design until materials are found.
- Use materials with interesting “stories” or cultural significance to the project.
- At start of project, evaluate project sites and old buildings for materials to reuse.
- Hire demo contractors with experience in deconstruction and salvage.
- Require contractors with experience in deconstruction and salvage.
- Require contractors to provide a plan for construction and demolition salvage and recycling.
- Use materials for their highest use—avoid “down-cycling.”
- Include appearance and environmental performance standards in the specifications.
- Get the contractor on board with using salvage early in the process.
- Avoid reuse of materials that are considered hazardous (e.g., CCA treated lumber) or remove hazardous finishes (e.g., lead paint) in a controlled manner.

The following is a guideline for design for material recycling. This process is developed from: “Materials for Sustainable Sites” (Calkins 2009), “Design and Detailing for Deconstruction” (Scotland Environmental Design Association 2010), Comprehensive Procurement Guidelines (U.S. Environmental Protection Agency 2012):

I. Planning the Material Recycling

Early goal setting that involves the client and the design team to allow extra time and budget is essential. Establishing measurable project goals such as the reduction of cost and labor, as well as the culture and environmental benefits. It is recommended to get the contractor on board with using salvage early in the process, so that the contractor can help provide a plan for construction and demolition salvage and recycling.

II. Locating Available Materials

It is essential to locate available materials that can be reclaimed, recycled, or reused in the early design process to inspire the design and to avoid major design revisions due to material availability. Designers need to understand the local resources for recycled, salvaged, and reclaimed materials, and deconstruction materials outlets. The local resources can include salvage stores, local contractors, municipal developers and clients who are involved in deconstruction projects, local park and recreation salvage yards, online materials exchange and salvage distributors. Some national resources for recycled and recycled content materials are listed below:

- U.S. EPA Comprehensive Procurement Guideline (CPG) program database
- GreenSpec Directory
- Oikos Green Building Source
- RecyclingMarket.net
- CIWMB Recycled Content Product Directory
- King County Environmental Purchasing Program
- Materiom
- Cradle to Cradle Certified Products Registry

III. Site Assessment

During the site assessment and analysis process, designers should evaluate the project's site currently under design, and adjacent deconstruction project sites, if there is any, for sourcing reusable materials. The evaluation should include: 1. in site structures and products that can be reuse in whole; 2. onsite materials that can be recycled, reclaimed, or reprocessed to reuse; 3. onsite land clearing materials that can be recycled, reused or reprocessed; 4. Adjacent deconstruction materials.

IV. Let the Materials Inspire the Design

Materials can inspire the design. For example, using local materials can reflect the historical/culture background and identity. The design of Menomonee River Valley Plaza, Milwaukee, WI, by Wenk Associates reflects and strengthen the site's identity in an industrial district by using recycled smokestack and concrete pipes as design features.

V. Design with Recycled Materials

Designers need to spend extra time and effort to specify recycled materials. It is highly recommended to work with contractors to determine the materials used, the size and quantity and installation methods. The contractor can help provide a plan for construction and demolition salvage and recycling materials. Non-hazardous treatment, coating or finishing of materials should also be specified. While the cost of salvaged materials is often less than new materials, designers need to work with contractors to see if there is extra labor costs for refurbishing and installing recycled materials.

2.43.2 Design for Material Disassembly

Beside the design for recycling, design for material disassembly is another significant aspect of circular design. Design for disassembly (DFD), or sometimes design for deconstruction, is a concept in which the site, structure, building or product is intentionally designed for future material recovery, ensuring the materials in the product can be recycled or that whole components can be reused (World Business Council for Sustainable Development 2020). The major goal of DFD is to promote a closed-loop material life cycle by using design strategies that make future end-of-life recycling easier (Calkins 2009).

The following is a process for DFD, which has been informed by: "Materials for Sustainable Sites" (Calkins 2009), "A Guide to Design for Disassembly" (Cutieru 2008), "DFD: Design for Disassembly in the Built Environment: A Guide to Closed-Loop Design and Building" (Guy et.al 2004).

I. Planning the Disassembly/Deconstruction

Early goal setting that involves the client and the whole team to allow extra time and budget is essential. Establishing DFD targets and benchmarks that are measurable such as a percentage of structure/site reused, the numbers of times a component is reused, and the site and structure's longevity.

It is important to plan for change and design for maximum flexibility and adaptability. For site design, flexible spatial configuration and multiuse spaces are preferred. For both site and structure, ordering extra materials or spare parts will save time and energy for adjustment, repairs or replacement.

II. Assessing Materials

Research the recycling stream will help designers assessing and specify materials with good reuse or recycling potential. Sometimes materials and products from manufacturers have a take-back program in place. When specifying materials for DFD, the hierarchy is materials that can be: 1. reused, 2. recycled, 3. easily removed. Avoid composite materials and complicated assemblies unless the design can be reused in whole form. When designing site or structure for DFD, standard size materials, structure and site design that are flexible, durable and modular are highly preferred. Durable materials that are carefully disassembled or deconstructed can be reused many times. During this process, designers can develop a set of disassembly or deconstruction drawings that might include: "As-built" drawings listing all components and materials in project, including all manufacturer contacts and warranties, three dimensional or section drawings showing disassembly and information on hidden or subgrade materials, specifics on connections and their disassembly and materials finishing or chemistries. Figure 2.43.2.1 shows the common construction materials' capacity to be disassembled.

Figure 2.43.2.1 Common construction materials' capacity to be disassembled. Adapted from Calkins 2009 pg.93 Table 4-8.

Materials that are Relatively Easy to Disassemble	Materials that Require Additional Labors to Disassemble
Non-mortared unit paver: concrete, brick, stone Interlocking block retaining wall systems: no mortar Low-impact foundation technology Gravel trench foundations Aggregates Pre-cast concrete element	Unit walls (brick, stone, CMU) with lime mortar Unit paving (brick, stone, concrete units) with lime mortar Untreated lumber Plastic lumber Metal structures with mechanical connections
Materials that Require Reprocessing after Disassembled	**Materials that Can't be Disassembled**
Concrete slabs and walls Asphalt pavement Soil cement Rammed earth Aggregates Recyclable construction materials Metals: steel, aluminum, stainless steel, copper, iron Wood (not pressure treated) Some plastics: HDPE, LDPE, PE, PP, PS Glass	PVC product Treated lumber Some coated metals Composite products (fiberglass, composite lumber) Mixed-material assemblies that are not easily separated

III. Connection Detailing

Use bolts, screw, or standard connector palettes that are visually and physically accessible instead of chemical connections such as mortar (except lime mortar for brick disassembly), adhesives, and welds. The designed joints and connectors should be able to withstand repeated assembly and disassembly. Figure 2.43.2.2 shows the pros and cons of common construction materials' connections in terms of DFD.

Figure 2.43.3 Pros and cons of common construction materials' connections. Informed by Calkins 2009 pg.92 Table 4-7.

Types of Connection	Pros	Cons
Screw Fixing	Easily removable	Limited reuse of both hole and screws Cost
Bolt Fixing	Strong Can be reused a number of times	Can seize up, making removal difficult Cost
Nail Fixing	Speed of construction Cost	Difficult to remove Removal usually destroys a key area of element
Friction	Keep construction element whole during removal	Poor choice of fixings Structurally weaker Relatively undeveloped area
Mortar	Can be made to vari-ous strength	Mostly can't be reused (unless clay or lime) Hard to separate bonded layers
Resin Bonding	Strong and efficient Deal with awkward joints	Hard to separate bonded layers Can't be easily recycled or reused
Adhesives	Can be made to various strength	Hard to recycle or reuse; many also impossi-ble to separate
Riveted Fixing	Speed of construction	Hard to remove without destroying the component

IV. Finishing & Chemistry

It is important to specify finishes and coatings that are easily removable thus allowing for future reusing and recycling. Try to select and use materials that need no, or natural, finishes and coatings. For example, try to use tung oil or soy wax for wood, instead of chemical finishing. Some finishes and coatings that make disassembly difficult are: sealers, paint or powder coating, and some plastic-coated or electroplated metals are not recyclable.

2.43.3 Circular Design Considerations for Material Selection in Other Design Fields

As previously mentioned, there is no published circular design process for material selection in site design. However, there are existing circular design guidelines for material selection in other design fields, which can be used to inform key considerations for material selection in site design. The Cradle-to-Cradle Products Innovation Institute and the Ellen MacArthur Foundation have established multiple guidelines such as "The Circular Design Framework for Product Industry" and "The Circular Design Toolkit" for material selection and management that have been used mostly in product design. These guidelines are synthesized and reformatted into three sections: I. Smart material choices; II. Material journey mapping; III. Building a circular economy model:

I. Smart Material Choices

- **Understand the parts**

  The first step is to consider what parts constitues the product. In landscape architecture, the parts would include elements like shade structures, seatwalls, retaining walls, paving, and signage.

- **Look at the homogenous material in the parts**

  After understanding the parts, the second step is to define the homogenous materials that make up the parts, and create a list of the raw materials (stone, water, metal and etc.) and components (coatings, process chemicals, joinery and etc.) that are required to build or manufacture the parts in a product. In landscape architecture, this may include the gravel, filter fabric, PVC drainage pipe, aggregate, soil and mortar that made up a stone retaining wall.

- **Classify the spheres of the circle**

  The third step is to classify the homogenous materials defined during step two into either a renewable/organic material sphere or a finite/technical material sphere (Appendix IV. III). Materials in the renewable/organic sphere are designed to return to the environment during or after their use phase. The examples of these materials can be wood, cotton fiber, and paper. On the other hand, materials in the finite/technical sphere are designed to be dismantled/ disassembled, physically or chemically transformed and reused after their use phase. The examples of these materials can be metals and plastics.

- **Try to dig deeper**

  The chemical composition of material is often regarded as the intellectual property of its supplier and thus hard to access. The effort can be made by start identifying the highest volume materials you use and build cooperation trust with the suppliers of those materials. You can also ask the suppliers for a Material Safety Data Sheet (MSDS).

Resources are also available for materials that have been assessed for their health, reutilization, energy, water stewardship and social fairness. Designers can use these resources to limit the material choices from the beginning. These resources include:

- Cradle to Cradle Certified Materials for Designers, certified materials that are safe, more sustainable, and made for the circular economy
- EU Reach Regulation, is a list of substances of very high concern
- The Cradle to Cradle Banned List, is a list of known hazardous materials
- MaterialWise tool by Ellen MacArthur Foundation, provides crucial information about known hazards.

• Feedstock selection

Feedstock selection refers to material selection based on where they geographically come from, and how they are sourced. Circular design highly encourages selection of feedstock from recycled, reused, or properly managed renewable resources in order to avoid negative impacts on the environment and local communities, associated with from raw material extraction.

According to the Ellen MacArthur Foundation, materials in the renewable/organic sphere should be sourced in an ecological responsible and renewable manner. These materials can be derived from waste, such as agricultural byproducts and food waste.

Key considerations for renewable/organic sphere material feedstock include:

- Are they sourced locally?
- Are they recycled or reclaimed?
- Are they occurred at a slower rate than the consumption?
- Are they certified by environmental organization such as FSC (Forest Stewardship Council), PEFC (Programme for the Endorsement of Forest Certification) and the Sustainable Agriculture Standard?

Key considerations for materials in finite/technical sphere include:

- Are they sourced locally?
- How are they sourced?
- Are there any coatings, finishes, dyes, bleaching agents, or other chemicals?

• After-use phase

This step considers materials' capacity to be reused, repurposed, or recycled. Examples of those considerations are: materials capacity to be disassembled, materials capacity to be combined with others materials or chemicals, and materials capacity to maintain their value after-use.

For the renewable/organic sphere:

- Can the materials be biodegraded safely?
- Do the materials need special process, technology or infrastructure before it can return to the biological cycle? An example in landscape design can be the waste-water treatment before the harvest water return to the nature environment.

For the finite/technical sphere:

- Can the materials be recycled in their whole forms?
- What parts of the materials need to be recycled separately?
- Do the materials need extra process before it can be recycled and reused?

II. Material Journey Mapping

Material journey mapping is a holistic calculation of the 'distance' a material needs to travel from sourcing to production, from production to processing, and from processing to implementation, and then to the users/customers. In circular design, locality is highly valued for reducing energy, cost, and carbon emission. The discovery, extraction, manufacturing, installation, maintenance, and reuse of materials are important to understand within a chronological and geographical context.

III. Building a Circular Economy Model

Circular economy model is a strategic model to build a local network and achieve circular design through collaboration. The model and its application vary on the scale and speed of the circle. In order to build this model, it's important to understand inventory, the organizations involved and the supply chain. It is highly recommended to involve the supply chain and the design team in the process of making circular material choices. Also, online resources for certified materials such as "Material Health Certificate Registry" and "Cradle to Cradle Certified Products Registry" are helpful tools.

2.43.4 Circular Design Factsheets

This section synthesizes and summarizes key circular design considerations for materials commonly used in site design into a set of material factsheets. These factsheets are used as reference in the projective design in Ch. 5 Site Design. These factsheets include three categories of information: 1. Recycling limitation & opportunities; 2. Potential recycling applications; 3. Assembly & disassembly considerations

The included factsheets (see Appendix I) focus on materials commonly used in site design and construction, including: concrete, asphalt, brick, aggregate and stone, soil and sand, wood, metal (steel, cooper, aluminum, iron, stainless steel), rubber, plastic, and glass. The individual components of composite materials (a material produced from two or more constituent materials with different chemical or physical properties) are not included in these factsheets.

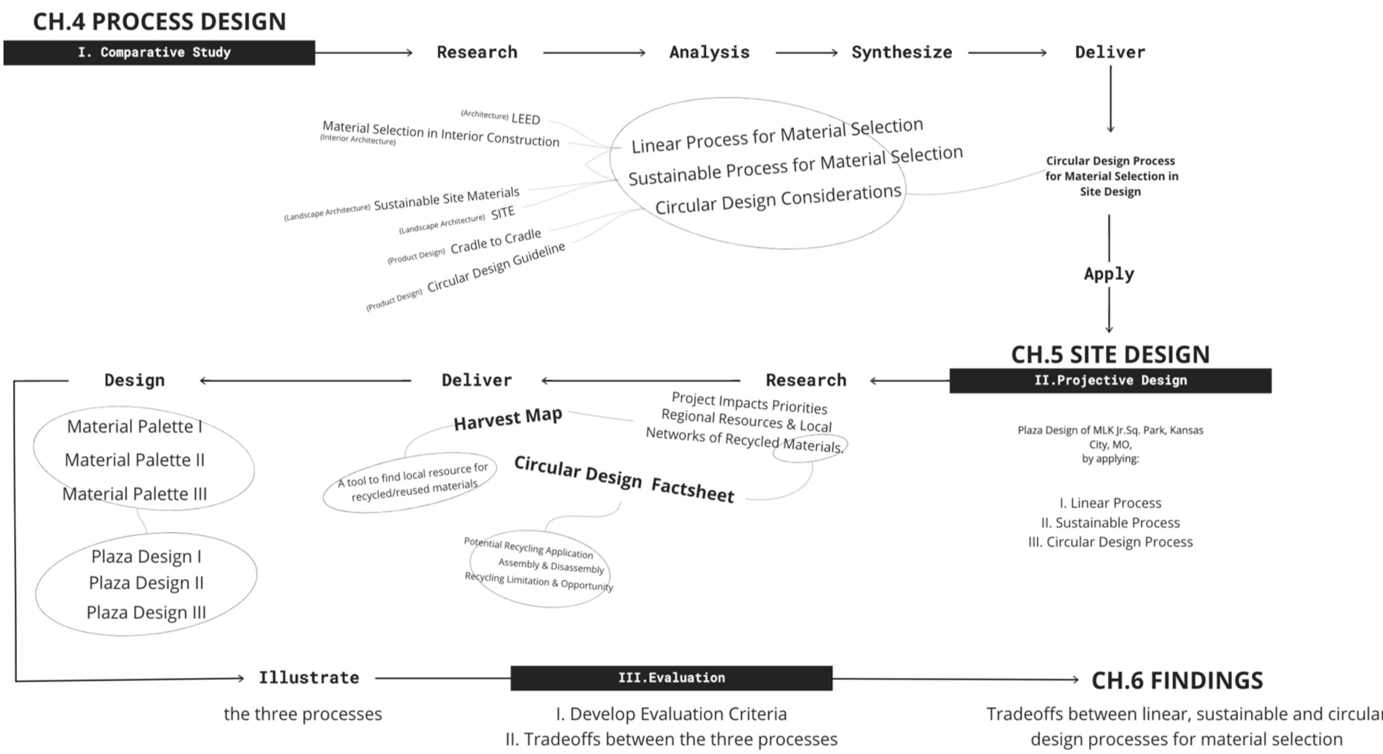
METHODOLOGY

Ch. 3

3. METHODOLOGY

While the first two chapters established the dilemmas and background for developing a circular design process for material selection in site design, this chapter outlines the methodology used to develop the proposed process in Ch.4 Process Design, and to apply the process in projective designs in Ch.5 Site Design. The methodology includes three major parts: comparative study, projective design, and evaluation [3.1].

Figure 3.1 Methodology



3.1 Comparative Study

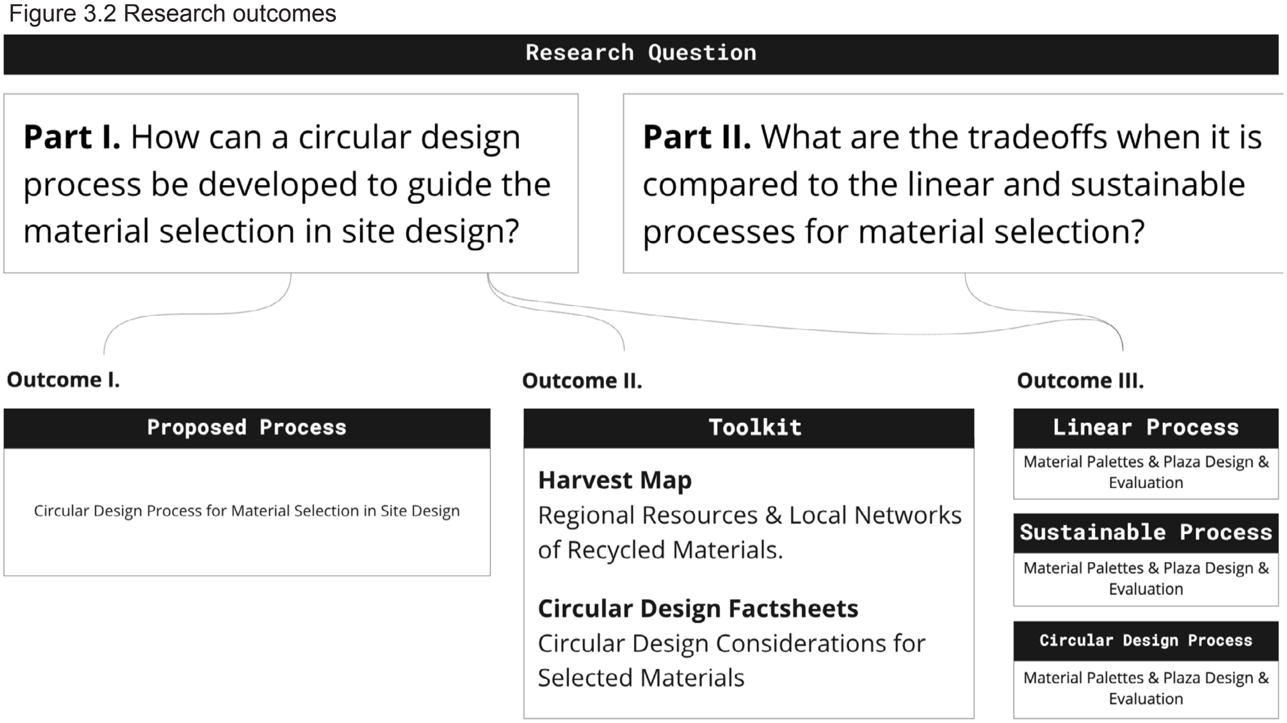
The first part of the methodology (Ch.4 Process Design) developed a circular design process for material selection in site design and compared it with linear and sustianable design processes for material selection, as described in 2.41 The Linear Process for Material Selection and 2.42 The Sustainable Process for Material Selection. This proposed circular design process is informed from 2.43.1 Design for Material Recycling, 2.43.2 Design for Material Disassembly, and 2.43.3 Circular Design Considerations for Material Selection in Other Design Fields. The primary sources include: “The Circular Design Framework for Product Industry” and “The Circular Design Toolkit” (Ellen MacArthur Foundation 2017), “SITES Rating System” (SITES 2009), “Materials for Sustainable Sites” (Calkins 2009), and “Circular City: Shaping Our Urban Future” (Vind 2009). The proposed circular design process for material selection in site design answers the first part of the research question, “how can a circular design process be developead to guide the material selection in site design.”

[3.2] The proposed process is then used to compare with the linear and sustainable design processes for material selection. The strengths and weakness for the linear, sustainable, and circular design processes for material selection in site design are illustrated and discussed.

3.2 Projective Design

The second part of the methodology (Ch.5 Site Design) is projective design. Through projective design the linear, sustainable, and circular design processes for material selection are applied to a proposed plaza in MLK Park in Kansas City, MO. In doing so, three different design concepts with corresponding material palettes were generated, compared and evaluated [3.1]. During the projective design process, research was conducted to explore regional resources and networks of recycled/reused materials, and a harvest map was developed as part of the circular design process for material selection. Three site design concepts were ceatedto illustrate the nuaunces between each material selection process. Materials' performance characteristics and environmental impacts were researched to help inform the material palettes. The three material selection processes were documented for later evaluation and comparison in Ch.6 Findings.

Figure 3.2 Research outcomes



3.3 Evaluation

The last part of methodology (Ch.6 Findings) evaluated and compared the results from the three projective design concepts. The evaluation consists of three parts: 1. Process Application Evaluation; 2. Design Results Evaluation; 3. Material Palette Evaluation. The evaluation answers the second part of the research question, "what are the tradeoffs when the proposed circular design process is compared to the linear and sustainable processes for material selection in site design" [3.2].

PROPOSED CIRCULAR DESIGN PROCESS

Ch. 4

4. Proposed Circular Design Process

4.1 Circular Design Process for Material Selection

A circular design process for material selection in site design is developed from 2.43.1 Design for Material Recycling, 2.43.2 Design for Material Disassembly, and 2.43.3 Circular Design Considerations for Material Selection in Other Design Fields. The information in the aforementioned section was adapted and modified from the following sources: “The Circular Design Framework for Product Industry” and “The Circular Design Toolkit” (Ellen MacArthur Foundation 2003), “SITES Rating System” (SITES 2009), “Materials for Sustainable Sites” (Calkins 2009), and “Circular City: Shaping Our Urban Future” (Vind 2009). Both Ellen MacArthur Foundation and GXN Group play a critical role in the development of circular economy and design. On the other hand, “SITES Rating System” and “Materials for Sustainable Sites” both provide useful information on resource conservation and materials recycling. Figure 4.1 shows an overview of the proposed circular design process for material selection in site design.

Figure 4.1 An overview of a circular design process for material selection

An Overview of The Circular Design Process for Material Selection

Project Initiation
Phase 1 **Early Planning & Goal Setting**

Schematic Design
Phase 2 **Identify and Source Materials**

Phase 3 **Specify Circular Design Materials**

Design Development
Construction Documentation & Administration
Phase 4 **Inter-exchange with Design & Final Material Selection**

Post Construction
Phase 5 **Building Circular Economy Model**

The following is the proposed circular design process for material selection in site design, with descriptions of purpose and an example to help explain each phase:

Phase 1: Early Planning & Goal Setting

Purpose: During project initiation, understand the opportunities and limitations of using recycled, reused, and repurposed materials, and establish a clear vision for circular design outcomes, such as use no new materials, or all materials should come from recycled or renewable resources, and specify the percentage of materials to be used that can be recycled in a future (e.g. design for disassembly). Allow extra time and budget for sourcing and working with recycled materials. Identify the local resources for recycled materials through the contractor, clients or other agencies.

Step 1. Understand Project's Impact Priorities

Understand project's impact priorities such as project's scope, programs need, budget, and performance requirements related to the design and use of material.

Step 2. Establish Measurable Circular Design Goals

Establish measurable circular design goals such as the percentage of existing structures or site elements to be reused, the number of times a component has been reused, or the increase in the longevity of a site or structure. Early goal setting that involves the client and the whole team needs extra time and budget for being able to source and design with recycled, reused, or repurposed materials.

Step 3. Build Local Connection for Sourcing Recycled Materials

The contractor and client may be familiar with the local recycled materials market and supply-chain. Discuss using salvaged materials early in the design phase, so that the broader project team can help provide resources for materials sourcing. Prepare a demolition or site-clearing plan with the contractor, include strategies to reuse and recycle existing resources on site.

Step 4. Plan for Design Change to Adapt to the Use of Recycled Materials

Plan for maximum flexibility and adaptability in the design with clients and contractors. Consider the following: the final length of a seatwall will depend on ammount of recycled brick available. Ordering extra material will save time and energy if adjustment, repairs or replacement is needed in the future.

Example: A public art museum needed a small garden space that was low-maintenance. The client liked the idea of using recycled materials to save resources and reduce energy consumption. The project scope allows extra time and budget to be able to use recycled materials.

Phase 2: Identify and Source Material

Purpose: In schematic design, develop a harvest map of regional resources for recycled, reused, or repurposed materials available within a sustainable delivery distance. Understand the opportunities and limitations of using recycled materials for their sites.

Step 1. Assess the Bioregional Resources

Understand the locally available materials and avoid the use or reuse of exotic materials. Using, reusing or recycling exotic materials requires extra reprocessing with more transportation which increases energy output.

Step 2. Identify Existing Resources that can be Reused or Recycled

Identify existing resources that can be reused or recycled by using the "Resources Conservation Assessment" [4.2]. Not all existing resources are efficient enough to be reused. Circular design encourages existing resource conservation with high-resource efficiency, and resources that can be easily conserved, reused, or recycled (European Commission 2003). Designers can use Figure 4.3 as a reference to access the resource efficiency for existing on-site materials.

Figure 4.2 Resources conservation assessment. Adapted from Calkins 2009.

Resources Conservation Assessment

1. Identify in situ structure that can be reused on site

Purpose and Considerations: Identify structure, includes sub-grade ones, on the site that can be refurbished and reused in place. Structure reuse can influence the design of the site so a detailed inventory of all structures must be undertaken prior to preliminary design.

2. Identify on-site reclaimed materials that can be recycled or reused

Purpose and Considerations: Identify structures, including sub-grade ones, that can be deconstructed and the members reused in whole form. Include a deconstruction contractor can help identify materials for reuse.

3. Identify on-site reclaimed land clearing materials that can be recycled or reused

Purpose and Considerations: Identify plants, soil, or rocks that can be reclaimed during site preparation and reused in new construction.

4. Identify on-site materials that can be reprocessed to use

Purpose and Considerations: Identify structures on site that can be removed and reprocessed to use all or part of the materials.

5. Identify on-site land clearing materials that can be reprocessed for another use

Purpose and Considerations: Identify land-clearing materials on site that can be reprocessed for another use.

6. Identify local deconstruction material outlets

Purpose and Considerations: Identify local outlets that will recycle the used materials. These facilities should be in close proximity to the project site. Facilities that will take heavy materials should be within 50 miles of the site. A deconstruction contractor can help identify material outlets during the site assessment phase.

7. Identify off-site sources of materials

Purpose and Considerations: Identify sources of locally manufactured, reclaimed, recycled content, bio-based, and other appropriate construction materials and products. Soils and aggregates should be extracted within 50 miles of the site, plants within 250 miles, and other materials within 500 miles.

Figure 4.3 A reference to access the resource efficiency for existing on-site materials. Informed by Calkins 2012, Azapagic et al. 2003, and European Commission 2003.

High Resource Efficiency

Types of Materials, Products and Structures	Examples	Reason
Existing structures and products that were brought to site and installed with little or no modifications on-site.	e.g. light fixtures, pumps, controllers, irrigation systems	They can be conserved and reused in situ on site.
Existing structures and products that were fabricated off-site, but assembled on-site.	e.g. structural steel, precast concrete elements, guardrail panels, fence panels	They can be removed, usually not in whole form. They need to be lightly reprocessed before reuse.
Existing materials and products that were mixed or processed off-site, but placed, cast, or finished on-site.	e.g. cast in place concrete, asphalt pavement, aggregates	They can be removed, usually not in whole form. They need to be lightly reprocessed before reuse.
Existing materials and products that were fabricated, finished, and processed on-site.	e.g. dimensional lumber, plastic lumber, piping	Connections need to be designed for disassembly to make recycle process easier. Otherwise secondary process are needed before they can be recycled and reused.
Existing products that were applied to structures on-site.	e.g. paints, sealers, glues, mastics.	They are too hard to separate.

Low Resource Efficiency

Step 3. Harvest Mapping

The concept of a harvest map comes from Oogstkaart, an online platform from Germany, designed to find leftover industrial building materials and other forms of recycled materials. A harvest map provides information about purchasable recycled materials including location and type. The following steps explain how to make a harvest map:

3.1 Define the Harvest Boundary

The boundary defines a sustainable delivering distance from site to the source of recycled materials. A sustainable material delivering distance is adapted from “SITES v2 Rating System” (SITES 2009) and “The Sustainable Sites Handbook” (Calkins 2009) [4.4]. The distance should be based on the regional availability of resources (e.g., extend the distance if no resources are available).

Figure 4.4 Sustainable material delivering distance. Adapted from SITES 2009 and Calkins 2012.

Material Type	Distance Requirements
Soils, compost, and mulch	Extraction, harvest or recovery, and manufacture must occur within 50 miles
Boulders, rocks, and aggregate, brick, concrete	Extraction, harvest or recovery, and manufacture must occur within 50 miles
Plants	All growing facilities and suppliers for the plant must be within 250 miles
All other materials	Extraction, harvest or recovery, and manufacture must occur within 500 miles

3.2 Map the Mateiral Resources

Locate the following sources within the defined boundary of the harvest map, reveal inventory from each source:

- Deconstruction Contractors
- Existing organization for recycling materials
- Salvage/Junk Yards
- Product manufacture with waste materials

Example: There are two deconstruction projects with available recycled brick and crushed aggregate near the project site. Recycled lumber and stone is also available within the harvest map area.

Phase 3: Specify Circular Design Materials

Purpose: In schematic design, develop a draft of potential materials from the harvest map to inspire the future design. Assess and specify materials according to the circular design considerations.

Step 1. Define Preliminary Programs

Define the preliminary design program based on project impact priorities and the circular design goals.

Step 2. Develop the “Parts” of Programs

The “parts” refer to the structures or elements included in the design program. For example, the “parts” may include a shade structure, seating, paving, or a retaining wall. Design and adjust the “parts” according to the availability of recycled, reused, or repurposed materials as identified on the harvest map.

Step 3. Circular Design Considerations

Develop primary and secondary material selections for the “parts” in the proposed design program. Specify materials based on circular design considerations (refer to 2.4 Circular Design Considerations and Appendix Circular Design Factsheets). These considerations are categorized into two phases: the material sourcing phase and the material end-of-life phase.

3.1 Material Sourcing

Circular design highly encourages the selection of materials from recycled, reused, repurposed, or properly managed renewable resources in order to avoid negative impacts on the environment and local communities, caused by raw material extraction. Renewable and organic materials should be sourced in an ecologically responsible and renewable manner, and then can be derived from waste, such as agricultural byproducts and food waste.

Key considerations for renewable/organic material selection include:

- Are they sourced locally?
- Are they recycled or reclaimed?
- Are they reproduced at a slower rate than consumped?
- Are they certified by environmental organization such as FSC (Forest Stewardship Council), PEFC (Programme for the Endorsement of Forest Certification) and the Sustainable Agriculture Standard?

On the other hand, key considerations for finite/technical materials include:

- Are they sourced locally?
- How are they sourced?
- Are there any coatings, finishes, dyes, bleaching agents, or other chemicals?

3.2 Material End-of-Life

Circular design highly encourages reusing or recycling materials at the end of their life-cycle. The materials’ end-of-life is determined by: materials’ capacity to be disassembled, materials’ capacity to be combined with others materials or chemicals, and materials’ capacity to maintain their value after-use.

Key considerations for renewable/organic materials' end-of-life include:

- Can the materials be biodegraded safely?
- Do the materials need special process, technology or infrastructure before it can return to the biological cycle? An example in landscape design can be the waste-water treatment before the harvest water return to the nature environment.

On the other hand, key considerations for the finite/technical materials include:

- Can the materials be recycled in the whole forms?
- What parts of the materials need to be recycled separately
- Do the materials need extra process before it can be recycled and reused?
- Do the materials need extra process before it can be recycled and reused?

Step 4. Classify the potential materials into the circular design sphere

Classify the selected materials into either a renewable/organic material sphere or a finite/technical material sphere (Appendix I). Materials in the renewable/organic sphere are designed to return to the environment during or after their initial use phase. Examples of these materials can be wood, cotton fiber, and paper. On the other hand, materials in the finite/technical sphere are designed to be dismantled/ disassembled, physically or chemically transformed and reused after their initial use phase. Examples of these materials are metals and plastics.

Step 5. Let the Materials Inspire the Design

Materials can inspire and inform design outcomes. Consider the various economic, environmental, and social benefits of the circular design materials.

Example: The design included a path in the garden. The recycled brick, crushed aggregate, lumber and stone were all potential materials to be used because they were all sourced locally, close to the site. Brick and crushed aggregate were ultimately selected because they were easy to disassemble and could be reused with minimal processing, in addition to their available quantity.

Phase 4: Inter-exchange with Design & Final Material Selection

Purpose: During design development, construction documentation and administration, revise the design based on the availability of circular design materials. Work with contractors and engineers to determine the final selection of materials that maximize the circular design performance.

Step 1. Design Iterations

Collaborate with contractors, engineers or circular design agencies. Communicate and get suggestions on design layouts that can optimize the use of recycled, reused, or repurposed materials.

Step 2. Final Material Selection

Communicate implementation can optimize the use of recycled, reused, or repurposed materials with contractors, engineers or other circular design organizations. Ensure that most of the selected materials can also be recycled and disassembled in a future phase.

Step 3. Construction Documentation

Collaborate with contractors, engineers, or other circular design agencies. Develop an implementation and maintenance plan to ensure the materials can be reused or recycled easily at their end of life.

Step 4. Design for Disassembly

Circular design encourages design for disassembly to increase the recycling rates of used materials. Develop a set of disassembly or deconstruction drawings that might include: "As-built" drawings listing all components and materials in the project, including all manufacturer contacts and warranties; three dimensional or section drawings showing disassembly and information, including hidden or subgrade materials; specifics on connections and their disassembly; materials finishing or chemistries.

Example: Excessive curve geometry was avoided in the design to reduce the nedd for custom-cut or irregular-shaped materials, thus avoiding unecessary waste pieces. Crushed aggregate paving with brick edging was selected for durability and, because they can be reused or recycled after-use. With input from the contractor, a construction document with a disassembly plan and end of life material recycling plan were developed.

Phase 5: Building Circular Economy Model

Purpose: After construction, connect and share the local resources for material recycling, which helps reduce the time and labor for sourcing and designing with recycled materials. By measuring the circular design results, the project promotes the understanding of circular design in ways that positively influences designer, contractor and client behaviors.

Step 1. Provide for storage and collection of recyclables

Provide collection containers for recyclables next to all trash receptacles. Advocate and facilitate a local recycling program on site.

Step 2. Recycle organic matter

Recycle excess vegetation generated during site construction and maintenance to generate compost and mulch.

Step 3. Establish local material recycling network

Connect and share the local resources for sourcing and recycling materials.

Step 4. Circular design result measurement

Create programs, on-site features and pop-up activities that promote and educate circular design principles in ways that positively influence user behavior.

Example: As a result, 80% of the path is made from recycled materials, which saves resource and energy consumption from using new materials. Additionally, a local material recycling network was developed in the process, to reduce the time and energy for inputting and outputting recycled materials.

4.2 Comparative Study

In previous chapters, the linear and sustainable processes for material selection were presented. In this section, they are used to compare with the proposed circular design process for material selection. Figure 4.5 shows the phases and steps of each of the three material selection process side-by-side.

While all three material selection processes seek to fulfill project goals, client's needs, and budget, they each have different priorities in terms of material selection and use. The linear process prioritizes design; the sustainable process prioritizes environmental impacts; and the proposed circular design process prioritizes material recycling. The linear process for material selection is the most straight forward where as both the sustainable and circular design processes require extra effort during project initiation, schematic design, design development, construction documentation and administration, and post construction. Moreover, sustainable and circular design processes for material selection need more multi-disciplinary collaboration in early planning and goal setting, and they are more iterative in materials specification, design, and construction detailing phases. Both the sustainable and circular design processes directly address the environmental impacts of materials, whereas the linear process inherently prioritize environmental impacts, but may do so depending on a project's goals and client's needs. The sustainable design process more addresses comprehensively various environmental impacts, while the circular design process focuses mostly on resource conservation and waste reduction. The sustainable process emphasizes research on a variety of factors of environmental impacts from construction materials and their use during the schematic design phase. The circular design process emphasizes recycled material sourcing, design for disassembly, and design for recycling.

Figures 4.6-4.8 portray the typical design process in conjunction with aspects from the linear, sustainable and circular design processes for material selection. These figures were inspired from the "Specification Process for New and Reclaimed Materials" diagrams in "Materials for Sustainable Sites" (Calkins 2009). In contrast to the linear design process, sustainable and circular design processes represent a closed-loop system. Both sustainable and circular design processes require more steps with back-and-forth thinking between the design and material selection. For the sustainable design process, early planning and goal setting directly influence the initial design. For the circular design process, the initial design is directly impacted by the availability of recycled materials. The primary difference between the sustainable and circular design processes is that circular design requires additional considerations about post- construction, including design for disassembly and planning for future reuse and recycling of materials [4.8]. The linear, sustainable and circular design processes for material selection will be further evaluated in Ch.6 Findings.

Figure 4.5 Comparison of linear, sustainable, and circular design process for material selection

Notes: The following phases and steps are specifically related to material selection. The following contents are summarized from Section 2.71, 2.72 and 4.11 in previous chapters.

Related Design Phase	Linear Process for Material Selection	Sustainable Process for Material Selection	Circular Design Process for Material Selection
Project Initiation	**Phase 1** **Early Planning & Goal Setting** **Step:** **1.** Understand project's impact priorities **2.** Establish design goals that influence the material selection	**Phase 1** **Early Planning & Goal Setting** **Step:** **1.** Understand project's impact priorities **2.** Establish measurable sustainable goals and practices with the client and the whole team to allow extra time and budget	**Phase 1** **Early Planning & Goal Setting** **Step:** **1.** Understand project's impact priorities **2.** Establish measurable circular design goals to allow extra time and budget for designing with recycled, reused, and repurposed materials **3.** Build local connections for material sourcing **4.** Plan for design changes to adapt the use of recycled, reused, or repurposed materials
Schematic Design	**Phase 2** **Develop Design Intention & Concept** **Step:** **1.** Conduct site analysis to address design priority, and develop design intention and concept that influence the material selection **Step:** **2.** Develop design intention and concept that inform the material's performance requirements	**Phase 2** **Regional & Site Assessment Related to Material Selection** **Step:** **1.** Assess bio-regional resources. **2.** Site assessment for environmental concerns, owner & stakeholder priorities, and resources conservation **3.** Define a sustainable boundary for sourcing materials **Phase 3** **Inter-exchange with Preliminary Design & Material Selection** **Step:** **1.** Consider preliminary programs and list out potential materials & selection rationales to ensure the sustainable design goals **Phase 4** **Specify Sustainable Materials** **Step:** **1.** From the preliminary material inventory, research and understand the sourcing parameters such as: • Acquisition • Transportation & Delivering • Processing & Refurbishing • Secondary Processing & Finishing • Construction, Use & Maintenance • Post Construction & End of Life • Ecological and Social Benefit	**Phase 2** **Identify and Source Materials** **Step:** **1.** Assess bio-regional resources **2.** Assess on-site materials that can be recycled, reused or repurposed. **3.** Harvest mapping for available recycled and recycled content materials **Phase 3** **Specify Circular Design Materials** **Step:** **1.** Define preliminary programs **2.** Design the programs based on the recycled, reused, and repurposed materials on-site, and the available mateirals on the harvest map. **3.** Circular design considerations for materials sourcing and end-of-life **4.** Categorized the potential materials into the two circular design spheres **5.** Let the materials inspire the design
Design Development + Construction Documentation & Administration	**Phase 3** **Select Material Based on Design Properties** **Step:** **1.** Consider materials' attribute along with the environmental and structural conditions of the space in which it will be installed **Phase 4** **Installation & Maintenance** **Step:** **1.** Review manufacturer's and contractor's recommendations for installation and fabrication **2.** Consider how materials will be constructed and installed based on the existing conditions and the recommendations **3.** Consider how materials will be maintained, repaired, and serviced throughout its useful lifespan	**Phase 5** **Establish a Local Sustainable Design Collaborative** **Step:** **1.** Communicate and get suggestion on material selection and implementation from local agents, contractors, engineers, or related sustainable organization **Phase 6** **Design Iterations & Final Material Selection** **Step:** **1.** Design iterations & final material selections **2.** Construction documentation	**Phase 4** **Inter-exchange with Design & Final Material Selection** **Step:** **1.** Design iterations **2.** Final material selection **3.** Construction documentation **4.** Design for disassembly
Post Construction		**Phase 7** **Maintenance, Result Measurement and Post Construction Monitoring** **Step:** **1.** Plan to monitor and report site performance	**Phase 5** **Building Circular Economy Model** **Step:** **1.** Provide for storage and collection of recyclables **2.** Plan for recycle organic matter **3.** Establish local material recycling network **4.** Circular design result measurement

Figure 4.6 Design process in relation to the linear material selection process. Adapted from Calkins 2009 pg.96 Figure 4-3.

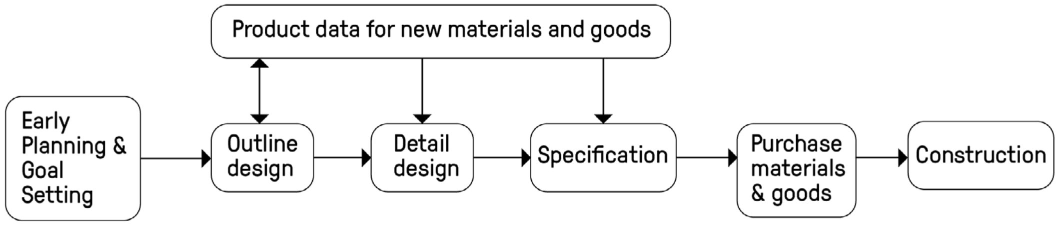


Figure 4.7 Design process in relation to the sustainable material selection process. Adapted from Calkins 2009 pg.96 Figure 4-3.

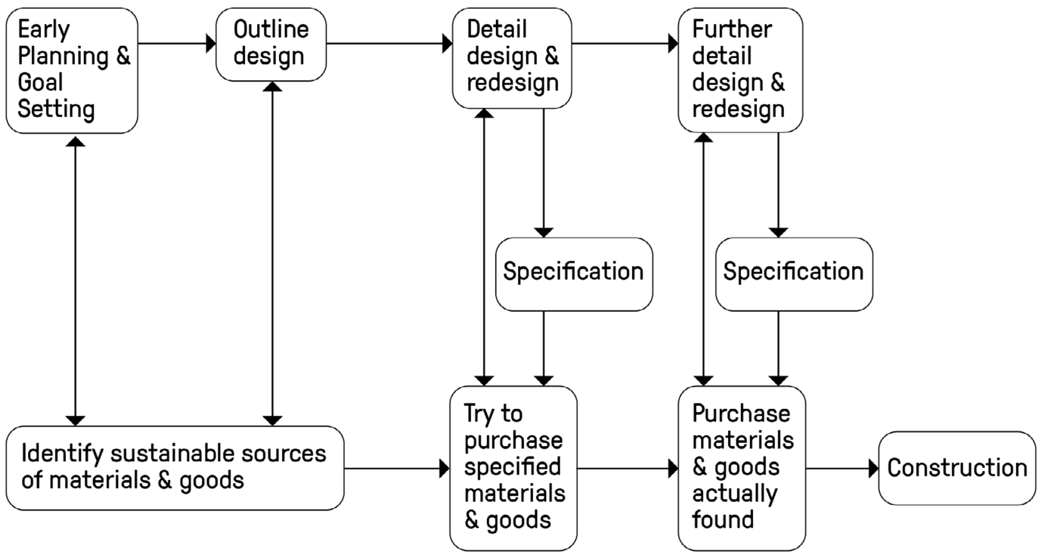
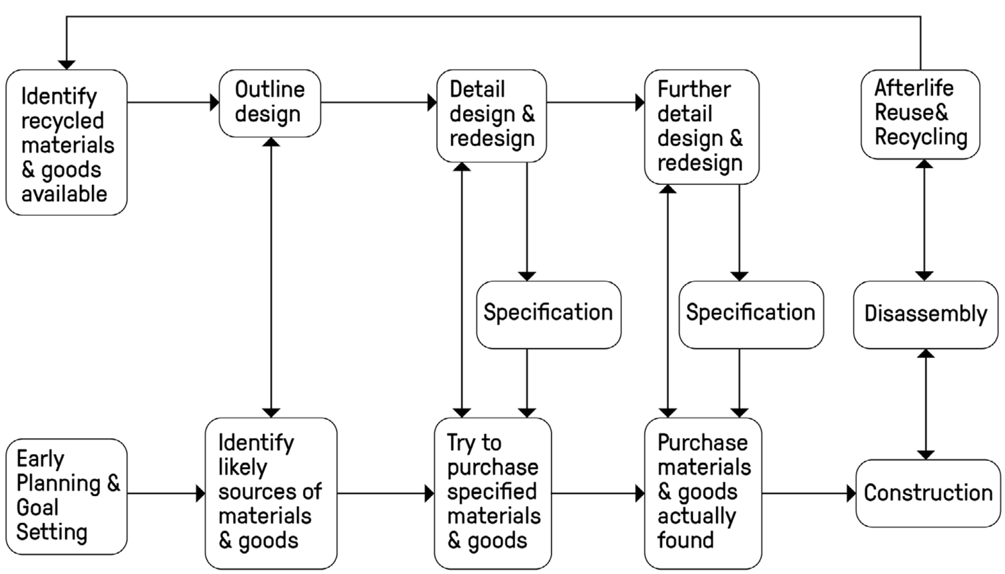


Figure 4.8 Design process in relation to the circular design material selection process. Adapted from Calkins 2009 pg.96 Figure 4-3.



SITE DESIGN

Ch. 5

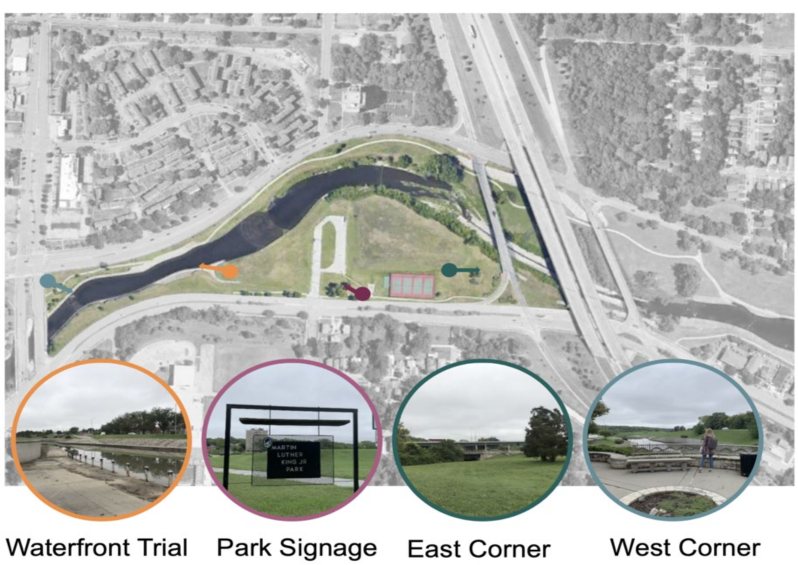
5. Site Design

5.1 Projective Design Background

The projective design portion of thsi project focuses on a proposed plaza at the Martin Luther King Jr. Square Park (MLK Park) in Kansas City, MO to show on application of the linear, sustainable and circular design processes for material selection [5.1.1]. The site was selected because it was the focus of the concurrent Master’s Project Studio in fall 2020. MLK Park is a 42 acre site that provides recreational and open space for the public [5.1.2].

Figure 5.1.1 Martin Luther King Jr. Square Park geographical context. (Master Project Studio, 2020).

Figure 5.1.2 Martin Luther King Jr. Square Park existing site context. (Master Project Studio 2020).



The studio members conducted a site analysis which revealed the following design challenges: intense grade change, lack of accessibility, flood risk, lack of bio-diversity, lack of public amenity, and a disconnected trail system. Following an in-depth site programming, the studio members collaboratively developed a site master plan that activates the park through inclusive amenities and programs that support physical activity, social connection and climate adaptation [5.1.3].

Figure 5.1.3 MLK Park proposed site master plan. (Master Project Studio, 2020).

The proposed master plan is organized around the theme of “Play, Gather and Connect.” Notable features include: a flexible lawn, plaza space, destination playground, nature play area, trail system, multi-sport courts, and an outdoor classroom. Detailed site design and material selection were not within the scope of the proposed master plan. Thus the projective design protion of this project research focuses on furthering the design of the proposed plaza space [5.1.4].

Figure 5.1.4 Plaza space of the proposed MLK master plan. (Master Project Studio, 2020).

Three plaza design concepts and corresponding material palettes are developed to illustrate the linear, sustainable, and circular design processes for material selection. Each concept includes teh following features: a flexible public space, seating, shade structure, and splash pad with play features. The spatial configuration of the plaza space is slightly in each projective design concept to best reflect the corresponding process for material selection [5.1.6].

5.2 Application of the Linear Process for Material Selection

The following section documents the application of the linear process for material selection to the plaza design of MLK Park. The design does not include construction documentation (which is outside the possible scope of this project).

Phase 1: Early Planning & Goal Setting

Step 1. Understand Project's Impact Priorities

For the site master plan, the studio members worked with stakeholders to understand the project's impact priorities. According to the shared project vision, the proposed plaza design should support the community's desire to play, gather and connect.

Step 2. Establish Design Goals

The plaza should create a welcoming, safe, and inclusive space with public amenities for physical activity and social gathering. The design should include a flexible public space, seating, shade structure, and splash pad with play features. Part of the plaza should be accessible for food trucks and other vehicles for events and park services.

Phase 2: Develop Design Intention & Concept

Step 1. Site Analysis and Design Concept

Guided by a site analysis and the project impact priorities, a design concept was developed. It prioritizes design fulfillment over use of sustainably sourced materials.

Step 2. Identify Material's Performance Requirement

The plaza design makes use of visually interesting material textures and patterns to increase public attraction [5.2.1]. The use of curves creates a varied spatial experience for different gathering purposes [5.2.1]. The arrangement of the splash pad and shade structures reinforce the designed geometry with a visual hierarchy [5.2.1]. The design configuration requires materials that are customizable. To reduce cost, materials should be readily available, easily sourced, low-maintenance, and durable. Hazardous materials should be avoided in all circumstances.

Figure 5.2.1 Proposed site plan from the application of the linear process for material selection

Phase 3: Select Material Based on Properties and Performance Characteristics

Step 1. Consider Material's Attributes

Materials with appropriate properties and performance characteristics were selected [2.5.2]. The attributes of selected materials are listed in [2.5.2]. Final plaza design and material palettes are illustrated in Figures 2.5.3 and 2.5.4.

Figure 5.2.2 The chosen materials with selection rationale from the application of the linear process for material selection

SELECTED MATERIAL	SELECTION RATIONALES	OTHER CONSIDERATIONS
Precast Concrete with Water-based Acrylic Resins Application: Amphitheater, Pedestrian & Vehicle-Access Plaza.	Precast Concrete: reduce cost, versatile/adaptability to design with, low maintenance, readiness, durability. Water-based Acrylic Resins Sealer: reduce VOCs, easy to clean-up, less odor and off-gas.	Precast Concrete: high embodied energy, environmental impacts in manufacturing and transportation process, connection may be difficult, limited design change and flexibility. Water-based Acrylic Resins Sealer: need to re-apply every 3-5 years.
Sand & Gravels Application: Pavers base layer	Can support paver, can allow moisture to get in and drain, can absorb ground tension which prevent paver from sinking.	Might have to regrade depending on how much traffic pass through.
PVC Application: Pavers Edge Restraint, Drainage Pipes	Reduce cost, durability, versatile/adaptability to design with, lightweight, corrosion resistant.	Poor heat stability, emit toxic fumes when melted or subject to a fire, non-recyclable.
Composite Wood Application: Seating.	Won't splinter, rot & moisture-resistant, reduce cost, low maintenance, great workability.	Higher cost.
Aluminum with Baked Enamel Paint Application: Shade Structure, Splash Pad, Play Features.	Aluminum: great aesthetic value, weather resistant, strength, lightweight, durable, corrosion resistant. Baked enamel paint: reduce cost, can be removed easily.	Aluminum: higher cost, regular maintenance, repair for damage can be challenging. Baked enamel paint: regular maintenance
Galvanized Steel with Clear Coat Paint Application: Bollards, Connections for Shade Structure.	Galvanized Steel: low-maintenance, durability, rust-free. Clear coat paint: provide protection from contamination.	Galvanized Steel: higher cost, extra processing. Clear coat paint: more labor if need to remove the paint
Vinyl with Acrylic Paint Way-finding/Signage	Vinyl: low-maintenance, longevity, great workability, have aesthetic values, splinter & stain & scratch & mold & rot resistant. Acrylic paint: less cost, can be removed easily	Vinyl: higher cost, extra processing, less strength. Acrylic paint: might contain toxins within their pigments, regular maintenance.
Rubber with Anti-Slip Aliphatic Sealer Application: Splash Pad Surface	Rubber: easy to install and remove, reduce cost, increase safety. Aliphatic sealer: protection from UV, reduce maintenance.	Rubber: regular maintenance, color fade in direct sunlight. Aliphatic sealer: higher cost

Phase 4: Installation & Maintenance

Step 1. Review with Manufacturer or Contractor

This step was skipped because no manufacturer and contractor were involved. Ideally, designers will gain insight on how materials can be expected to perform from manufacturers and contractors.

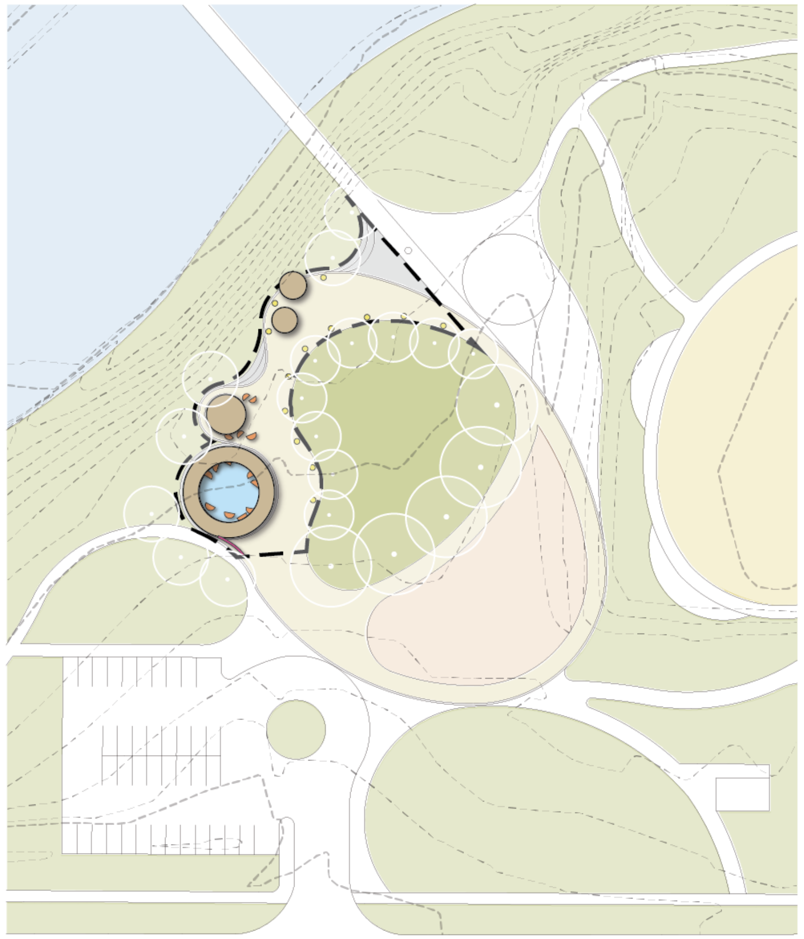
Step 2. Define Construction and Installation Methods

Due to limits of project scope, this design does not include construction documentation and administration. Ideally, the proposed design features will be constructed and installed based on materials' properties and performance characteristics, and the existing site conditions. Some construction and installation considerations are listed in Figures 5.2.2 and 5.2.3.

Step 3. Consider Installation and Maintenance Requirements

Considerations of how materials will be maintained are summarized in Figure 5.2.2.

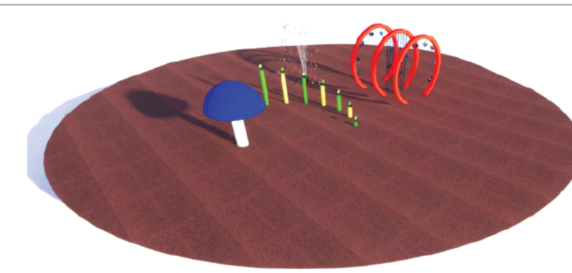
Figure 5.2.3 Design and material palettes from the application of the linear process for material selection



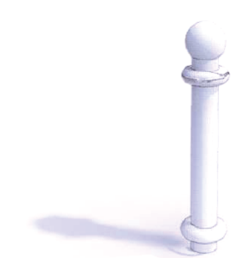
FEATURE	SIZE/COUNT	MATERIAL	FINISHING
Amphitheater, Pedestrian-Access Plaza	7620 sqft, 4" depth	Surface: Precast Concrete	Water-based Acrylic Resins
	7620 sqft, 6" depth	Base: Sand & Gravels	
Vehicle-Access Plaza	16242 sqft, 6" depth	Surface: Precast Concrete	Water-based Acrylic Resins
	16242 sqft, 8" depth	Base: Sand & Gravels	
	943 linear ft	Edge Restraint: PVC	
Splash Pad	2386 sqft, 2.5" depth	Surface: Rubber	
	2386 sqft, 4" depth	Base: Concrete	Anti-Slip Aliphatic Sealer
	4" diameter	Drainage Pipe: PVC	
	6 counts	Play Feature: Aluminum	Baked Enamel Paint
Shade Structure	4585 sqft of overhead structure	Aluminum	Baked Enamel Paint
Seating	30 counts	Composite Wood Connection: Galvanized Steel	
Way-finding/Signage	1 count	Vinyl	Acrylic Paint
Bollards	16 counts	Galvanized Steel	Clear Coat Paint
Small Shade Tree	9 counts	Redbud (Cercis Canadensis)	
Medium Shade Tree	7 counts	Amur Maple (Acer ginnala)	
Large Shade Tree	5 counts	Honey Locust (Gleditsia triacanthos)	

0 25 50 100ft
Limit of Work
2' Interval Contour
10' Interval Contour

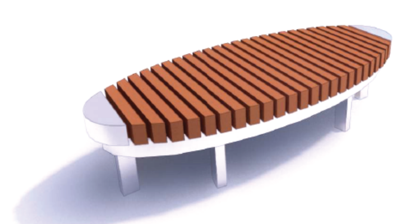
Shade Structure
Aluminum Volume: 1582 cu ft in total



Splash Pad
Aluminum Volume: 18 cu ft in total



Bollards
Galvanized Steel Volume: 2 cu ft per count



Seating
Composite Wood Volume: 10 cu ft per count
Galvanized Steel Volume: 3 cu ft per count

Way-finding/Signage
Vinyl Volume: 10 cu ft per count

Figure 5.2.4 Aerial Perspective of the plaza design from the application of the linear process for material selection

Figure 5.2.5 Plaza design perspective-1 from the application of the linear process for material selection

Figure 5.2.6 Plaza design perspective-2 from the application of the linear process for material selection

5.3 Sustainable Process for Material Selection

The following section documents the application of the sustainable process for material selection to the plaza design of MLK Park. The design does not include construction documentation (which is outside the possible scope of this project).

Phase 1. Early Planning & Goal Setting

Step 1. Understand Project Impact Priority

For the site master plan, the studio members worked with stakeholders to understand the project's impact priorities. According to the shared project vision, the proposed plaza design should support the community's desire to play, gather and connect.

Step 2. Establish Sustainable Goals and Practices

The following sustainable goals for the plaza design were developed:

1. Activate the park through inclusive public amenities
2. Increase the site's capacity to sequester carbon
3. Mitigate the stormwater runoff and flooding impacts

Phase 2. Regional & Site Assessment Related to Material Selection

Step 1. Bioregional Assessment

The site is located in Missouri. Both Kansas and Iowa are located within 200 miles from the site. As a result, research on the mineral industry of Missouri, Kansas and Iowa was conducted and summarized below (U.S. Geological Survey 2020):

Figure 5.3.1 Natural mineral resources in Missouri, Kansas, and Iowa.

Natural Mineral Resources		
Missouri	**Kansas**	**Iowa**
Copper	Cement	Portland Cement
Limestone	Clay & Shale	Clay
Gemstone	Sand & Gravel	Sand & Gravel
Sandstone	River Rock	Limestone
Granite	Flagstone	Dolomite
Sand & Gravel;	Limestone	Gemstone
Clay	Aggregates	
Silver	Baryte	
Marble		
Dolomite		

Step 2. Site Assessment

A site analysis was conducted at the master plan level [5.1.3]. The major environmental challenges that could impact the use of construction materials are:

1. Increasing heavy rain and flooding events (NCICS 2001)
2. Increasing temperature and numbers of hot day in summer (NCICS 2001)
3. Intense stromwater runoff due to the grade change (20-30%).

The major social and economic challenges that could impact the selection and use of cmaterials are:

1. There is a low-budget for community improvement and public amenities
2. There is a lack of public accessibility.

Step 3. Defining a Sustainable Boundary for Sourcing Materials

The site is located in a metropolitan area with access to sufficient resources for construction materials. Commonly used construction materials are available within 50 miles from the project site and most of them (except metals and plastics) are excavated, manufactured, and harvested within 200 miles. As a result, the sustainable boundary for material sourcing is defined as a 50 miles radius from the site.

Phase 3. Inter-exchange with Preliminary Design & Material Selection

Step 1. Preliminary Programming and Materials Inventory

The following design features were proposed according to the shared project vision (the potential materials are available within the defined sustainable boundary):

- Flexible public plaza for social activities and events, such as art display, daily gathering, recreation, and local markets. Part of the plaza should be vehicular accessible for food truck and other vehicles for park services.
  (Potential Material to Use: Limestone, Concrete, Brick, Stone & Aggregate)
- Amphitheater for social gathering and outdoor classroom.
  (Potential Material to Use: Limestone, Granite, Concrete, Brick, Stone & Aggregate)

• Seating area with shade structure
(Potential Material to Use: Limestone, Stones, Wood, Metal, Concrete)
• Splash pad with play features
(Potential Material to Use: Concrete, Rubber, Metal, Plastic, Stone & Aggregate)

Phase 4. Specify Sustainable Material

Step 1. Research Sustainable Material Parameters and Specify Sustainable Materials

Research was conducted to understand the sustainability of the potential materials:

Acquisition

Brick: consume a significant amount of energy by firing in a kiln.

Concrete: one of the most energy intensive processes; the amount of carbon dioxide account for approximately 5% of the global emission; water intensive; contribute to VOCs emission.

Stone & Aggregate: less than gravel & brick due to less secondary processing.

Granite: acquisition is highly energy and water intensive; contributes to VOCs emission.

Limestone: extraction contribute to VOCs emission; processing affects ground water quality.

Wood: contributes to loss of habitat, desert encroachment, loss of carbon storage capacity.

Metal: production causes physical disturbance to the landscape, soil, and water quality, concerns for human health and safety.

Rubber: production causes soil and water contamination, concerns for human health and safety. Most rubber products are made from recycled rubber, which significantly reduces environmental and human health impacts.

Plastic: production contributes a significant amount of carbon dioxide emission, and affects air quality.

Transportation & Delivering

Brick: energy intensive, crates emissions of carbon dioxide, sulfur dioxide, and nitrogen oxides.

Concrete: energy intensive, causes emissions of sulfur dioxide, nitrogen oxides, and carbon dioxide.

Stone & Aggregates: energy intensive, causes emissions of sulfur dioxide, nitrogen oxides, and carbon dioxide.

Granite: highly energy intensive, causes emissions of sulfur dioxide, nitrogen oxides, and carbon dioxide; contributes to VOCs emission.

Limestone: highly energy intensive, causes emissions of sulfur dioxide, nitrogen oxides, and carbon dioxide; contributes to VOCs emission.

Wood: causes emissions of carbon dioxide, sulfur dioxide, and nitrogen

Metal: highly energy intensive, causes large emissions of sulfur dioxide, nitrogen oxides, and carbon dioxide; contributes to VOCs emission.

Rubber: less energy intensive to transport due to its light weight, causes emissions of carbon dioxide, sulfur dioxide, and nitrogen oxides.

Plastic: less energy intensive to transport due to iits light weight, causes emissions of carbon dioxide, sulfur dioxide, and nitrogen oxides.

Processing & Refurbishing

Brick: Need

Concrete: Need

Stone & Aggregates: Need

Granite: Need

Limestone: Need

Wood: Need

Metal: Need

Rubber: Need

Plastic: Need

Secondary Processing & Finishing

Brick: Need

Concrete: Need

Stone & Aggregates: Don't Need

Granite: Don't Need

Limestone: Don't Need

Metal: Need

Rubber: Need

Plastic: Need

Construction, Use & Maintenance

Brick: moderately easy to construct and maintain, moderate level of carbon emission during construction.

Concrete: easy to construct and maintain, higher amount of carbon emission during construction.

Stone & Aggregates: easy to construct and maintain, low carbon emission during construction, low maintenance.

Granite: energy and labor intensive, high carbon emission during construction, need regular maintenance.

Limestone: moderately easy to work with, need regular maintenance, moderate level of carbon emission during construction.

Metal: workability varies depending on types of metal, high carbon emission during construction, often low or less maintenance.

Rubber: easy to construct and maintain, moderate level of carbon emission during construction.

Plastic: easy to construct and maintain, moderate level of carbon emission during construction.

<u>**Post Construction & End of Life**</u>

Brick: can be reused and recycled.

Concrete: can be recycled, need secondary process.

Stone & Aggregates: can be reused and recycled.

Granite: can be reused and recycled, need secondary process for recycling, energy intensive.

Limestone: can be reused and recycled.

Metal: can be reused and recycled, need secondary process for recycling, energy intensive.

Rubber: can be recycled, need secondary process.

Plastic: recyclability varies depending on plastic types, some are non-recyclable.

Phase 5. Establish a Local Sustainable Design Collaborative

Step 1. Collaborative Design and Material Selection Review

This step was skipped because no engineers and contractors were involved.

Phase 6. Design Iterations & Final Material Selection

Step 1. Design Iterations

For the site master plan, studio members worked on several design iterations to create a final design that supported the sustainable goals. Figure 5.3.2 and Figure 5.3.3 illustrate the sustainable plaza design and material palettes. The sustainable design integrates moderate curves to increase spatial variation and visual interest. Compared to the linear design, the sustainable design uses fewer organic design configuration to reduce construction labor and material waste. The sustainable design also uses fewer seatings and shade structures than the linear design to save resources and energy.

Step 2. Construction Documentation

Due to the limit project scope, this design does not include construction documentation and administration. Ideally, the sustainable practices will be implemented throughout the construction documentation and administration with help from contractors and engineers. Some of the sustainable construction and installation considerations are listed in Figure 5.3.3.

Phase 7. Maintenance, Result Measurement and Post Construction Monitoring

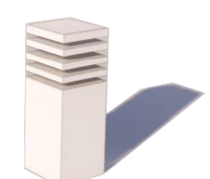
Step 1. Plan to monitor and report site performance

This step was skipped because the proposed design is pypothetical, and will not be built. Ideally, designer will work with the contractor and client to develop a monitoring plan that measure the materials' performance overtime.

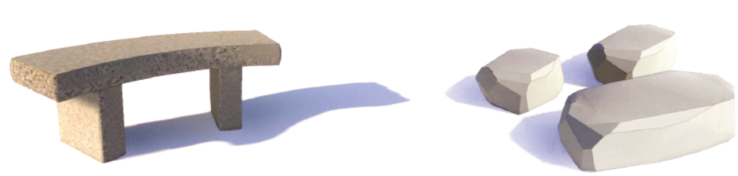
Figure 5.3.2 Design and material palettes from the application of the sustainable process for material selection

FEATURE	SIZE/COUNT	MATERIAL	FINISHING
Amphitheater, Pedestrian-Access Plaza	9150 sqft, 4" depth	Surface: Porous Aggregate Concrete	Certified Bio-based Sealant
	9150 sqft, 6" depth	Base: Sand & Gravels	
	731 linear ft	Edge Restraint: Precast Concrete	Certified Bio-based Sealant
Vehicle-Access Plaza	13800 sqft, 4" depth	Surface: Permeable Concrete Paver	Certified Bio-based Sealant
	13800 sqft, 6" depth	Base: Sand & Gravels	
	871 linear ft	Edge Restraint: HDPE	Certified Bio-based Sealant
Splash Pad	2934 sqft, 2.5" depth	Surface: Recycled Crumb Rubber	
	2934 sqft, 4" depth	Base: Compacted Aggregates	
	4" diameter	Drainage Pipe: HDPE	
	6 counts	Play Feature: Composite Wood	
Shade Structure	3248 sqft of overhead structure	Composite Wood Connection: Stainless Steel	
Seating	25 counts	Limestone	Certified Bio-based Sealant
Way-finding/Signage	1 count	Limestone	Certified Bio-based Sealant
Bollards	12 counts	Limestone	Certified Bio-based Sealant
Small Shade Tree	8 counts	Redbud (Cercis Canadensis)	
Medium Shade Tree	8 counts	Amur Maple (Acer ginnala)	
Large Shade Tree	5 counts	Honey Locust (Gleditsia triacanthos)	

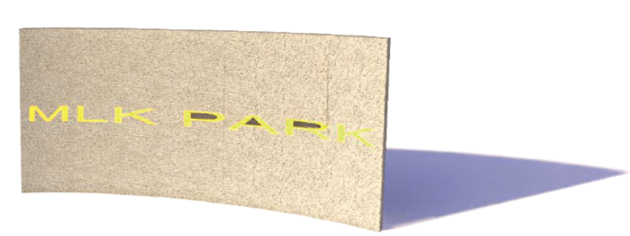
Shade Structure
Composite Wood Volume: 939 cu ft in total



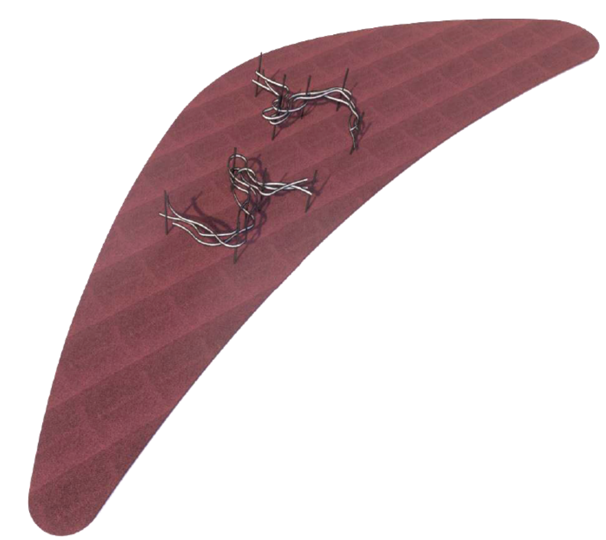
Bollards
Limestone Volume: 3 cu ft per count



Seating
Limestone (Left) Volume: 8 cu ft per count
Limestone (Right) Volume: 8-12 cu ft per count



Way-finding/Signage
Limestone Volume: 3.5 cu ft per count



Splash Pad
Composite Wood Volume: 9 cu ft in total

Figure 5.3.3 The chosen materials with selection rationale from the application of the sustainable process for material selection

SELECTED MATERIAL	SELECTION RATIONALES	OTHER CONSIDERATIONS
Porous Aggregate Concrete Application: Amphitheater, Pedestrian & Vehicle-Access Plaza.	Can be achieved within a sustainable distance. Materials assist sustainable production (use cement substitutes). Porous paving can allow storm water infiltration. Mix with recycled aggregate to minimize use of nonrenewable raw materials and negative environmental impacts of their excavation. Use cement substitutes such as fly ash to reuse industrial waste products, reduce emission and the use of water and cement. Recyclable.	Use light-colored concrete to reduce UHI effect. Need regular maintenance, typically every 3 months. More (typically 15%-20%) expanse and labor.
Permeable Concrete Paver Pedestrian & Vehicle-Access Plaza.	Can be achieved within a sustainable distance. Use certified sustainable products. Permeable paver can reduce run-off, allow storm water infiltration, reduce the amount of hardscape and the carbon dioxide emission. Recyclable.	Use light-colored concrete to reduce UHI effect. Need regular maintenance, typically every 3 months. More (typically 15%-20%) expanse and labor.
Sand & Gravels Application: Pavement base layer.	Can be achieved within a sustainable distance. Allow moisture to get in and drain, great support for paver, absorb ground tension which prevents paver from sinking. Recyclable.	Might have to regrade depending on how much traffic pass through.
Certified Bio-based Sealant Application: Surface Sealer.	Use certified bio-based sealants such as those made from soybean oil are VOC-free can reduce the use of non-renewable material, and reduce air emission and pollutants.	Require more frequent application.
HDPE Application: Paver Edge Restraint, Drainage Pipes.	Can be achieved within a sustainable distance. Easily recyclable and the products are made from recycled materials. Pose fewer pollutants and human health risk than PVC and ABS. Recyclable.	More expansive than PVC. Production can be a source of pollution from the extraction of fossil fuels to air emissions of combustion fuels used in processing. Resistance to breakage.
Recycled Crumb Rubber Application: Splash Pad Surface.	Can be achieved within a sustainable distance. Recover energy, reduce the use of nonrenewable raw materials, and reduce the toxic pollution from burning used rubber. Cost-saving, improve safety rating. Recyclable.	Color fade quickly in direct sun. Need regular maintenance (typically monthly). Durable.
Composite Wood Application: Play Features, Shade Structure.	Can be achieved within a sustainable distance. Recycled content materials, save wood and other waste, save the use of natural wood. Do not need sealant. Mostly recyclable (ones mixed with resin is not recyclable).	Higher cost than natural wood. Rot & moisture-resistant, reduced cost, low maintenance, won't splinter, workability.
Stainless Steel Application: Shade Structure connection.	Can be achieved within a sustainable distance. Stainless steel are often made with recycled materials, which save a significant amount of environmental impact for raw material excavation. Do not need sealant. Recyclable.	Higher cost than other types of metal. Corrosion-resistant, durable,versatile, workability. Recycling process can be energy consumptive.
Limestone Application: Seating, Way-finding/signage, Bollards.	Can be achieved within a sustainable distance. Locally abundant. Low embodied energy, carbon dioxide, and VOC. Recyclable.	Need regular maintenance (typically monthly). React with acidic water.

Figure 5.3.4 Aerial Perspective of the plaza design from the application of the sustainable process for material selection

Figure 5.3.5 Plaza design perspective-1 from the application of the sustainable process for material selection

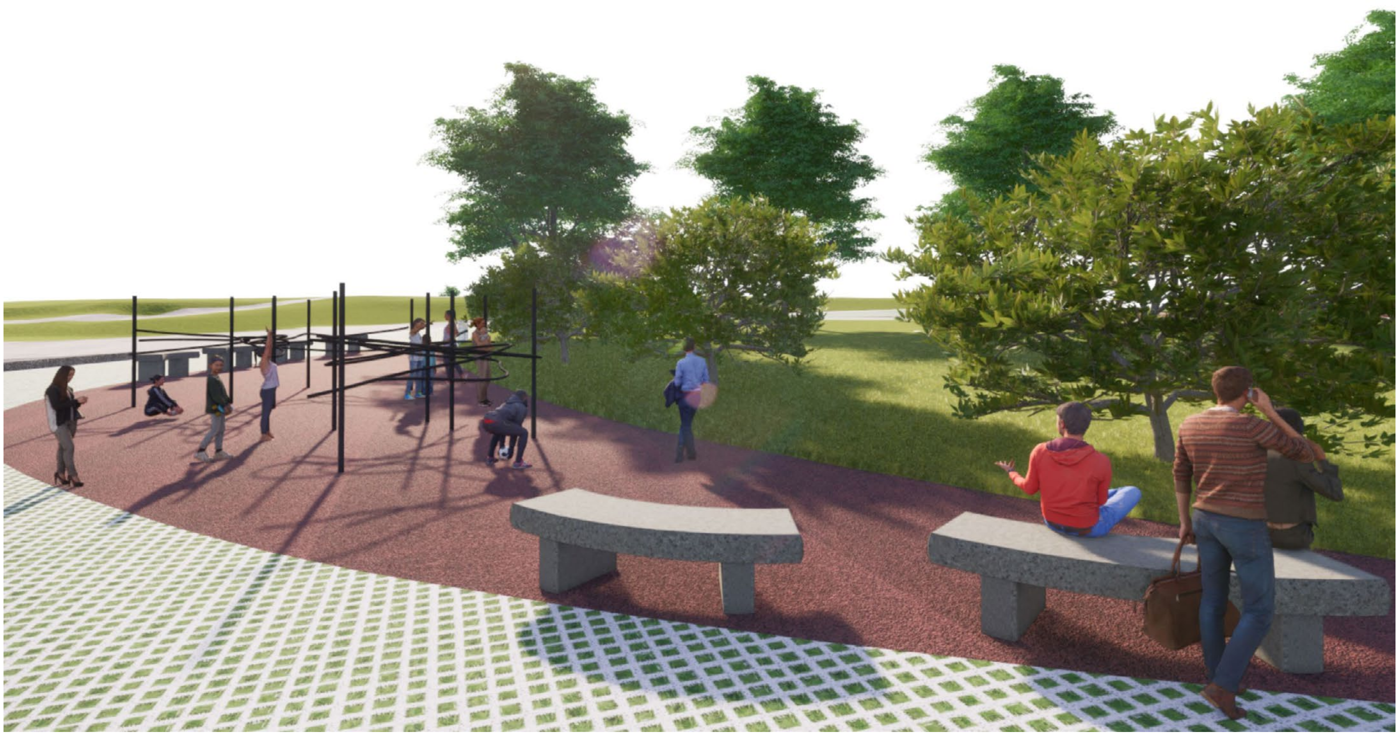


Figure 5.3.6 Plaza design perspective-2 from the application of the sustainable process for material selection

5.4 Circular Design Process for Material Selection

The following section documents the application of the proposed circular design process for material selection to the plaza design of MLK Park. The design does not include construction documentation (which is outside the possible scope of this project).

Phase 1: Early Planning & Goal Setting

Step 1. Understand Project Impact Priority

For the site master plan, the studio members worked with stakeholders to understand the project's impact priorities. According to the shared project vision, the proposed plaza design should support the community's desire to play, gather and connect.

Step 2. Establish Measurable Circular Design Goals

The following circular design goals were established to guide the design process:

1. At least 60% of the design elements should use recycled or recycled content materials.
2. At least 80% of materials should be designed and used in a way that they can be easily reused and recycled.
3. At least 80% of materials should be designed for disassembly.

Step 3. Build Local Connection for Sourcing Recycled Materials

This step was skipped because no contractor and local connections were involved.

Step 4. Plan for Design Change to Adapt the Use of Recycled Materials

This step was skipped because there is no budget requirement. Ideally, designers need to work with the client and contractor to increase their flexibility and adaptability for design change due to the use of recycled materials.

Phase 2: Identify and Source Material

Step 1. Assess the Bioregional Resources

The site is located in Missouri. Both Kansas and Iowa are located within 200 miles from the site. Same as the sustainable process, research on the mineral industry of Missouri, Kansas and Iowa was conducted and summarized below (U.S. Geological Survey 2020):

Figure 5.3.1 Natural mineral resources in Missouri, Kansas, and Iowa.

Natural Mineral Resources		
Missouri	**Kansas**	**Iowa**
Copper	Cement	Portland Cement
Limestone	Clay & Shale	Clay
Gemstone	Sand & Gravel	Sand & Gravel
Sandstone	River Rock	Limestone
Granite	Flagstone	Dolomite
Sand & Gravel;	Limestone	Gemstone
Clay	Aggregates	
Silver	Baryte	
Marble		
Dolomite		

Step 2. Identify Existing Resources that can be Reused or Recycled

The existing condition of the site is lawn. There is no in-situ structure that can be reused or repurposed the plaza design. Any soil and aggregates harvested from the land clearing process will be conserved and reused on site.

Step 3. Harvest Mapping

A harvest map was made to source recycled materials and recycled content materials. The process of harvest mapping is illustrated below:

3.1 Define the Boundary

A research boundary is defined based on the availability of regional resources and the maximum distance for sustainable material extraction, harvest and delivering [4.4]. Since the site is located in a metropolitan area with accessibility to sufficient resources, most of the commonly used recycled construction materials and recycled content materials were found within 10 miles from the site. However, there are limited suppliers outside of 10 miles from the site, because those areas are more rural. As a result, the harvest mapping area is defined within the 10 miles radius from the site.

Figure 4.4 Sustainable material delivering distance (SITES 2009, Calkins 2012)

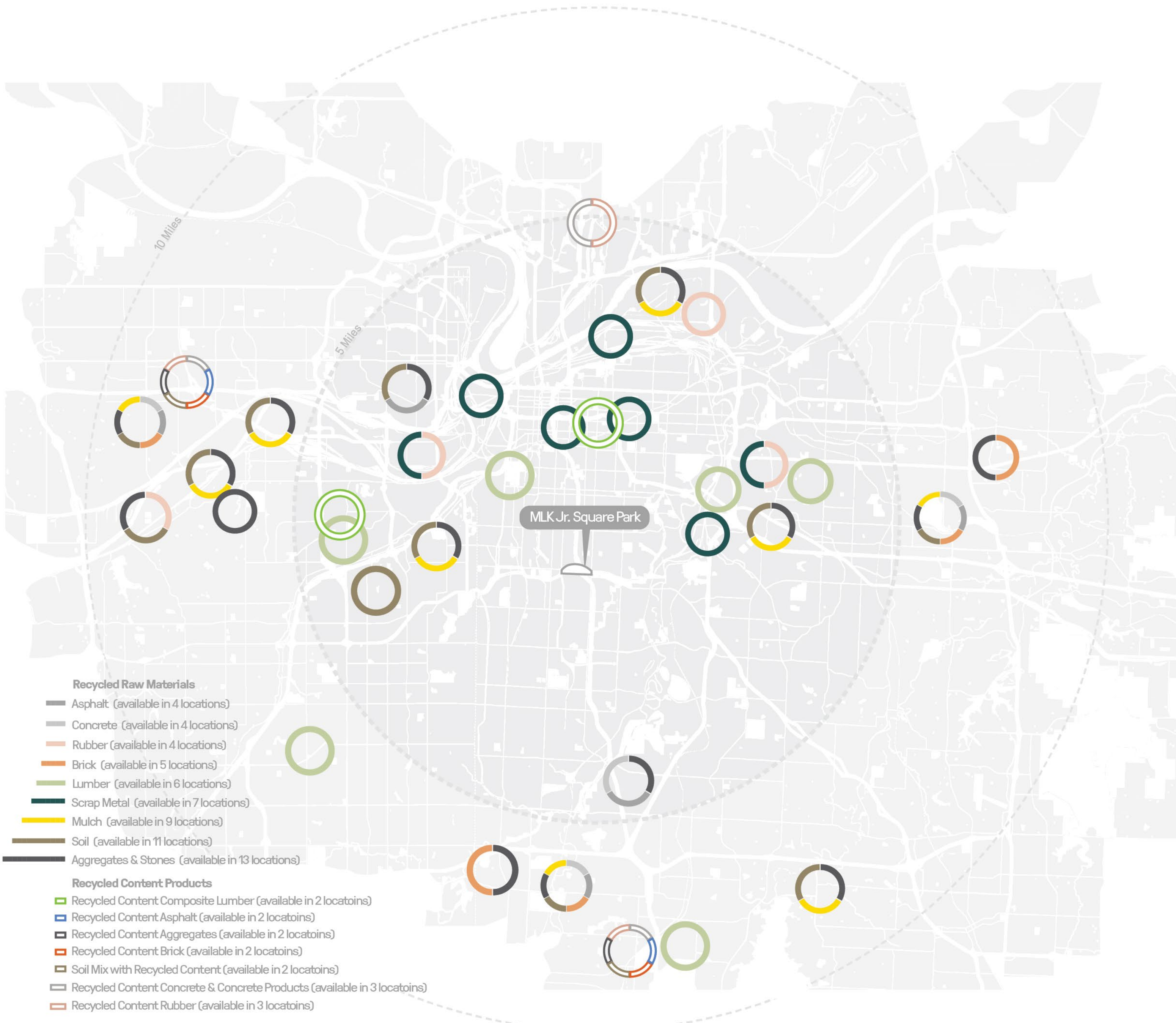
Material Type	Distance Requirements
Soils, compost, and mulch	**Extraction, harvest or recovery, and manufacture must occur within 50 miles**
Boulders, rocks, and aggregate, brick, concrete	**Extraction, harvest or recovery, and manufacture must occur within 50 miles**
Plants	**All growing facilities and suppliers for the plant must be within 250 miles**
All other materials	**Extraction, harvest or recovery, and manufacture must occur within 500 miles**

3.2 Map the Resources

The harvest map illustrates the location and types of recycled materials (from recycled construction materials suppliers and salvage/junk yards) and recycled content materials (from construction materials suppliers) within the defined boundary [5.4.1]. The aggregates in the harvest map include sand and gravels.

This harvest map does not include information on adjacent deconstruction projects because no local contractors and clients are involved in the project. Ideally, adjacent deconstruction projects should also be mapped as sources for recycled materials. The information on adjacent on-going deconstruction projects can be informed by local contractor and client knowledge.

Figure 5.4.1 Harvest map of recycled and recycled content materials in Kansas City.



Phase 3: Specify Circular Design Materials

Step 1. Define Preliminary Programs

- Flexible public plaza for social activities and events, such as art display, daily gathering, recreation, and local markets. Part of the plaza should be vehicular accessible for food truck and other vehicles for park services.
  (Potential Material to Use: Limestone, Concrete, Brick, Stone & Aggregate)
- Amphitheater for social gathering and outdoor classroom.
  (Potential Material to Use: Limestone, Granite, Concrete, Brick, Stone & Aggregate)
- Seating area with shade structure
  (Potential Material to Use: Limestone, Stones, Wood, Metal, Concrete)
- Splash pad with play features
  (Potential Material to Use: Concrete, Rubber, Metal, Plastic, Stone & Aggregate)

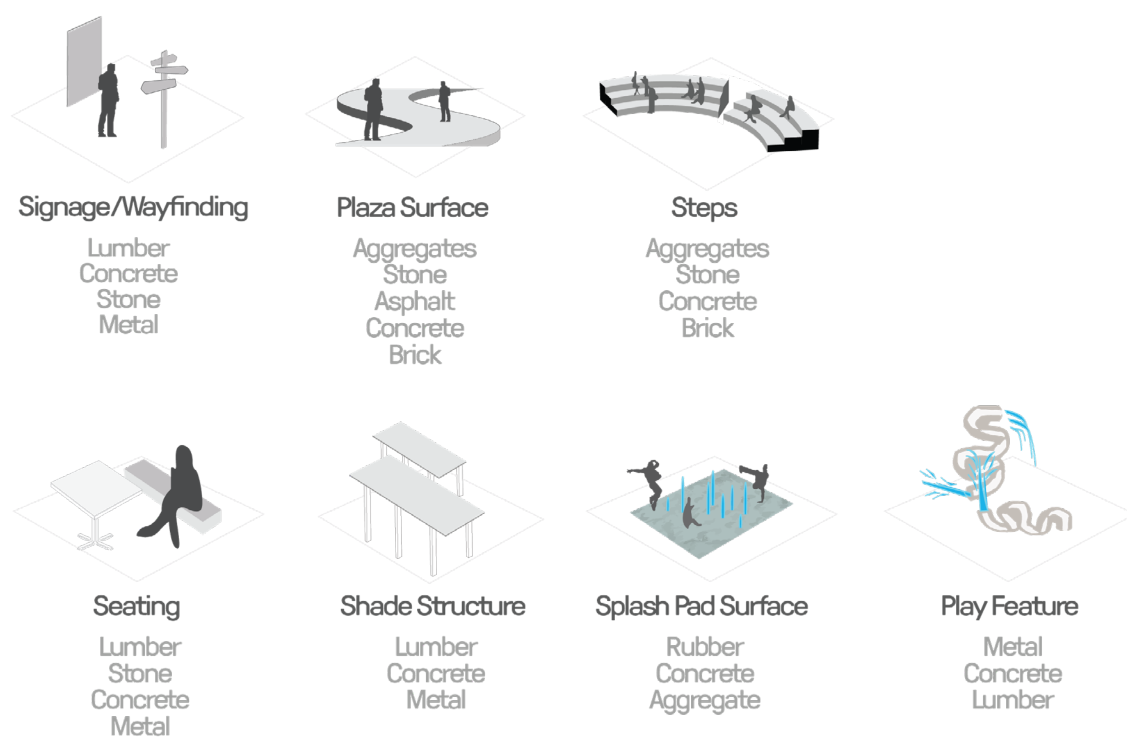
Step 2. Develop the "Parts" of Programs

Following are "parts" of the proposed design program:

- Flexible Public Plaza: Signage/Wayfinding, Plaza Surface.
- Amphitheater: Steps.
- Seating Area with Shade: Seating, Shade Structures.
- Splash Pad: Splash Pad Surface, Play features.

A list of potential materials for each "part" of the proposed program is developed according to the availability of recycled materials from the harvest map [5.4.2]. The aggregates in Figure 5.4.2 include sand and gravels.

Figure 5.4.2 Potential materials for proposed design feature



Step 3. Circular Design Considerations

Research for circular design considerations of the potential aforementioned materials was conducted. Figure 5.4.3 summarizes the key considerations of the potential materials.

Figure 5.4.3 The chosen materials with selection rationale from the application of the circular design process for material selection

SELECTED MATERIAL	SELECTION RATIONALES	OTHER CONSIDERATIONS
Recycled Aggregate Application: Pedestrian & Vehicle-Access Plaza.	Can be achieved within a sustainable distance. Can be recycled for multiple times, which reduces a significant amount of waste and energy for excavation and processing. Can reduce the use of natural stone by substituting reclaimed Portland cement, asphalt, iron and steel slags. Easy to disassemble without the use of mortar.	Durable, low-maintenance, solidity, one of the most accessible and abundant natural resources. Transportation cost high amount of energy.
Recycled Soil & Sand Application: Base layer for aggregate plaza.	Can be achieved within a sustainable distance. Can be reused and recycled on-site or with minimal processing.	Inexpensive, easy to source, low embodied energy, can return to earth if there is no contamination. Prone to degradation.
Geotextile Fabric Application: Base layer for aggregate plaza.	Can be achieved within a sustainable distance. Can choose recycled geotextile membrane or recycled content geotextile fabric.	Avoid the use of polyester geotextile (non-recyclable).
Recycled Content Concrete Paver Application: Pedestrian & Vehicle-Access Plaza.	Can be achieved within a sustainable distance. Easy to recycle and disassemble if there's no use of contaminating chemicals, sometimes can be recycled on-site.	Durable. Low maintenance, low cost.
Recycled Brick Application: Amphitheater, Pedestrian-Access Plaza.	Can be achieved within a sustainable distance. Can be recycled and reused easily for multiple times, which save a significant amount of energy and emission from brick production. Can be disassembled easily if no mortar or less lime mortar were used.	Durable, low maintenance, waste is minimal, slip and fire resistant. Price often varies for recycled brick.
Recycled Stone Application: Amphitheater, Pedestrian-Access Plaza, Seating, Way-finding/signage.	Can be achieved within a sustainable distance. Can be recycled and reused for multiple times to reduce the high cost of transportation. Can be disassembled easily if no mortar or less lime mortar were used.	Durable, low maintenance, solidity, locally abundant.
Recycled Content Precast Concrete Application: Bollards, Edge Restraint.	Can be achieved within a sustainable distance. Easy to recycle and disassemble if there's no use of contaminating chemicals, sometimes can be recycled on-site.	Durable, low cost, low maintenance.
Recycled Crumbed Rubber Application: Trail, Splash pad.	Can be achieved within a sustainable distance. Can be recycled, but process might be challenging depending on the sourcing of the recycled rubber.	Need regular maintenance (typically monthly). Durable. Hard to maintain the original characteristics.
HDPE Application: Drainage Pipe.	Can be achieved within a sustainable distance. Easily reuse and the products are made from recycled materials. Can be easily designed for disassembly because of the flexible and light structure. Recyclable, but less sustainable than reuse in whole form.	Light, durable, water resistant, flexible, low cost, low maintenance. Production consume significant fossil fuels, by products cause waste and emission.
Recycled Wood Application: Shade Structure.	Can be achieved within a sustainable distance. Can be recycled and reused in whole or other wood products such as mulch or composite lumber with minimal or some processing. Avoid CCA treated recycled wood. Can be easily disassemble if there is no glue or pneumatically nailed connection.	Aesthetic quality, carbon sequestration, dried ready, hidden cost and labors if there are nails and staples, concerns about the availability of specific size and quality.
Recycled Stainless Steel Application: Shade Structure Connection.	Can be achieved within a sustainable distance. Stainless steel are often made with recycled materials, which save a significant amount of environmental impact for raw material excavation. Design removable fasteners, screws and bolts for easy disassembly. Do not need sealant. Recyclable.	Recycling process can be energy, labor and time consumptive.
Bio/water-based Sealant Application: Surface Sealer.	Use bio/water-based sealant for easy disassembly and recycling.	

Step 4. Classify the potential materials into the circular design sphere

Soil, wood, and bio/water-based sealant are in the renewable/organic sphere and are designed to return to the environment during or after their use phase. All the other materials are in the finite/technical sphere and are designed to be dismantled/disassembled, physically or chemically transformed and reused after their use phase.

Step 5. Let the Materials Inspire the Design

Due to the uncertainty of available recycled materials within the sustainable harvest boundary, orthogonal geometry was used to allow more flexibility for potential material and design changes. Multiple materials for the plaza surface are preferred to adapt to limited supply of one type of material, and to increase the visual interest of the space.

Phase 4: Inter-exchange with Design & Final Material Selection

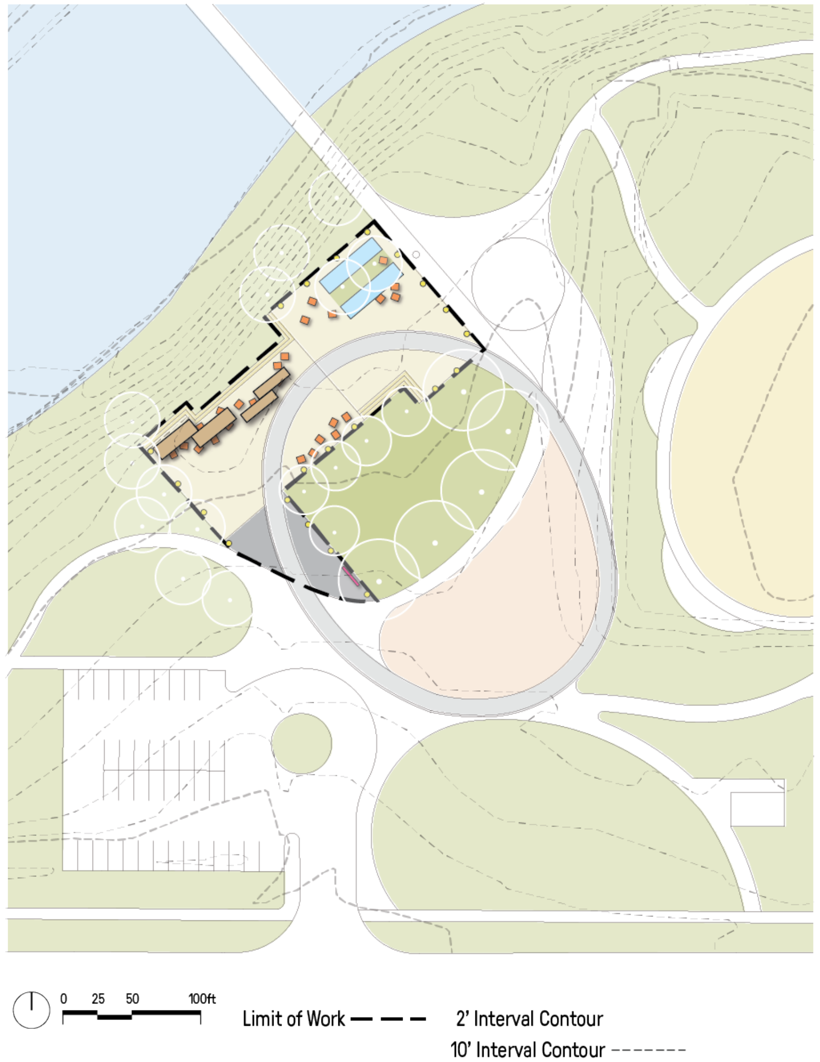
Step 1. Design Iterations

Design iterations were made to test different spatial arrangements and geometry configurations. While the master plan suggested the plaza have an irregular form, it would be challenging to achieve a circular design process because circular design encourages the use of standardized elements and regular forms. With these considerations in mind, the plaza design and material palette were developed accordingly [5.4.4]. Compared to the linear and sustainable design, circular design uses fewer irregular elements to conserve reusable resources. The trail located adjacent to the plaza remained and was surfaced to strengthen the visual and physical connection between the plaza and the larger park site. Using multiple recycled materials can prevent exhausting one type of materials if there is not enough available supply.

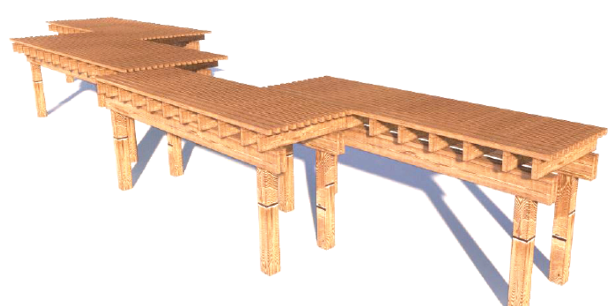
Step 2. Final Material Selection

It was assumed that all selected materials are available within the defined sustainable harvest boundary [5.4.4].

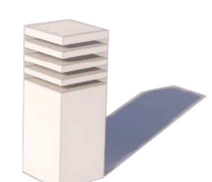
Figure 5.4.4 Design and material palettes from the application of the circular design process for material selection



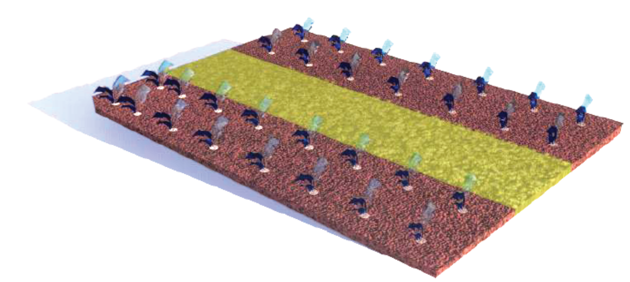
FEATURE	SIZE/COUNT	MATERIAL	FINISHING
Vehicle-Access Plaza	3678 sqft, 4" depth	Surface: Recycled Aggregate	Bio/Water-based Sealant
	3678 sqft, 6" depth	Base: Compacted Soil & Geotextile Fabric	
	323 sqft, 6" depth	Edge Restraint: Recycle Content Precast Concrete	
Vehicle-Access Plaza	24704 sqft, 4" depth	Surface: Recycle Content Concrete Paver	Bio/Water-based Sealant
	24704 sqft, 6" depth	Base: Recycled Compacted Aggregate & Geotextile Fabric	
	1334 linear ft	Edge Restraint: Recycled Content Precast Concrete	
Amphitheater, Pedestrian-Access Plaza	1811 sqft, 4" depth	Surface: Recycled Brick & Stone Paver	Bio/Water-based Sealant
	1811 sqft, 4" depth	Base: Sand & Recycled Aggregate	
	556 linear ft	Edge Restraint: Recycle Content Precast Concrete	
Trail	5237 sqft, 3" depth	Surface: Recycled Crumbed Rubber Paver	Bio/Water-based Sealant
	5237 sqft, 4" depth	Base: Sand & Recycled Aggregate	
	705 linear ft	Edge Restraint: Recycle Content Precast Concrete	
Splash Pad	2270 sqft, 3" depth	Surface: Recycled Crumb Rubber	
	2270 sqft, 4" depth	Base: Recycled Compacted Aggregates	
	4" diameter	Drainage Pipe: HDPE	
Shade Structure	2330 sqft of overhead structure	Recycled Wood	Bio/Water-based Sealant
		Connection: Recycled Stainless Steel	
Seating	25 counts	Recycled Stone Connection: Steel	Bio/Water-based Sealant
Way-finding/Signage	1 count	Recycled Stone	Bio/Water-based Sealant



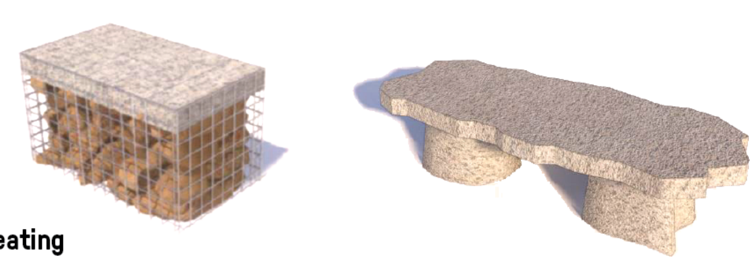
Shade Structure
Recycled Wood Volume: 1018 cu ft in total



Bollards
Recycled Content Precast Concrete Volume: 3 cu ft per count



Splash Pad



Seating
Recycled Stone (Left) Volume: 8-10 cu ft per count
Recycled Stone (Right) Volume: 10 cu ft per count

Way-finding/Signage
Recycled Stone Volume: 3 cu ft per count

Step 3. Construction Documentation

Due to the limit project scope, this design does not include construction documentation. Ideally, implementation and maintenance plan will be developed together with the contractors and clients to ensure the materials can be disassembled, reused and recycled easily at their end of life. Considerations of construction and maintenance for the selected materials were listed in Figure 5.4.3.

Step 4. Design for Disassembly (DFD)

Due to the limit project scope, this design only includes DFD drawings for pavement, shade structure, and seating [5.4.5-5.4.8]. Figure 5.4.5 illustrates the DFD technique for all pavers used in the plaza. Instead of using mortar, the pavers are stabilized by stronger edge restraint [5.4.5]. Figure 5.4.6 and 5.4.7 illustrate the DFD techniques for the connections in the bollard and shade structure. The proposed design for bollard and shade structure aims to avoid nail fixing and adhesives. Figure 5.4.8 illustrates the DFD for seating which uses less or no technical connection. Other considerations of design for disassembly for the selected materials are explained in Figure 5.4.3.

Figure 5.4.5 DFD drawing for paver from the application of the circular design process for material selection

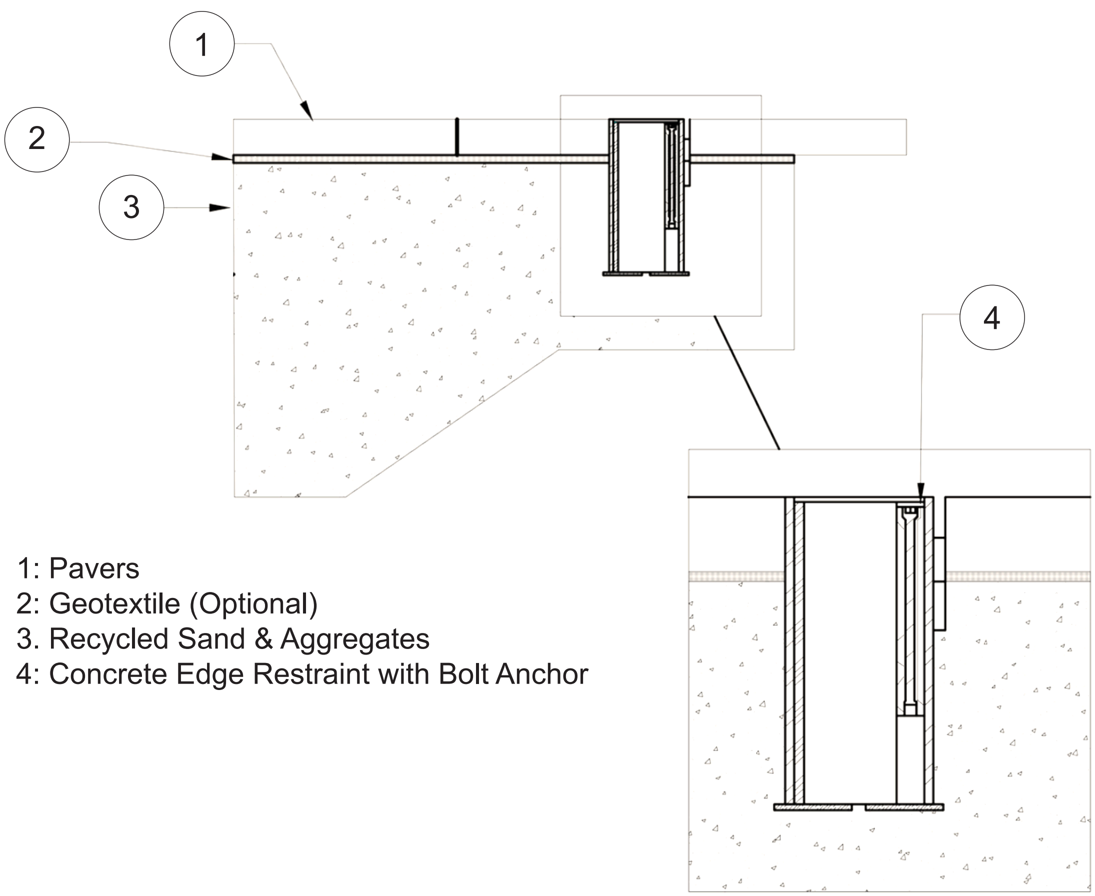


Figure 5.4.6 DFD drawing for bollard from the application of the circular design process for material selection

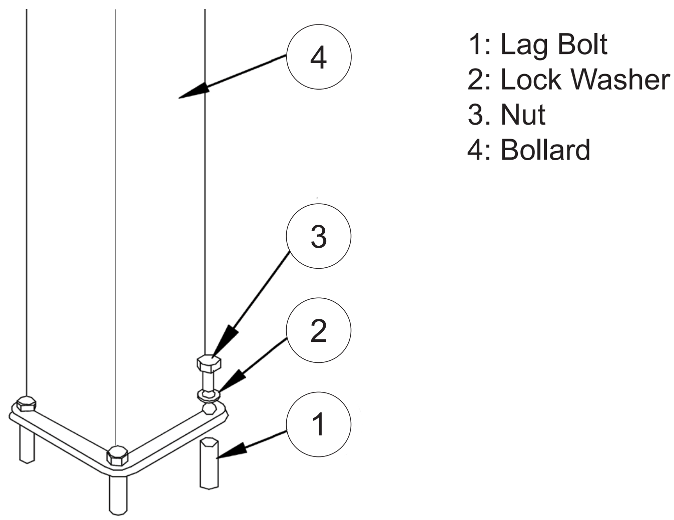


Figure 5.4.7 DFD drawing for shade structure from the application of the circular design process for material selection

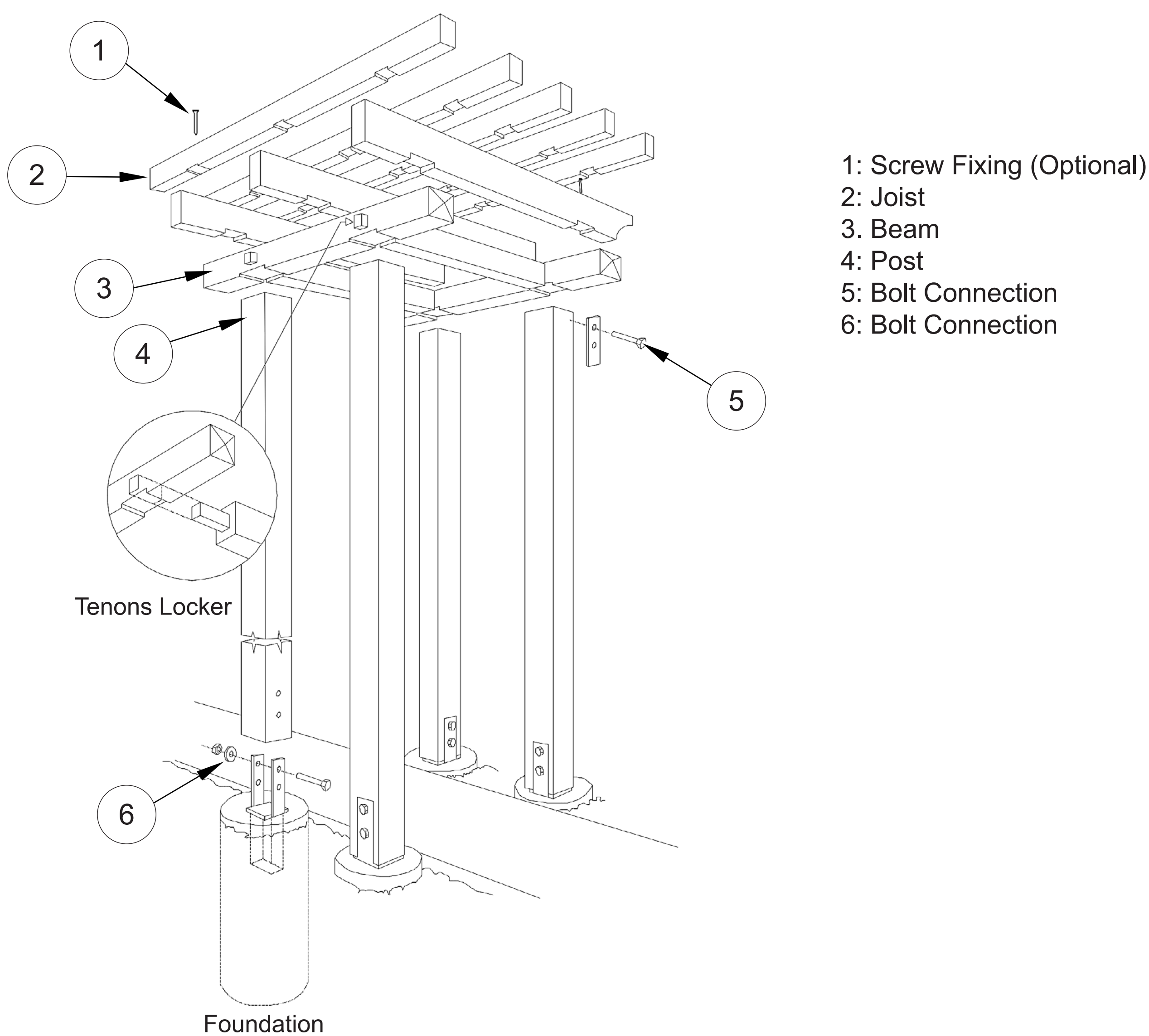
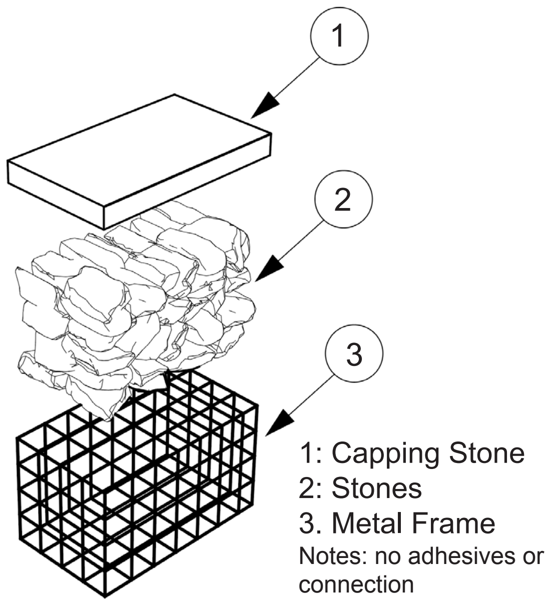
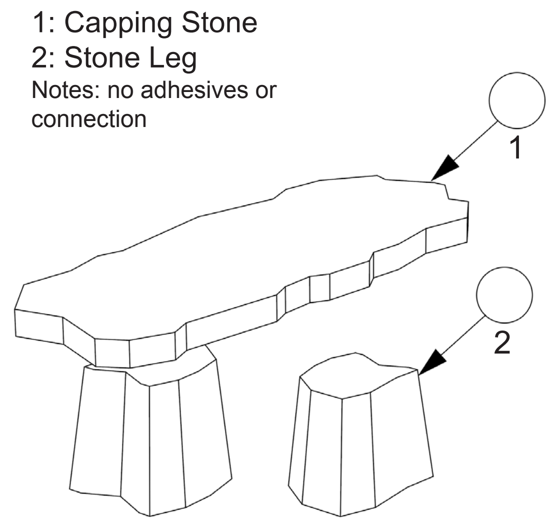


Figure 5.4.8 DFD drawing for seating from the application of the circular design process for material selection





Phase 5: Building Circular Economy Model

Step 1. Provide for storage and collection of recyclables

This step was skipped because the design is not going to be built. Ideally, when the design is built, collection containers for recyclables next to all trash receptacles will be provided to advocate and facilitate a local recycling program on site.

Step 2. Recycle organic matter

This step was skipped because the design is not going to be built. Ideally, excess vegetation generated during site construction and maintenance will be collected to generate compost and mulch for on-site usages.

Step 3. Establish local material recycling network

This step was skipped because no local recycling network was involved. Ideally, designers will connect and share knowledge of local resources for sourcing recycled materials so that in the future, circular design processes for material selection will be easier and faster to perform.

Step 4. Circular design result measurement

This step was skipped because no local recycling network was involved. Ideally, on-site features, programs, and pop-up activities will be established to promote and educate circular design principles in ways that positively influence user behavior on resource conservation.

Figure 5.4.9 Aerial Perspective of the plaza design from the application of the circular design process for material selection

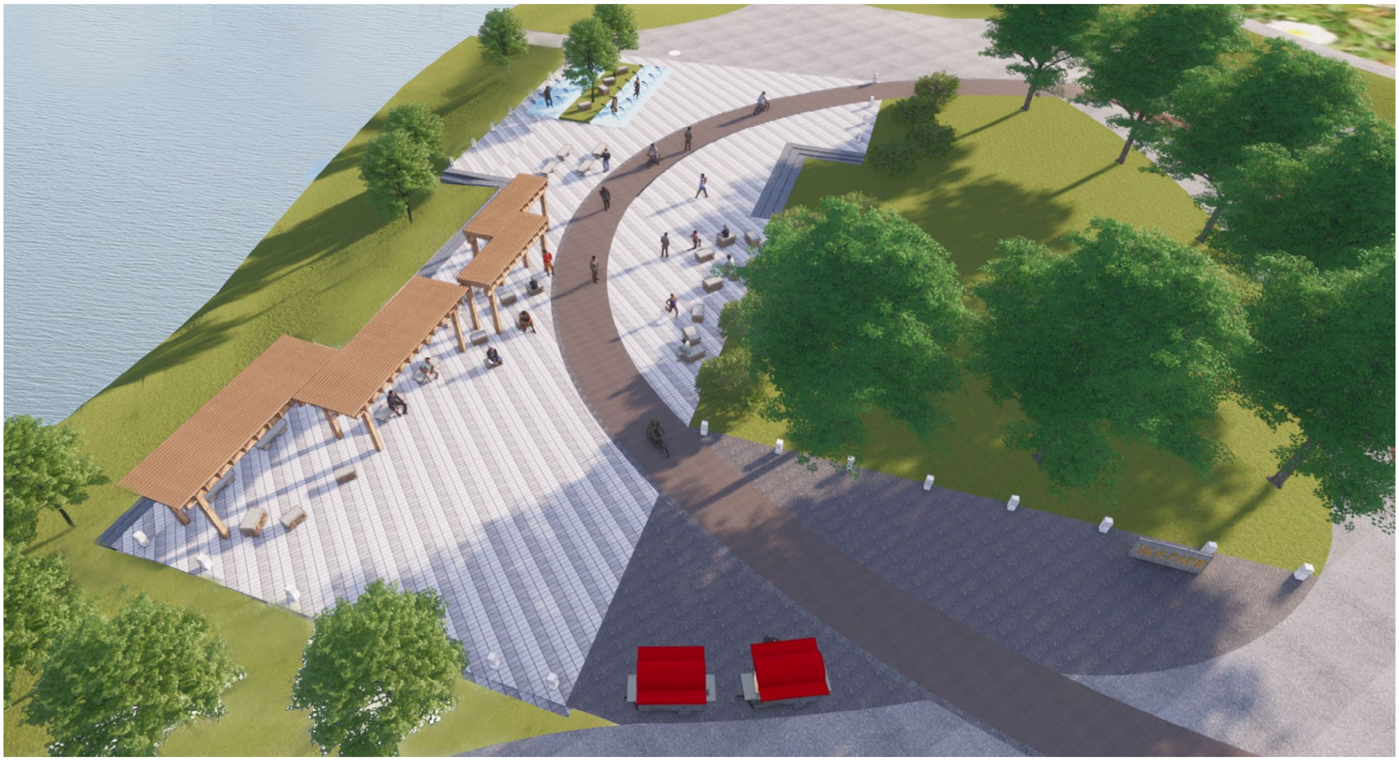


Figure 5.4.10 Plaza design perspective-1 from the application of the circular design process for material selection

Figure 5.4.11 Plaza design perspective-2 from the application of the circular design process for material selection

FINDINGS

Ch. 6

6. FINDINGS

In the previous chapters, a circular design process for material selection in site design was developed, and it was applied along with the linear and sustainable processes, to the plaza design of MLK Park in Kansas City, MO. The applications of the three material selection processes and their design outcomes were documented. This chapter discusses and evaluates the different successes and shortcomings of the linear, sustainable and circular design material selection processes through their application, design result, and material palettes.

6.1 Evaluation of the Process Application

By documenting the projective design applications of the linear, sustainable and circular design processes, for material selection, pros and cons of each are discussed in terms of project management, design, construction, and performance [6.1]. Since the linear process is shorter and simpler than the other two, there are fewer considerations to be documented in its application [6.1]. The strength of the linear process is its freedom in design and material selection. During the linear process, fulfilling the design intent is most important and the use and of sustainable or recycled materials is secondary or irrelevant. The linear process gives more freedom to the design configuration and material selection, but the linear process tends to cause more negative environmental and human health impacts during and after construction due to not prioritizing the use of sustainable or recycled materials. However, thats not to say the linear process would exclude such materials, but just that design fulfillment is prioritized over other considerations.

In contrast to the linear process, both the sustainable and circular design processes require more effort in project management, design and construction phases, but they provide more benefits in construction and performance. Both the sustainable and circular design processes integrate multi-disciplinary collaboration for better design and material performance. While the sustainable process addresses all environmental and human health impacts during the material life-cycle, circular design process prioritizes on resource conservation. More in-depth research analysis was conducted in the sustainable and circular design processes to guide the material selection and design. During the sustainable process, the design was closely associated to the use of the materials, and design iterations were made to ensure sustainable practices could be used during and after the construction phase. As a result, the sustainable use of materials might limit the design configuration. On the other hand, in the circular design process, the design is directly impacted by the availability and use of recycled materials, and the uncertainty of the materials' availability. Therefore, circular design needs to be flexible and adaptive to potential changes. Although it takes more time and effort to address the design limits for the sustainable and circular design process, overcoming these challenges can result in more social, environmental, and economic benefits in the long term.

Figure 6.1 Summary of the three material selection process' application outcomes

Areas of Impact	Linear Process	Sustainable Process	Circular Design Process
Project Management Include: scope setting, team management, communication	Pros Less time and effort are needed.	Cons Need extra time and effort to educate stakeholders and clients about the cost and benefits of sustainable design. Cons Need extra time and effort to establish integrated design teams for multi-disciplinary collaboration.	Cons Need extra time and effort to educate stakeholders and clients about the cost and benefits of circular design. Cons Need extra time and effort to establish integrated design teams for multi-disciplinary collaboration. Cons Need extra time and effort to build local connection and networks for sourcing recycled materials and goods.
Design	Pros Less time and effort are needed. Pros More freedom to use organic form and irregular element in the design.	Cons Need extra time and effort to research more information on the construction materials' characteristics and performances related to their environmental impacts. Cons Need extra time and effort to research and analyze environmental impact priorities of the project and their relationship with the use of construction materials. Cons Need extra time and effort to source sustainable materials and specify sustainable use of materials. Cons More possible to have design iterations for a sustainable use of construction materials. Cons The sustainable use of construction materials might limit the design configuration.	Cons Need extra time and effort to research more information on the construction materials' characteristics and performances related to their capacity to be recycled/reused. Cons Need extra time and effort to research the available resource of recycled materials and goods if local connection and networks have not been established. Cons Need extra time and effort to constantly update the information on the availability of recycled materials and goods. Cons More possible to have design iterations to adapt the use and availability of recycled materials and goods. Cons There might be no, or no enough, recycled materials and goods that are available to be used during the time of the project. Cons The circular design considerations of construction materials might limited the design configuration.
Construction	Cons More irregular the design configuration is, more budget, time and effort are needed in construction documentation and administration. Cons More irregular the design configuration is, less change the design can adapt during the construction documentation and administration.	Cons Need extra budget, time and effort to perform sustainable practices in construction documentation and administration. Cons Often need extra budget to purchase sustainable materials. Pros Provide economic and social benefits to the local communities by purchasing local materials and services.	Cons Need extra budget, time and effort in construction documentation and administration for design for disassembly. Cons Might need extra budget to purchase recycled materials. Pros Might need less budget to purchase recycled materials. Cons Need extra time and effort to purchase recycled materials because the availability and inventory are unstable. Pros Provide economic and social benefits to the local community by purchasing local materials and services. Pros Often the design configuration is flexible and adaptive to changes due to installation requirement and materials' availability.

Performance	Cons Might need extra labors in maintenance if the selection and use of materials are not sustainable. Cons Might cause more negative environmental impacts if the selection and use of materials are not sustainable.	Pros Reduce negative environmental impacts by sustainable selection and use of materials. Pros Added opportunity to promote sustainability awareness and education by monitoring and reporting the sustainable materials performance overtime. Pros Lower the maintenance cost by sustainable selection and use of materials. Pros Increase the longevity of the design by sustainable selection and use of materials.	Pros Reduce waste and energy consumption, conserve resources by using recycled materials and reusing and recycling them after-use. Pros Added opportunity to promote and educate about material reusing and recycling by engaging public in material recycling and showcasing the recycled materials in the design. Pros Increase the longevity of materials by reusing and recycling them after-use. Pros Using recycled materials from adjacent areas might reflect and strengthen the identity of the place. Cons Might not able to find same materials if replacement is needed.

6.2 Evaluation of the Projective Design Results

The projective design results are evaluated in terms of social, environmental, and economic considerations [6.2]. To better illustrate the differences between the linear, sustainable and circular design outcomes, hypothetical calculations were conducted to quantify the results. In social considerations, the percentage of the plaza space is calculated using the square footage of the paving area for different materials, and so is the percentage of the plaza surface in the environmental considerations. On the other hand, in the environmental considerations, the percentage of the standardized elements of the plaza surface is calculated according to the following steps: 1. dividing the plaza surface by 10x10 ft grid; 2. calculated the total square footage of the irregular part of the plaza surface that do not fit the 10x10 ft grid; 3. Dividing the square footage calculated in the last step from the total area of the plaza. The percentage of the low-maintenance materials in the economic considerations is calculated by dividing the volume of targeted materials from the total volume of all materials. Geotextile, edge restraint, connections for shade structure, drainage pipes, mortar and sealant are excluded from the calculation due to the lack of information for calculation. These hypothetical numbers give a sense of the differences between the linear, sustainable and circular design results.

The evaluation shows the strength and weakness of the projective design outcomes from the application of the linear, sustainable and circular processes for material selection. The strength of the projective design outcomes from the application of the linear process is its high capacity to meet social requirements for programming, accessibility, and safety; the weakness is its the lack of environmental priorities. In contrast to the projective design outcome from the application of the linear process, the strength of design outcome from the application of the sustainable and circular design processes are their prioritization of environmental considerations such as reducing carbon emission and waste, conserving energy and raw materials, and mitigating urban heat island effect. On the other hand, there are some tradeoffs in the sustainable and circular design process in order to meet all social requirements for programming and accessibility, and their designs may be less visually exciting than in the linear process. However, the sustainable and circular design processes have higher social benefits in promoting sustainable awareness and education. Lastly, although the weakness of the sustainable and circular design processes are their uncertainty to meet or exceed project budget, they can save cost on post-construction maintenance and eventually have more long-term values.

Figure 6.2 Summary of the projective design outcomes

	Areas of Impact	Linear Design	Sustainable Design	Circular Design
Social Considerations	The plaza design meets the programs requirements.	Yes.	Yes.	Yes.
	The plaza design meets the circulation requirements, including pedestrian, bike and vehicle traffic.	Yes.	Yes.	Yes.
	The plaza design is safe and meets the universal design requirements.	Yes.	Yes, but 35% of the plaza space (permeable paver) might be bumpy to access.	Yes, but 10% of the plaza space (aggregate paving) might be bumpy to access.
	The hard surface portion of the design makes use of visually interesting texture and patterns.	The organic configuration makes visually interesting patterns.	Although less dramatic than the linear design, the organic configuration still makes visually interesting patterns, while the intersection of different paving materials strengthen the visual effect of the surface texture.	While the simple linear configuration is less visually interesting, the intersection of different paving materials strengthen the visual effect of the surface texture and pattern.
	The plaza design promotes sustainable awareness and education.	No.	The use of permeable paver can promote the sustainable awareness of storm-water runoff.	The use of recycled materials can promote the sustainable awareness of resources conservation.
	The design supports or reflects the identity of the region.	No.	The use of local limestone reflects the regional identity.	The use of recycled materials might reflects the regional identity in some degrees.
Environmental Considerations	The plaza design acknowledges the growing conditions for the site's climatic challenges.	The use of concrete has a large amount of embodied energy and carbon dioxide, and is prone to UHI effect.	The use of light-colored concrete and permeable paver reduce UHI effect. The use of wood shelter absorbs carbon dioxide and reflects less heat and radiation.	The use of wood shelter absorbs carbon dioxide and reflects less heat and radiation.
	The plaza design help manage the run-off on site.	No.	The use of permeable paver 35% of the plaza surface and porous aggregate reduce the storm-water runoff.	The use of aggregate paving 10% of the plaza surface and porous aggregate reduce the storm-water runoff.
	The plaza design reduce the energy consumption and carbon dioxide emission by using regional and locally available materials.	Some.	Yes.	Yes.
	The plaza design support design for disassembly.	No.	63% of the plaza surface (the plaza surface made from permeable concrete paver), splash pads, play features, shade structure with stainless steel connection can be disassembled easily.	90% of the plaza surface (except trail), splash pads, play features, shade structure with stainless steel connection support design for disassembly.
	The plaza design support resource conservation and waste reduction.	34% (percentage of the standardized elements) of the plaza surface , splash pads, seating can be reused and recycled easily. Shade structure, and play features can be recycled but the process is highly energy, time and labor consumptive.	76% (percentage of the standardized elements) of the plaza surface, splash pads, seating, shade structure, drainage pipe, and play features can be reused and recycled easily.	92% (percentage of the standardized elements) of the plaza surface, amphitheater, splash pads, seating, trial, shade structure, drainage pipe, and play features can be reused and recycled easily.

Economic Considerations	The plaza design meets the budget requirement.	This project does not have a budget requirement. The use of irregular elements might increase the budget on labor and material.	This project does not have a budget requirement. Sustainable materials and products might increase the project budget.	This project does not have a budget requirement. Using recycled materials might increase or reduce the project budget based on materials' types and where they are sourced.
	The plaza design saves the cost on post construction maintenance.	No. Exact numbers of cost-saving was not able to be calculated, but only 34% of the materials (composite wood, galvanized steel, vinyl, rubber) are low-maintenance.	Yes. Exact numbers of cost-saving was not able to be calculated, but 63% of the materials (porous aggregate concrete, permeable concrete paver) reduce the maintenance cost on stormwater management.	Yes. Exact numbers of cost-saving was not able to be calculated, but 83% of the materials (recycled aggregate, recycled soil & sand, recycled content concrete paver, recycled brick, recycled stone, recycled content precast concrete, recycled crumbed rubber, HDPE) are low-maintenance.

6.3 Evaluation of the Material Palettes from the Projective Design

The material palettes for all three processes are evaluated in Figure 6.3.1. To better illustrate the differences between the material palettes from the application of the linear, sustainable, and circular design processes, hypothetical calculations were conducted to quantify the results. The percentage of materials is calculated by dividing the volume of targeted materials from the total volume of all materials. Geotextile, edge restraint, connections for shade structure, drainage pipes, mortar and sealant are excluded from the calculation due to the lack of information for calculation. These hypothetical numbers give a sense of the differences between the linear, sustainable and circular design processes results.

Figure 6.3.1 Summary of the material palettes from the projective design

Considerations of Materials and their Use	Linear Design	Sustainable Design	Circular Design
Percentage of low-maintenance materials	34% (composite wood, galvanized steel, vinyl, rubber)	42% (sand & gravels, HDPE, recycled crumb rubber, composite wood, stainless steel)	83% (recycled aggregate, recycled soil & sand, recycled content concrete paver, recycled brick, recycled stone, recycled content precast concrete, recycled crumbed rubber, HDPE)
Percentage of materials that are easy to disassemble	0%	47% (the plaza surface made from permeable concrete paver, splash pads, play features, shade/shelter with stainless steel connection)	78% (part of the plaza, splash pads, play features, shade/shelter with stainless steel connection)
Percentage of recycled materials and recycled content materials used in the plaza design	0%	11% (recycled rubber, composite wood)	78% (recycled aggregate, recycled content precast concrete, recycled content concrete paver, recycled brick & stone paver, recycled rubber, recycled wood)
Percentage of materials that are recyclable or reusable after their useful lifespan	34% (the plaza surface, paving base layer, splash pads, seating can be recycled)	86% (part of the plaza surface,paving base layer, splash pads, seating, way-finding/signage, bollards, shade structure, drainage pipe, and play features can be reused and recycled easily)	90% (part of the plaza surface, paving base-layer, amphitheater, way-finding, bollards, splash pads, table and benches, trial, shade structure, drainage pipe, and play features can be reused and recycled easily)
Percentage of materials that reduce stormwater runoff	0%	68% (permeable paver and porous aggregate)	10% (aggregate paving)
Selected Materials that have a low embodied carbon (less than 50kg CO_2/Metric Ton) Numbers of the embodied carbon of construction materials by weight are sourced from “Materials for Sustainable Sites” (Calkin 2009).	Sand: 5.3 kg CO_2/Metric Ton Gravels: 16 kg CO_2/Metric Ton	Sand: 5.3 kg CO_2/Metric Ton Gravels: 16 kg CO_2/Metric Ton Limestone: 12 kg CO_2/Metric Ton Aggregate: 8 kg CO_2/Metric Ton	Sand: 5.3 kg CO_2/Metric Ton Gravels: 16 kg CO_2/Metric Ton Aggregate: 8 kg CO_2/Metric Ton Stone: 24 kg CO_2/Metric Ton

CONCLUSION

Ch. 7

7. CONCLUSION

7.1 Project Summary

This research explored the potential for a circular design process to guide material selection in site design, thus helping to reduce waste and other negative environmental impacts associated with construction materials. To answer the research question “How can a circular design process be developed to guide the material selection in site design, and what are the tradeoffs when it is compared to the existing linear and sustainable processes,” the following major efforts were conducted:

1. synthesizing the existing linear and sustainable processes for material selection in site design
2. researching the background of circular design and related topics
3. collecting information on circular design considerations for material selection
4. developing a circular design process for material selection in site design
5. applying the linear, sustainable, and proposed circular design processes for material selection in projective designs for a plaza at MLK Park in Kansas City, MO.
6. evaluating the application, design results, and material palettes of the linear, sustainable and proposed circular design processes for material selection.

With the development and application of a proposed circular design process for material selection in site design, the first part of the research question was answered. And when compared to the projective design applications of the linear and sustainable processes for material selection, the second part of the research question was answered.

This research found that a project will likely require more time and budget when sustainable and circular design processes for material selection are used. Both sustainable and circular design processes require extra effort on project initiation, schematic design, design development, construction documentation & administration, and post construction; moreover, they include more multi-disciplinary approaches in early planning and goal setting, materials specification, design and construction detailing iterations. Both the sustainable and circular design processes require more steps, with back-and-forth thinking and decision making between design and material selection. For the sustainable process, early planning and goal setting directly influence the initial design; for the circular design process, the initial design is more impacted by the availability of recycled materials and goods. On the other hand, the major difference between sustainable and circular design processes are their priorities; although both aim for alleviating negative environmental impacts, sustainable process focuses on reducing environmental and human health impacts in all phases while the circular design process focuses primarily on resource conservation and waste reduction. Circular design requires extra effort after construction as well, which includes design for disassembly and future material reuse and recycling. The strength of the linear process is its ease to use and high capacity to meet social requirements for programming, accessibility, and safety. The weakness of the linear process is that it does not prioritize environmental impacts. However, the linear process may use sustainable materials and practices, but this is not a central focus. In contrast to the linear process, the strength of sustainable and circular design processes are their long-term environmental benefits.

The circular design process for material selection perform well in terms of resource conservation and waste reduction by prioritizing the use of recycled and recycled content materials, and by detailing design elements in a way that they can be disassembled and further recycled and reused in the future, after their useful life in the current design. By reducing the need for and use of new materials, the circular design process substantially reduces negative environmental impacts associated with new material extraction, manufacturing, processing, and transportation. However, it can be challenging to apply the circular design process for material selection in site design because of the uncertainty about available supply of recycled and recycled content materials, which is always in-flux. The key is to understand locally available recycled materials suppliers, resources, and networks at the start of the design process in order to determine if the circular design process for material selection can be applied to the project.

7.2 Limitation of the Study

Since no local contractors were involved, the only used information available on the internet to identify local recycled and recycled content materials. Ideally, for the sustainable use of the circular design process, it would be necessary to continually update information on the size, quantity, and availability of local recycled materials. However, due to the research project scope and time limit, hypothetical information about the size and quantity of available recycled and recycled content materials was used. Additionally, only the “surface” materials were considered from the application of the three processes. For example, in the proposed splash pad feature, the design and evaluation do not include the plumbing, mechanical, or electrical aspects. On the other hand, the harvest mapping in the application of circular design process did not include information on adjacent deconstruction projects because no local contractor or client were involved. Ideally, adjacent deconstruction projects should also be mapped as sources for recycled materials. The design does not include construction documentation. The three design would be more realistic if construction documentation and administration was included.

This research didn’t include an evaluation of the specific materials in each design, because there are too many nuances and trade-offs to address between the three projective designs. In the evaluation of materials palettes, the percentage of materials was calculated using the volumes of the materials; geotextile, edge restraint, connections for shade structure, drainage pipes, mortar and sealant were excluded from the calculation. Since the research did not include construction documentation, the volume information did not reflect the reality, instead, it gave a sense of the possible result.

7.3 Potential of Future Study

While the circular design process for material selection seeks to design for disassembly (DFD) where materials can be reused, disassembled, and recycled after a design's useful life, there is not a lot of published literature available about DFD. The concept is still emerging in site design and could use for future study. The application of the circular design process for material selection could be more effective and efficient if there was a published database, network, or platform of information about regionally available recycled materials. Developing such a database, network, or platform, like ones that exist in Europe, for site design in the U.S. could be a future study.

Additionally, it would be important to understand how the circular design process for material selection may be influenced by a project's contract type and by the various priorities and roles of consultants on the project team. For instance, can a landscape architect use the circular design process while the architect uses the linear process? Or do all involved parties need to agree to using the circular design process? Dose the client need to have buy-in, or can the process just be part of standard design services? To answer these questions, future study could test the circular design process on real projects with multi-disciplinary design teams.

Lastly, it would be interesting to see how to aspects of the three processes for material selection could be combined to achieve project goals and client's needs. For instance, the linear process may be modified to prioritize specific sustainable or circular design processes considerations, such as reducing carbon emissions, selecting recycled content materials, and designing for disassembly. The idea of modifying or combining aspects from all three processes might be easier and more practical to perform in real landscape architecture projects, and should be studied further.

7.3 Personal Reflection

Materials in site design is one of my most favorite topics. My motivation for this research stems from concerns of waste and resource scarcity associated with the selection and use of materials in site design. Academic projects often do not require material specification, and as students, our experience to actual site implementation is limited. Thus, to expand my understanding of materials, with the help from my major professor, Jessica Canfield, also my committee members, Kirby Barret and Katie Loughmiller, I was able to focus my research on material selection and use. They also helped me to broaden my mind when consider the possible drawbacks and challenges of the application of the proposed circular design process, from practical aspects. There are still areas that can be further considered, explored, and evaluated in this research. And there are still gaps to apply the circular design process for material selection in site design. However, in my opinion, this research is not designed to provide a solution to improve the material selection process, instead, it provides a means to explore a potential solution. The most valuable lesson I've learned from this project is how to develop and conduct research in the area of interest. And I will continually build on my area of interest in the practice of landscape architecture by using what I've learned from this project.

Appendix I

Material Factsheets

CONCRETE, PAVING

End of Life

Concrete paving can end-up as disposal in a landfill or as recycled materials in various forms.

Recycling Limitation & Opportunities:

Recycling concrete pavement is a relatively simple process which involves breaking, removing and crushing concrete from an existing pavement into a material with a specified size and quality. Although there are no restrictions on the types of concrete pavements that can be recycled, it is recommended to consult with demolition and recycling contractors to choose the best recycling methods for the project purpose. Additionally, rebar or wire-mesh in concrete can be an issue.

Potential Recycling Applications:

-RCA, Recycled Concrete Aggregate: used as aggregate base in road construction.
-Soil Stabilization: used to improve the load-bearing capacity of sub-grade with a mixture of recycled aggregate and fly ash; or control stream bank erosion with larger pieces of crushed concrete.
-Permeable Paving: for walkways, driveways, and other outdoor surfaces.
-Mixing New Concrete: a more sustainable way of making new concrete is with recycled aggregate, substitute cement with fly ash and other recycled materials.
-Trenches, Pipes, and Utility Bedding: recycled crushed concrete makes a good, inexpensive substitute for gravel as the firm foundation for underground utilities.
-Materials for Reef Habitats: large pieces of recycled concrete carefully positioned offshore can form the foundation for coral to build new reefs.
-Landscaping Materials: Ground-Covers, Substitute for Mulch/Boulders/Stepping Stones, Screening/Retaining Walls, Underpass Abutment Structures, Water Feature, Fill for Wire Gabions, and etc.

Assembly & Disassembly Considerations:

After the concrete is broken up, it usually runs through a secondary impactor to separate the large and small aggregate. Additional processes and equipment, such as water flotation, separators, and magnets, may also be used to remove specific elements, such as metal rebars, from the crushed concrete. An alternative method is to pulverize the concrete, but it's harder to complete the separation process and may leave more contamination from smaller byproducts.

Benefits: price, relatively easy to recycle, durability.

Concerns: metals re-bars are embedded; energy consumption if use recycled aggregate to make new concrete structure; watch for contaminating substances such as pigments, calcium sulfate, chlorides, and oils.

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

ASPHALT, PAVING

End of Life

Most asphalt pavement can be removed and recycled directly back into new asphalt pavement on-site, or it can go to an asphalt plant for recycling. The Asphalt Recycling and Reclaiming Association (ARRA) estimates that 80% of demolished asphalt is recycled, primarily in new asphalt paving and base applications.

Recycling Limitation & Opportunities:

Asphalt takes up a tremendous amount of space in a landfill, and it is not biodegradable. Asphalt creation is environmentally destructive and requires a lot of water. However, asphalt can be repurposed into a like-new material. And it is one of the most commonly recycled construction materials. Recycled asphalt appears to be stronger than new asphalt (ARRA 2001). Also it can be more cost effective to recycle asphalt than to create new mix.

Potential Recycling Applications:

-Recycled Asphalt Pavement (RAP): cold-milled asphalt from old pavements that is transported to an asphalt plant, crushed, and mixed with virgin asphalt binder and aggregate.
-Hot Mix Asphalt On Location: Hot mix asphalt can also be made in place. This operation uses heating, compaction, and other processes that can be done on location to recycle used asphalt.
-Cold Mix Asphalt On Location: pavement is milled to desired depth for resurfacing, then processed and mixed on location.
-Asphalt Cement Supplement: for cement supplement, asphalt provides an additional binder for asphalt cement.
-Recycled Rubberized Asphalt Concrete (RAC): most common application being used for asphalt surface courses and chip and slurry seals.
-Sub-base Aggregate: used asphalt can be crushed, screened, and made into a stabilized base aggregate. It will need to be mixed with other materials before it is strong enough for use.
-Fill Material: fill or embankment, it's usually extra or leftover asphalt from other projects.

Assembly & Disassembly Considerations:

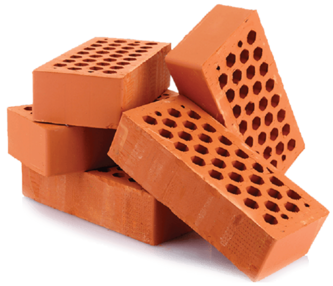
Asphalt demolition or recycling often includes crushing-up, screening for impurities, and re-processing in a facility for future use. Alternatively, asphalt can be pulverized on-location and mixed for use there.

Benefits: sealing ability, inert to greases an hydrocarbons, malleable, easier to maintain than concrete.

Concerns: possible harmful fumes, higher embodied energy than Portland cement concrete.

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014. ARRA 2001.
Images: Pngimg.com 2021.

CLAY BRICK



End of Life

Bricks can easily outlast the life of a site structure. They are often recycled after use and can be reused and reclaimed multiple times.

Recycling Limitation & Opportunities:

The Brick Industry Association (BIA) estimates that about 80& of manufacturers either reuse their own fired waste material or convert it into other products. Waste from recycling brick is minimal because they can be often returned into the mix. The high firing temperatures are said to neutralize, burn off or encapsulate any toxins in the waste in recycled brick and other materials. On the other hand, brick can be made from other recycled materials such as ashes. The average recycled content of bricks ranges from 5% to 30%.

Potential Recycling Applications:

-Use for Making New Brick
-Path/Walkway
-Planters
-Bench
-Edging for Garden Beds
-Walls
-Fire Pit
-Buildings/Construction Works
-Other Applications: crushed into powder for running tracks or baseball diamonds, mix with aggregate for construction projects, and etc.

Assembly & Disassembly Considerations:

When design with brick, try to use standard dimensions maximize the potential for future reuse. Try to minimize material quantity in structures such as freestanding walls. Carefully design and use control and expansion joints for longevity. The BIA recommends use of control joints in brick walls every 20-35 feet, and at points of stress and weakness such as level changes, openings, and between panels and columns. Use a dense graded aggregate base stabilized with Portland cement or other cementitious binder for brick paving to save materials. For installation, try to use no mortar or less mortar. Lime mortar is recommended for easier disassembly.

Benefits: fire resistant, slip resistant, durability, low maintenance, waste is minimal, often reused within the brick manufacturing process.

Concerns: 150%-400% more energy to produce than concrete paving bricks or CMUs.

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014. BIA 2007.
Images: Pngimg.com 2021.

AGGREGATE AND STONE

End of Life

Stone and aggregate are often recycled because the extraction and transportation are very costly. Sometimes they return as waste to fill in old quarry sites.

Recycling Limitation & Opportunities:

Natural Aggregate and stone can be recycled multiple times. This is same for the industrial aggregate which is produced by crushing concrete, and sometimes asphalt. Industrial aggregates are increasingly substituted for natural aggregates and stone in a wide variety of applications. Substituting recycled materials for virgin aggregate can reduce waste and energy use during mining and fabrication process. Common substitution for natural aggregates and stones include: reclaimed Portland cement concrete (PCC), reclaimed asphalt concrete (RAC), and iron and steel slags. Special consideration should be given to the toxic risks of recycled aggregate used in porous pavement and drainage situation, as water will constantly pass through it with greater potential for leaching.

Potential Recycling Applications:

-Surfacing Material: alternative to concrete or asphalt pavement such as parking, path, drive-way, and low-traffic roads.
-Dry Stack Walls/Gabions
-Retaining Walls
-Seat-walls/Seating/Amphitheater
-Sub-base Material: base course under the pavement, structural soil base, gravel trench, rubble, and stone foundations
-Reprocessed for Concrete and Asphalt

Assembly & Disassembly Considerations:

Stone structures should be designed to use less materials. Without the use of mortar, aggregate and stones can be reused multiple times in new structures or new applications after the useful life of the structure. Stone or recycled concrete "stones," called urbanite, used in dry stack walls with minimal mortar may be reusable whole if mortar is held back from the face of the wall and used sparingly. Sand-set stone or urbanite paving on sand can be easily re-leveled during use and reclaimed for reuse after the useful life. Gabions offer ease of disassembly, as steel cages are easily cut to removed and reclaim stones.

Benefits: durability, solidity, one of the most accessible and abundant natural resources.

Concerns: environment and economic cost for excavation and transportation, waste.

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

Soil And Sand

End of Life

Soil and sand can be returned to the earth or used in other projects with minimal processing.

Recycling Limitation & Opportunities:

Soil and sand used in site design are often locally obtained or recycled from adjacent site. It is important to recycle soil because it is a non-renewable and limited natural resources. It can take 500 years or more for an inch of topsoil to form. Reusing uncontaminated construction soil on-site is beneficial because it reduces disposal costs and environmental burdens. Various methods and techniques for on-site soil reuse have been explored. However, there are various prerequisites to consider, such as construction schedules, soil type, trading volume, incurred costs, and soil health. Reusing the excavated soil by transferring it to other sites requires construction management coordination for both the cut and fill sites. For contaminated soil, remediation is necessary before reusing.

Potential Recycling Applications:

-Fill
-Wall/Edging
-Paving/Surfacing
-Planting Bed
-Earthen Structure

Other Considerations:

Sustainable use of soil includes creating a soil management plan (SMP) prior to construction that provides locations of existing healthy soils onsite and any vegetation and soil protection zones. Maintain existing ecosystem services and landscape performance by limiting the disturbance of healthy soils and plants. Maintaining and restoring soil health by using recycled organic matter to support soil nutrient and by planting functional vegetation would maximize the rate of soil recycling in the future.

Benefits: inexpensive, relatively easy to find, low embodied energy, carbon sequestration, aesthetic,can return to earth or be reused easily in a new earth structure.

Concerns: contamination, prone to degradation.

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

WOOD, AND WOOD PRODUCTS

End of Life

Wood is reasonably biodegradable, especially if not treated, and the decomposition will return carbon to the soil. The majority of lumber ends up being disposed in a landfill, while the rest are either recycled or burnt. Treated lumber, especially chromate copper arsenate-treated (CCA) pose a large disposal problem Wood is called a theoretically renewable material, since it is used at a rate much faster than its renewal.

Recycling Limitation & Opportunities:

Nearly all types of solid wood can be reused. Untreated wood can't be reclaimed and reused whole, it can be recycled into other wood products such as mulch or composite lumber. Reclaimed lumber can be denser, stronger, closer grained, and more free of structural defects than virgin ones because they were harvest at a much slower rate in old days. Reclaimed wood can be drier and may split when nailing. If reclaimed wood is not cleaned, surfaced, graded and dimensioned to requirement, extra time and cost need to be considered. It is better to keep and use big wood members whole when possible because they can't easily be found in virgin lumberyards. Reclaimed wood often has some irregularities and bolt holes, fastener marks, stains, and blemishes. The reclaimed wood with undesirable appearance can be used for structural work that is not very visible. It is highly recommended to let the materials inspire the design, since finding specific member sizes and species of reclaimed wood after the design phase can be challenge.

Potential Recycling Applications:

Reclaimed wood has a wide range of use which includes but not limit to :

-Mulch & Ground cover
-Furniture
-Walkway/Path/Flooring/Steps/Stairs
-Decking/Balcony
-Framing/Shelving
-Edging
-Fencing/Screening
-Wall
-Ceiling/Overhead Structure
-Structural Works
-Decorated Element
-Smaller, less valuable wood scraps can be used for composite products such as particleboard

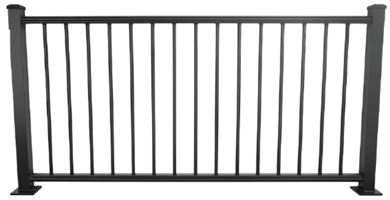
Assembly & Disassembly Considerations:

Use screws and bolt connection instead of glued or pneumatically nailed connection for disassembly. Some reclaimed wood may need to be trimmed or routed to work with standard wood connectors, thus the design will need to be altered to fit wood sizes.

Benefits: aesthetic quality, various usages, carbon 'sink', dried ready, environmental friendly, strength.

Concerns: hidden cost & time, extra works, concerns of risky treatment and finishes such as CCA and lead paint, nails and staples, locating specific size and quality, weathering.

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.



METAL, STEEL

End of Life

Carbon Steel is one of the most recycled construction materials. About 80% of steel end up being recycled each year in North America. Uses of carbon steel scrap is an integral part of steel manufacture because its use lowers the cost of producing new steel. Currently, carbon steel has a high scrap value due to the high recycling rate.

Recycling Limitation & Opportunities:

Steel recycling industry is well established and economically strong because steel is nearly endless recyclable and does without loosing its quality. Carbon steel is the most commonly used steel in construction industry, and its vulnerable to corrosion and often coated for exterior uses. Weathering steel, or Corten steel, is a family member of low-carbon steel. Although Corten steel is recyclable and has gained popularity for its aesthetics, it is criticized for the fast rate of corrosion which makes it only last around 15 years. Recycling carbon steel is relatively easy with magnets; its high melting point requires substantial energy, and toxins are released from burning off paints and removal of surface alloys. Some concerns for recycling carbon steel also include the removal of finishing. For example, electroplating which often used in a mixed metal product is not recyclable. Powder coating or galvanizing may pose toxic risks during their removal.

Potential Recycling Applications:

Recycled carbon steel often is processed to make new steel product. Scrap carbon steels are commonly used in construction of automobiles, aircraft, appliances, industrial containers, ductwork, and plumbing. Common uses for carbon steel in landscape architecture include:

-Railing & Stairs/Steps
-Fencing/Screening & Edging
-Sculptures/Decorated Element
-Site Furniture (Table&Chair, Trash Bin, Bike Rack, Planter, Fire Pits, Seat-Walls)
-Bollard & Lighting Fixture

Assembly & Disassembly Considerations:

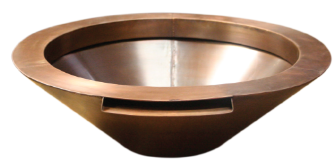
Carbon steels need to be separated from other materials, sometimes manually before recycling. It is recommended to use less types of materials in the design product. Since recycling carbon steels involves melting, the use of any risky chemical coating or finishing should be avoid (noted that stainless steels do not need finishing). Reusing steel whole will save most energy and resources. On the other hand, connections made from carbon steel such as removable fasteners, screws and bolts allow for the efficient disassembly of any design products. Reducing sizes and thickness, and taking fabrication and finishing process on site will save energy and resources.

Benefits: aesthetic, versatile, flexibility, easy to recycle, reduce the significant environmental impact for raw material extraction

Concerns: recycling process can be energy, labor and time consumptive, corrosion, maintenance, toxins from risky coating and finishing

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

METAL, COPPER



End of Life

The end of life for copper is often recycle due to the high scrap value. It is one of the few materials that can be recycled repeatedly without any loss of performance. According to the International Copper Association, about 40% of copper is recycled each year.

Recycling Limitation & Opportunities:

The copper recycling requires 80-90% less energy than primary production. The recycling of complex copper scrap drives the recovery of many other metals such as gold, silver, nickle, tin, lead and zinc. It's highly recommended to reuse copper in whole because it is hard wearing and long lasting. The common recycling process for copper scrap includes: gathering, dismantling, sorting, melting, casting, and manufacturing for new metal product. Some disadvantages of recycling copper include: time and energy for collecting, transporting sorting and purifying the mixed metal. Good news is that if copper is recycled for construction uses, it does not requires a high purity. This means that scrap copper can easily be added to the steel furnace when steel is being made.

Potential Recycling Applications:

Recycling copper for construction use does not require a complex cleaning and purifying process. As a result, recycled copper is often used for plumbing, roofing, and cladding. About 50% of recycled copper is used in tube manufacturing. Scrap copper with tin and lead presence are valuable as they are used to make gun metals and bronzes. Common uses for carbon steel in landscape architecture include:

-Structural Components
-Railing
-Fencing/Screening & Edging
-Sculptures/Decorated Element
-Site Furniture
-Bollard & Lighting Fixture
-Planter
-Water Feature

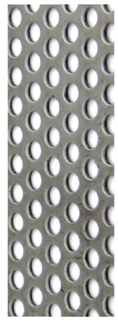
Assembly & Disassembly Considerations:

Copper needs to be separated from other materials, sometimes manually before recycling because copper is not magnetic. It is recommended to use less types of materials in the design product. Since recycling carbon steels involves melting, the use of any risky chemical coating or finishing should be avoid (noted that stainless steels do not need finishing). Reusing copper in whole will save most energy and resources. Reducing sizes and thickness, and taking fabrication and finishing process on site will save energy and resources. Choosing mechanical fasteners such as screws and bot rather than welded connections makes disassembling easier.

Benefits: light, corrosion resistant, versatile, durable, less maintenance, aesthetic, reduce the significant environmental impact for raw material extraction.

Concerns: cost, challenging to source

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.



METAL, ALUMINUM

End of Life

The end of life recycling of aluminum around the world have continued to improve. It United States, 2019 statistics shows more than 60% of aluminum is recycled. And more than 40% of aluminum products in United State in 2019 is secondary production from scrap and recycling. However, it is recorded that demand for new aluminum exceeds the supply of used material.

Recycling Limitation & Opportunities:

Recycling aluminum takes relatively low energy input, because aluminum has a low melting temperature. The International Aluminum Institute estimates that recycling aluminum saves 84 million tons of greenhouse gas emissions per year. Recycling aluminum can significantly reduce the tremendous environmental impacts of its raw material extraction. Although aluminum can be recycled through sorting, cleaning and melting, it needs to be separated from steel, plastic, and other debris. This process might be time and labor consuming since aluminum is not magnetic. Moreover, aluminum tends to lose its quality after recycling. The recycled aluminum is commonly used in furniture, aircrafts, appliances, and constructions. Other concerns of recycling aluminum include the large amount of electricity usage and contamination. It’s challenging to recycle and use aluminum exterior objects in its whole form, because they are often highly processed (e.g. Perforated aluminum fence or paneling).

Potential Recycling Applications:

Recycled aluminum is usually melted to make new metal product. Aluminum is light and ductile, thus it is not often used for heavy duty function. Common uses for aluminum in landscape architecture include:

-Railing
-Fencing/Screening & Edging
-Sculptures/Decorated Element
-Site Furniture
-Bollard & Lighting Fixture

Assembly & Disassembly Considerations:

Highly corroded pieces with metal loss are low in scrap value, reducing the chances that it will be recycled. Choosing the right coating and finishing to avoid toxins and pollution. Electroplated metals are not usually recyclable. Choosing mechanical fasteners such as screws and bot rather than welded connections makes disassembling easier. Reducing sizes and thickness, and taking fabrication and finishing process on site will save energy and resources.

Benefits: light, corrosion resistant, versatile, road salt resistant, reduce the significant environmental impact for raw material extraction,
Concerns: cost

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

METAL, IRON

End of Life

Iron (the most commonly used in contemporary site construction are cast iron and pig iron) is often recycled after use due to its high scrap value. 90% of all metal that is refined today include iron.

Recycling Limitation & Opportunities:

Iron is often recycled with carbon steel. It can be recycled without loosing its quality. It is the most commonly used steel in construction industry, and its vulnerable to corrosion and often coated for exterior uses. The life span and material characters vary depending on the types of the iron products. Recycling iron is relatively easy with magnets; its melting point is a little less than steel. Some concerns for recycling iron include the removal of finishing. For example, electroplating which often used in a mixed metal product is not recyclable. Powder coating or galvanizing may pose toxic risks during their removal.

Potential Recycling Applications: Recycled iron often is processed to make new iron, steel or other metal product. Common uses for carbon steel in landscape architecture include:
-Railing & Stairs/Steps
-Fencing/Screening & Edging
-Sculptures/Decorated Element
-Site Furniture (Table&Chair, Trash Bin, Bike Rack, Planter, Fire Pits, Seat-Walls)
-Bollard & Lighting Fixture

Assembly & Disassembly Considerations:

Careful design decision to avoid corrosion is important for choosing iron. Separating iron is fairly easy with magnet. Designing considerations for disassembling iron is similar to the ones for carbon steel. Choosing mechanical fasteners such as screws and bot rather than welded connections makes disassembling easier. Reducing sizes and thickness, and taking fabrication and finishing process on site will save energy and resources.

Benefits: durable, versatile, flexibility, easy to recycle, inexpensive

Concerns: reactive, corrosion, maintenance, toxins from risky coating and finishing, need to avoid acid environment, strength and ductility varies

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

METAL, STAINLESS STEEL

End of Life

Scraped stainless steel in the landfill is such a waste of resource. Team Stainless and Yale University had documented 85% of stainless steel are recycled at end if life in 2015; Among the recycled stainless steel, 56% of them is used to make new stainless steel, and 29% is used to make new carbon steel. Stainless steels can be in use for half century and beyond before they become available for recycling.

Recycling Limitation & Opportunities:

Stainless steel is highly recyclable with a very high scrap value. The majority of stainless steel is manufactured using recycled materials. However, the use of recycled metal does not completely eliminate the pollution and toxins. The typical process of recycling stainless steel includes: collecting, sorting, processing, melting, purification, solidifying, and transportation of the metal bars. A considerable amount of energy is used in these steps. Therefore, it is highly recommended to reuse the material before recycling it.

Potential Recycling Applications:

Recycled stainless steel often is processed to make new stainless steel product. Scrap stainless steels are commonly used in construction of automobiles, aircraft, appliances, industrial containers, ductwork, and plumbing.

Common uses for stainless steel in landscape architecture include:

-Railings
-Water fountains and other water features
-Sculptures
-Tables & hairs
-Trash Bins
-Framing
-Shade Structure
-Bollards
-Bike Racks
-Lighting Fixture
-Decorated Element

Assembly & Disassembly Considerations:

Stainless steels need to be separated from other materials, sometimes manually before recycling. Using less types of materials in the design product would prevent the cost of time and labor to disassemble. Since recycling stainless steels involves melting, the use of any risky chemical coating or finishing should be avoid (noted that stainless steels do not need finishing). On the other hand, connections made from stainless steel such as removable fasteners, screws and bolts allow for the efficient disassembly of any design products. Since stainless steel can be in use for many years, design a product that is intended to last long is the most sustainable way to use stainless steel.

Benefits: corrosion resistant, finishing free, versatile, easy to source, durability, non-reactive for bacteria, reduce the significant environmental impact for raw material extraction.

Concerns: recycling process can be energy, labor and time consumptive, some of the recycled materials are impure.

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

RUBBER

End of Life

Used rubber often ends up in landfill, incinerator or being recycled and reused in a variety of products.

Recycling Limitation & Opportunities:

The challenge of rubber recycling is to maintain its original characteristics. Rubber products that are commonly recycled for construction use include tires and surfaces. Ground rubber from scrap tires can be used for playground surfaces, both bound and unbound; running surfaces; athletic field turf amendments; and rubber sidewalks. The benefits from using ground rubber from scrap tires in site uses are potential cost savings, use of a local material, improved product performance, and safety ratings. Moreover, ground or crumb rubber can be used in relatively high percentages, many 100%, in the following application Categories:

1. Loose Cover: ground rubber provides a cushioned surface when placed under or around playground equipment. It can also be used as mulch in planting beds.
2. Rubber Surfacing Products: precast tiles and mats or poured-in-place surfacing.
3. Paving and Surfacing: applications are made by adding crumb rubber to a binder and then placing it.
4. Ground Rubber: used in turf topdressing applications and in turf soil.
5. Whole Form: use of tires in site applications includes retaining walls, erosion control, and dock bumpers.

Potential Recycling Applications:

-Rubber Mulch
-Playground Surfaces
-Running tracks
-Garden Hoses/Soaker Hoses
-Patio Blocks
-Rubberized Asphalt
-Asphalt Fill
-Athletic Field Turf Amendments
-Rubberized Sidewalks

Assembly & Disassembly Considerations:

Rubber can be demolished and recycled through a straight-forward process. Rubber can be broken down, ground up, or shredded into small pieces for reuse. Then the rubber goes through grinding and screening to remove unwanted materials such as stone, metal and fiber. This process might be challenge depending on the sourcing of recycled rubber.

Benefits: elasticity, resistance to breaking, good chemical barrier.

Concerns: difficult to recycle (thermosetting), deterioration over time.

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

PLASTIC

End of Life

With the exception of HDPE products, most plastics are disposed of in landfills or incinerators, as the recycling infrastructure for plastics faces challenges that limit the activity.

Recycling Limitation & Opportunities:

Not all plastics are recyclable (e.g., PVC), and recycling facilities for construction-used plastics are limit. The strength and durability of plastics makes some products good candidates for reuse in new applications without recycling. There are some products used in site construction that could be reused whole such as plastic lumber. On the other hand, plastics can be recycled multiple times to yield new polymeric materials and products. However, reusing plastics in whole is much more sustainable than recycling because recycling plastics requires additional processing. Despite relatively low plastic recycling rates, the large volume of plastics in the waste stream has resulted in the development of many construction products with recycled plastic content.

Potential Recycling Applications:

-Treated Recycled Plastic Aggregate (TRPA): recycled plastics can be used for aggregate or an asphalt cement additive in asphalt pavement.
-Recycled-Content Plastic Lumber: HDPE plastic lumber usually has a relatively high recycled content.
-Recycled-Content Composite Lumber: composite lumber is produced by blending other materials such as fiberglass or wood waste with recycled plastics. However, mixing resins with wood or glass fibers renders the composite lumber nonrecyclable.
-Recycled Content Construction Products: decking, composite decking, fencing, timbers and post, raised beds, retaining walls, terracing, edging, railings, benches and tables, construction/snow fencing, playground equipment, playground surfaces, running track, bike racks, garden hoses, soaker hoses, patio blocks, tree grates, tree guards, tree root barriers, bollards, parking stops, pipe, sound barriers.

Assembly & Disassembly Considerations:

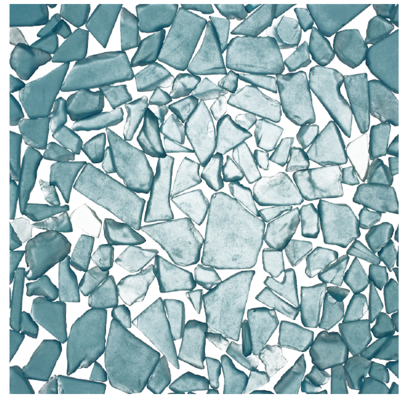
Plastics can easily be designed for disassembly because of their flexible and light structural characteristics.

Benefits: light, durable, water-proof, decay resistant, flexible, integrally colored, inexpensive, low maintenance.

Concerns: consume significant fossil fuels, by-products cause waste and emission, chemical additives can release toxins.

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

GLASS, AND GLASS PRODUCTS



End of Life

Although glass is highly recyclable and recycled glass is often used in new glass production, only one third of disposed glass get recycled. Most of glass ends up in trash, because the incorrect way of glass recycling, which is mixing glass with other types of materials or mixing different types of glass.

Recycling Limitation & Opportunities:

Glass is highly recyclable and can be recycled endless without loss in quality. While new glass is made from raw materials that need to be quarried such as sand, ash, and limestone, recycling glass can save raw materials and energy, and reduce emission. Glass containers for food and beverages are 100% recyclable, but not with other types (windows, Pyrex, crystal, and etc). The main problem with glass recycling is separating the types of glass, while some of them are not widely recycled (borosilicate glass for heat resistant product like Pyrex, lead glass for sparkling decorative glassware, and glass fiber for insulation and fiber optic cable).Common types of recyclable glass in construction industry are:

-Float Glass
-Shatterproof Glass
-Laminated Glass
-Extra Clean Glass
-Chromatic Glass
-Tinted Glass
-Toughened Glass
-Insulated Glazed Units

Potential Recycling Applications:

Reclaimed glass can create various visual elements and can be incorporated with other materials for :

-Mulch/Ground cover & Topping for Container
-Tiles
-Fire Pit
-Furniture
-Lighting
-Walkway/Path/Flooring/Steps/Stairs
-Edging
-Fencing/Screening/Wall
-Ceiling/Overhead Structure
-Decorated Element
-Water Feature/Pool
-Pavilion/Pergola

Assembly & Disassembly Considerations:

Glass recycling does not require much 'disassembly'. Once glass is collected and taken to be reprocessed, it is often crushed and mixed with other materials to make new glass products. Other times, glass bottles, light, jars and other products may be recycled in whole. One thing to note is to separate glass with other materials when disposing them to the recycling center.

Benefits: versatile, easy to recycle, aesthetics, can be recycled without loss in quality, durable, weather and rust resistance, insulator against electricity, heat absorbent

Concerns: Unsafe for earthquake proven areas, cost for maintenance, concerns for breaking

Sources: Calkins 2019. EPA 2020. Gesimondo 2011. Kula et al. 2014.
Images: Pngimg.com 2021.

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FIGURE CITATIONS

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