Barriers and Enablers to Circular Building Design in the US: An Empirical Study

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Abstract: As discussions around the circular economy (CE) start to move beyond Eurocentric approaches, US stakeholders are left with the mission of carving their way into CE. The US building sector has substantial impacts in resource use, waste generation, and carbon emissions, and a long way to go on the path toward CE. Circular building design involves strategies such as design for disassembly (DfD) to allow future repair, remanufacture, and reuse of building components, building adaptive reuse, and using salvaged materials in new construction. Although strategies like DfD have been discussed for the last 2 decades, they have failed to gain traction in building design. However, there is a limited body of literature devoted to understanding the barriers and enablers for key circular building design strategies like DfD. A few recent empirical studies in European countries have identified barriers for circular building design, which in this study were categorized according to their nature (regulatory, economic, technical, educational, cultural, technological, and environmental barriers). However, given the different regulatory, economic, and cultural contexts in which the US is situated when compared with European countries, the barriers identified in prior studies and their respective enablers may not apply to the US. For example, contrary to European countries, the US is yet to create a national CE-specific legislation or action plan. Thus, bottom-up efforts from industry stakeholders are key to achieve progress toward CE in the US. Yet there are no studies that investigated barriers and enablers to circular building design in the US context. This study aims to fill this knowledge gap. The authors interviewed architects across the US to understand the perceived and experienced barriers to circular building design in the US building sector and propose enablers to overcome these barriers. The barriers differed in nature from those found in European countries: although the share of technical and economic barriers were similar, more educational and cultural barriers were found in the US, as opposed to a larger shares of regulatory and technological barriers in European countries. The authors discuss the most mentioned barriers in the US (e.g., cost and schedule constraints, lack of clarity on what CE entails, and existing regulations and codes hinder reuse and repair), and the barriers that were new to the literature (e.g., belief that DfD compromises building durability and resiliency, conflicting goals between pre-engineered structures and future reuse, and the widespread use of nondurable building components). Finally, the authors propose enablers to address each barrier and discuss the role of different stakeholders in implementing enablers. Policymakers, non-governmental organizations (NGOs), industry associations, and researchers were the stakeholders with the highest leverage to enable CE in the US building sector. **DOI: 10.1061/(ASCE)CO.1943-7862.0002109.** *© 2021 American Society of Civil Engineers.*

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Introduction

Population growth, rising infrastructure needs, climate change, and the threat of resource scarcity have motivated increasing discussions around the circular economy (CE) in the last few years. The limitations of recycling have become clear: increasing recycling initiatives were not enough to stop the growth of material use and carbon emissions around the globe (Circle Economy 2019; Pomponi and Moncaster 2017). The goal of CE is to generate more value and economic opportunity while designing out waste and using fewer resources that can be reused (EMF 2013). Advocates for CE have highlighted the promise of circular strategies like resource durability, reuse, recovery, remanufacturing, repair, and disassembly (EMF 2019; Stahel 2016). As a leading industry in resource extraction and waste generation, the building sector has a key role in the path toward CE: a circular built environment could reduce global carbon emissions by 38% in 2050 (EMF 2019). In the US alone, construction and demolition activities generate 160 million tons of waste every year (Kibert 2013). Yet the construction industry recycles or reuses less than 30% of construction and demolition waste (CDW), which can be attributed to a lack of circular building design strategies like design for adaptability, disassembly, and reuse (EMF 2013).

Circular design principles include designing with fewer resources (also called dematerialization), preserving and extending natural and human-made resources, designing for long use, extended use, and recovery, and design for technical and biological cycles (Bocken et al. 2016; den Hollander et al. 2017; EMF 2020; Circle Economy 2020a; Braungart 2020). Strategies within the built environment may include design for disassembly (DfD) and adaptability, reuse of building components, building adaptive reuse, and the use of biodegradable building materials (Akinade et al. 2017; Kanters 2020; Rakhshan et al. 2020; Stahel 2019; Durmisevic 2019). Although the terminology circular building design is recent, strategies like DfD have been described in the literature since the late 1990s (Crowther 1999; Guy and Ciarimboli 2007). Designing a building for disassembly means to (1) minimize the number of

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different types of materials; (2) use lightweight materials and components; (3) provide standard and permanent identification of material and components; (4) design a flexible, adaptable building; (5) document a deconstruction plan; (6) design joints that can be dismantled; (7) specify durable, nontoxic, modular, and prefabricated components; (8) sort reusable and recyclable building products; (9) design components with standard dimensions; (10) procure salvaged materials for new projects when possible; and (11) store building construction and disassembly data (Crowther 2005; Guy and Ciarimboli 2007).

However, the concept of DfD has never gained traction in the building sector (Akinade et al. 2020). Instead, there are isolated examples of building that were designed for disassembly. One such example is the Bullitt Center, a commercial building opened in 2013 in Seattle, Washington, that was designed to be disassembled in the future. The building owner, Dennis Hayes, justified the DfD as a means to increase the building lifespan and resiliency (Hayes 2017). For example, when the façade system is ready for replacement, it can be detached from the core structure, inspired from a snail changing shells. According to Hayes, such an adaptable design can extend the life of the over 200 years.

Recently, a few authors have investigated the barriers and enablers of circular building design strategies like DfD and reuse in the built environment (e.g., Densley Tingley et al. 2017; Hart et al. 2019; Kanters 2020; Rakhshan et al. 2020; Cruz Rios et al. 2015). Examples of commonly identified barriers included cost and schedule constraints, underdeveloped market for salvaged materials, lack of stakeholders' knowledge and awareness of CE, competitive and fragmented nature of the construction sector; perceived lack of aesthetics and quality of salvaged materials, uncertainty about the end of life of products with a long life span, lack of fiscal and regulatory incentives, and lack of infrastructure and technology to collect, sort, and process salvaged materials. However, the empirical studies that have investigated barriers and enablers for circular building design strategies to date were conducted in European countries. To the authors' knowledge, no similar empirical study has been attempted to identify barriers and enablers for CE in the US building sector.

In this paper, the authors interviewed architects across the US to understand the challenges and opportunities for circular building design. The paper is structured as follows: the next section provides an overview on the emerging topic of CE, followed by a review of CE in the built environment, examples of circular building design strategies, and a summary of the barriers identified in the literature. Then, the authors present the methodology used in this study, followed by a discussion of the barriers perceived and experienced by the participants and the enablers proposed by the authors. Finally, in the "Discussion" section, the authors explain the role of different stakeholders in creating the necessary conditions to implement CE in the US built environment, which is followed by a section on the limitations of this study, and the conclusions.

Background

This section provides an overview of CE and its application to the built environment, describes circular building design strategies, and summarizes recent studies that investigated the barriers and enablers for CE in the building sector.

Circular Economy

Today, humanity is using resources 50% faster than they can be replaced, and the supply of certain materials will not be enough to meet the increasing demand (McGlyn 2015). Among the materials that face declining reserves and have no viable substitutes with comparable performance are metals like copper and rare earth metals (Althaf and Babbitt 2020; McGlyn 2015). That is especially concerning given the application of these materials in essential technologies like renewable energy (e.g., solar panels and wind turbines), electric vehicles, and electronic devices.

In response to these challenges, some countries have created national plans to support a shift toward CE. For example, China created the Circular Economy Promotion Law in 2009, the European Commission released an Action Plan for the Circular Economy in 2015 (McDowall et al. 2017), and more recently Australia is in the process of releasing a National Circular Economy Roadmap (CSIRO 2020). However, CE policymaking remains fragmented and lacks coordinated global efforts, and the world is still far from circularity. According to a circularity metric created by the Platform for Accelerating the Circular Economy (PACE), today's global economy is only 8.6% circular (Circle Economy 2020b).

The ultimate goal of the CE is to generate more value and economic opportunity while designing out waste and using fewer resources that can be reused for a long time (EMF 2013). CE has been advocated as a low-carbon economy. Researchers estimated that a combination of CE strategies like increasing the share of renewable resources, enhancing energy efficiency, and promoting products' durability and reuse can reduce country-level greenhouse gas emissions by 70% (Wijkman and Skånberg 2015). Although a consensus around one definition for CE is yet to be reached (Saidani et al. 2019), CE-related concepts have existed for many years. It can be argued that CE is a convergence of ideas from industrial ecology and symbiosis, cradle-to-cradle design, biomimicry, product-service systems, natural capitalism, and eco-efficiency, among others (Korhonen et al. 2018). Despite incorporating principles from other disciplines, CE brings a new focus on resource integrity and preventing obsolescence through slowing and closing resource loops (den Hollander et al. 2017; Bocken et al. 2016).

Geissdoerfer et al. (2017) attempted to conceptualize CE as a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. Such regenerative system can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.

The terminology of narrowing, slowing, and closing resource loops was introduced by Bocken et al. (2016). According to those authors, narrowing resource loops refers to resource efficiency strategies such as dematerialization (i.e., using as few resources as possible through design and service-based business models), using secondary resources, and prioritizing renewable resources. Slowing resource loops refers to product life extension strategies like reuse, repair, and remanufacturing. Finally, closing resource loops refers to recycling as a means to keep materials in circulation when products can no longer be reused or remanufactured (Bocken et al. 2016; Stahel 2016). Besides investing in design strategies to narrow, slow, and close resource loops, other enablers for CE include circular business models, incorporating digital technology, and creating joint value through multidisciplinary collaboration (Circle Economy 2020a).

As the world's largest consumer of raw materials (Pomponi and Moncaster 2017), the construction industry has a vital role in the transition toward CE. As the population grows, construction activities are projected to keep growing and material demand is expected to double by 2050 (Pacheco-Torgal 2014). As a result, the sector will need to increase resource efficiency from fourfold to 10fold in the next few decades (Pacheco-Torgal 2014). However, CE case studies in the built environment are just starting to emerge (Pomponi and Moncaster 2017), and there is a need for a

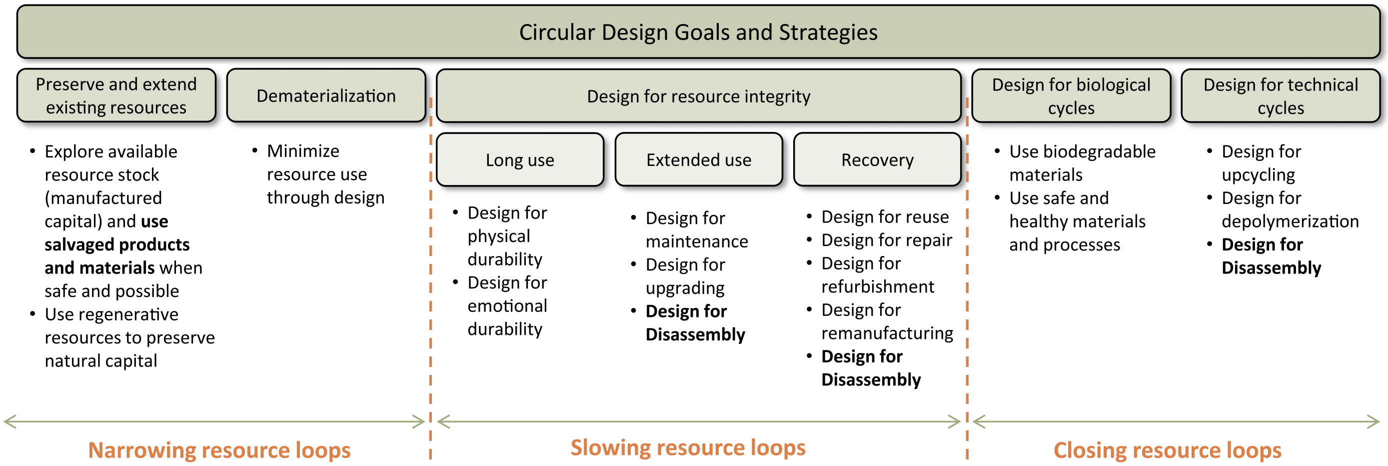

Fig. 1. Circular design goals and strategies.

widespread design of so-called circular buildings. The next section will discuss how a circular built environment would look like.

Circular Economy and the Built Environment

Pomponi and Moncaster (2017) defined circular buildings as buildings that are "designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles." In a circular built environment, buildings are designed and built with the adaptation and deconstruction in mind and operated and maintained through circular business models like product-service systems (Cruz Rios and Grau 2020). In product-service systems (PSS), manufacturers lease building products (e.g., a roofing system) to building owners, who pay not for the ownership of the products but for the service they provide (e.g., a dry environment). The manufacturers retain the ownership and are responsible for maintenance, repair, replacement, and take-back for remanufacturing or reuse (Cruz Rios and Grau 2020). These products are labeled and tracked using material tracking technologies like geographic information system (GIS) and radio frequency identification (RFID) (e.g., Ness et al. 2015). The labels, also called material passports or circularity passports, combine Internet of Things (IoT) and blockchain technologies to create and store trustworthy CE-relevant data over a product's life cycle (Heinrich and Lang 2019; Luscuere and Mulhall 2018). The end goal is to have a built environment where the buildings function as material banks (Copeland and Bilec 2020). In this scenario, virgin material extraction would give place to urban mining, that is, the process of recovering resources from existing stocks of products, materials, buildings, and infrastructure dispersed in urban systems that would otherwise be disposed of in landfills (Gaustad et al. 2020; Stephan and Athanassiadis 2017; Zhu 2014).

Such a transformation will require a shift in the way buildings are designed. Design is at the core of CE. If buildings and building products are not designed for disassembly, it will not be possible to recover these materials for reuse or remanufacturing, for example. This paper focuses on the design piece of circular built environments. The next section presents some specific circular design strategies applied to building design.

Circular Building Design Strategies

Most of the research on circular design frameworks to date aim at the product level (e.g., Blomsma and Tennant 2020; Bocken et al. 2017; Braungart 2020; Circle Economy 2020a; den Hollander et al. 2017). Fig. 1 summarizes circular design goals and strategies as proposed by the aforementioned authors and organizations. As discussed in the previous section, preserving existing resources and dematerialization are examples of narrowing resource loops. Designing for resource integrity through increasing durability and easing product recovery are examples of slowing resource loops. Finally, designing for biological or technical cycles are examples of closing resource loops by transforming waste in resource either through natural processes like biodegradation, or industrial processes like recycling. Slowing and closing resource-loop strategies are enabled by DfD (Fig. 1).

What does circular building design look like? To narrow resource loops, building designers should prioritize the adaptive reuse of buildings and the use of salvaged materials in new construction. Additionally, using renewable energy sources and closed-loop water systems are examples of how to preserve natural resources. Examples of dematerialization are reducing the number of materials and products used in buildings (e.g., avoiding unnecessary finishing materials), or eliminating the need for brick-and-mortar infrastructure altogether when possible (e.g., shared facilities like coworking spaces; online commerce; and remote work).

Slowing resource loops means preserving the value of resources over time, e.g., investing in physical and emotional durability strategies. Physical durability refers to designing with long-lasting materials and building resilient structures. Designing for emotional durability, in turn, means designing buildings that will be loved for longer by taking into consideration user experience and occupants' comfort, health, and productivity (biophilic design is a great example). Other strategies to slow resource loops include creating buildings that enable maintenance and upgrade of building parts. That can be achieved by easing the access to building parts, keeping detailed as-built documents, tracking building performance over time, and procuring building products from manufacturers that invest in product-service systems business models.

Finally, designing for recovery means to create buildings with components that are readily reusable, repairable, and able to be remanufactured or refurbished. DfD plays a key role in designing for recovery by allowing building components with different life spans to be detached from the building and repaired, remanufactured, or reused (Cruz Rios and Grau 2020; Durmisevic 2019; Stahel 2019).

Finally, building designers can help closing resource loops by selecting safe, healthy, and biodegradable materials (i.e., design for

Table 1. Studies that investigated barriers for circular design in the built environment

n	References	Country	Method	Empirical?
1	Akinade et al. (2020)	United Kingdom	Six focus group interviews with 28 construction stakeholders (23% architects and design managers) to identify barriers to DfD practice. Other barriers identified in the literature.	Y
2	Hossain et al. (2020)	Hong Kong and Canada	Systematic literature review to identify barriers to CE implementation in the construction industry.	N
3	Rakhshan et al. (2020)	United Kingdom	Systematic literature review to identify barriers to reuse of building materials. 23 barriers were divided into six categories.	N
4	Kanters (2020)	Denmark, United Kingdom, Netherlands, and Belgium	Semistructured interviews with 10 architects and two consultants that have designed for deconstruction and/or incorporated reused materials to understand the barriers and drivers to circular building design.	Y
5	Mahpour (2018)	Iran	Literature review to identify the barriers to CE in CDW. To prioritize: questionnaires (six experts in within industrial, civil, and environmental engineering) and TOPSIS method.	N[a]
6	Adams et al. (2017)	United Kingdom	Survey (110 responses; 7% designers) and follow-up workshop with 97 construction stakeholders (9% designers). Aimed at identifying barriers and enablers for CE in construction.	Y
7	Hart et al. (2019)	United Kingdom	Literature review of academic and industry papers to identify barriers and drivers to CE in the built environment.	N
8	Kozminska (2019)	Denmark, Poland, Germany, and the Netherlands	Barriers to circular building design were identified in the literature. Case studies were used to present how different construction materials can be reused.	N[a]
9	Rios et al. (2015)	United States	Literature review to identify barriers and enablers to deconstruction and reuse in the built environment	N
10	Densley Tingley et al. (2017)	United Kingdom	Interviews with 13 construction industry stakeholders (four structural engineers, four contractors, three fabricators, and two architects) to understand the barriers to reusing structural steel building components.	Y
11	This paper	United States	Interviews with 13 architects to identify barriers and enablers to circular building design in the architectural practice in the US.	Y

Note: TOPSIS = technique for order of preference by similarity to ideal solution. The last column identifies the presence (Y) or absence (N) of empirical methodology.
[a]Although the study used empirical methods, the barriers for circular design were identified through literature review.

biological cycles) and by choosing building materials that can be safely and effectively recycled several times into materials with similar properties (i.e., design for technical cycles). Examples of materials that can be recycled in closed loops are metals and recyclable polymers. Conversely, designers should avoid specifying composites (e.g., steel-reinforced concrete and composite wooden beams) that hinder disassembly and material recovery.

Although some of the aforementioned circular design solutions (e.g., adaptive reuse of buildings, biodegradable materials, and renewable energy) are commonly applied and gaining ground in building design, key strategies like DfD and reuse remain a niche practice in architecture (Kozminska 2019). Thus, understanding the systemic barriers and enablers that influence the lack of such circular design strategies in the construction sector is key to understanding how to create adequate conditions to implement CE in the built environment.

Barriers for Circular Building Design

The body of literature devoted to identifying barriers and enablers for CE strategies in the built environment is limited (Densley Tingley et al. 2017; Hart et al. 2019; Mahpour 2018; Kanters 2020). Table 1 summarizes the few and recent studies dedicated to this matter and reviewed in this section, and includes their affiliated countries, method, and whether they were empirical (e.g., case studies, interviews, surveys, or focus groups) or not. This section provides an overview of their main findings. A comprehensive list of regulatory, economic, cultural, technical, educational, environmental, and technological barriers identified in the relevant literature can be found in the Appendix.

A prior literature review identified barriers to deconstruction and material reuse in the building sector and the role of DfD as an enabler for deconstruction and reuse (Cruz Rios et al. 2015). Since then, other studies have attempted to identify barriers and enablers to DfD itself (e.g., Akinade et al. 2020; Hossain et al. 2020; Kanters 2020; Hart et al. 2019; Adams et al. 2017). Most studies in Table 1 have identified barriers and enablers for circular building design through literature reviews, and only four studies have analyzed barriers and enablers from empirical approaches like case studies, interviews, surveys, and focus groups. Researchers have found that empirical studies were key to identifying systemic barriers to CE and shedding light on important cultural and educational barriers often missed by the literature (Kirchherr et al. 2018; Densley Tingley et al. 2017). For example, after conducting 13 interviews with construction stakeholders, authors have found that cultural barriers like lack of clients' interest and the fragmented nature of the construction sectors were among the most significant challenges to structural steel reuse (Densley Tingley et al. 2017). A key enabler proposed by Densley Tingley et al. (2017) was providing technical guidance and education on circular building design strategies. Besides guidance and education, Hart et al. (2019) highlighted that research, innovation, and collaboration are important enablers to overcome cultural barriers.

From the empirical studies on circular building design, only Kanters (2020) had chosen a sample predominantly of architects, mostly from the Netherlands. Barriers found by Kanters (2020) included the conservative nature of the construction sector, the cost of labor, and the need for flexibility in existing building codes and regulations. The main enabler, as perceived by the architects, was a supportive client. Kanters (2020) highlighted how architects perceived their role as key actors for circular building design who can connect all the other players in the decision-making process (e.g., contractors, consultants, engineers, and building owners), which is consistent with Kozminska's (2019) description of the emerging role of the architect. Kozminska (2019) concluded that architects are required to learn from other stakeholders, educate themselves and the client on CE strategies, experiment with new design solutions, and evaluate tradeoffs.

However, architects struggle with the lack of a clear definition of CE, and many respondents relied on their own interpretation of CE for the built environment. That is not surprising: Hossain et al. (2020) has found that there is no proven case of circular building design to date, and a comprehensive circular building design framework is yet to be developed. Similarly, Adams et al. (2017) concluded that the lack of information on circular building design was a key barrier to CE implementation in the built environment. After analyzing data from over 100 surveys and a workshop, Adams et al. (2017) have found that designers, subcontractors, and building owners were the least informed.

Enablers proposed by Adams et al. (2017) included a clear economic case, metrics, and tools for circular building design. Focus groups conducted by Akinade et al. (2020) resulted in a few barriers new to the literature, most of which were related to circular building design tools. Among the barriers found by Akinade et al. (2020), there is a lack of tools for identifying and classifying salvaged materials, lack of performance analysis tools for evaluating end-of-life scenarios of buildings, and limited visualization capability for DfD in building information modeling (BIM). Other barriers found by Akinade et al. (2020) included lack of stringent regulations, lack of information at the design stage, underdeveloped marker for salvaged materials, and difficulty in developing a business case for DfD. The latter is related to the economic constraints documented by all studies in Table 1.

For example, the time and labor intensive nature of deconstruction increases the project costs and delays the schedule (which in turns delays the return on investment expected by building owners) (Rakhshan et al. 2020). Because of the higher initial investment often required by circular building design strategies, another barrier often reported by construction stakeholders is the lack of economic and fiscal incentives to engage in CE (Hart et al. 2019; Hossain et al. 2020; Kozminska 2019; Rakhshan et al. 2020). Regulatory barriers were also frequently mentioned in the literature. A common example are existing building codes and regulations that hinder deconstruction, reuse, and repair (Akinade et al. 2020; Hart et al. 2019; Kanters 2020; Kozminska 2019; Rakhshan et al. 2020). For instance, storing salvaged materials is prohibited in some countries where they are considered waste by the government (Rakhshan et al. 2020). Rakhshan et al. (2020) analyzed the interdependencies between barriers and concluded that economic and regulatory barriers should be prioritized, in addition to cultural and educational barriers (combined in their study under social barriers).

Besides the difference in regulations between countries, other factors make barriers and enablers dependent on their geographical context. Enablers identified by European stakeholders may become barriers in the US context, and vice-versa. For example, European countries have dense built environments with little room to grow, and the reuse of building infrastructure is a necessity to accommodate the growing population and changing spatial demands. Conversely, the US vast territory favors urban sprawl (i.e., the expansion of low-density, poorly planned urban developments). The contrary is also true, and barriers may become enablers in different geographical contexts. For example, the US has more land available for creating storage infrastructure for salvaged materials (e.g., salvage yards) than its European counterparts.

From the literature review, it is evident that circular built environments can mitigate global problems like resource scarcity and unsustainable waste streams. It is also clear that building designers have a central role in creating circular built environments. However, there are very few articles devoted to understanding barriers and enablers for circular building design. Strategies like DfD and reuse will not grow in the construction sector unless the body of knowledge available becomes less fragmented and able to guide construction stakeholders on taking progressive steps toward CE (Rakhshan et al. 2020). That is especially true for countries like the US, where there is a lack of CE-specific legislation and educational campaigns, and progress toward CE depends on bottom-up efforts from construction stakeholders. Yet no studies were found that investigated the US context.

This paper aims at filling this knowledge gap by investigating which barriers are hampering the full adoption of DfD and reuse in the US building design practice and recommending enablers for greater adoption of circular building design strategies within the US building sector. Specifically, the authors ask the following questions:

- What are the systemic barriers for circular building design strategies in the US as perceived by architects?
- How do these barriers and their nature (e.g., technological, economic, and cultural in nature) differ from those found or perceived in other countries?
- What are potential enablers for circular building design to overcome these barriers where they exist?

To the authors' knowledge, this is the first empirical study that aim at identifying barriers to circular building design in the US.

Methodology

The authors conducted semistructured interviews with 13 architects from 12 different design firms across the US to gather information on the perceived and experienced barriers for circular building design strategies. Interviewees were randomly selected from the webpages of the top 160 firms in the US ranked by revenue (BNP Media 2018). Previous experience with circular building design was not required to participate in this study. The interview questions were divided into three sections. The first section included questions about the interviewee background, design process, perceived role in reducing CDW, and clients' drivers for sustainable building design. The second section was structured around specific design tactics like the use of demountable joints, the procurement of salvaged building components, and their experience with modular design and prefabricated building components. Finally, in the third section, the authors asked about the architects' perception about design for disassembly and building adaptability. The complete set of questions can be found in the Supplemental Materials. The interviews were conducted by phone and lasted from 25 to 60 min, with an average of 40 min. Table 2 provides information on interviewees including the years of industry experience, US state, and the market sectors in which they have design experience. As required by the Institutional Review Board (IRB) protocol, the anonymity of the interviewees was preserved. In this paper, the authors use codenames (Table 2) to refer to each participant.

The interview data were transcribed and analyzed as follows:

- An inventory of barriers to circular building design was created based on the relevant literature (studies listed in Table 1).

Table 2. Interviewee information

Codename	Design experience (years)	State	Market sectors									
			Housing	Single-family	Civic	Institutional	Retail	Commercial	Corporate	Urban design	Health care	Nonprofit
Mark	39	California and Kansas	—	—	Yes	Yes	—	—	Yes	Yes	—	—
Kody	17	Illinois	Yes	—	—	Yes	—	—	Yes	—	Yes	—
Dylan	31	Washington, DC	—	—	Yes	Yes	—	—	—	—	Yes	—
Kevin	32	Arizona	—	—	Yes	Yes	—	—	—	—	—	—
Louis	30	Pennsylvania	—	—	—	Yes	—	—	—	—	Yes	—
Carol	31	Massachusetts	—	—	Yes	Yes	—	—	—	—	—	Yes
Roger	41	Virginia	—	—	—	Yes	—	Yes	Yes	—	—	Yes
Jack	20	South Carolina	—	—	—	Yes	Yes	—	Yes	—	—	—
Charlie	25	Arizona	Yes	—	—	Yes	Yes	Yes	—	Yes	—	—
Mary	3	Arizona	Yes	—	—	—	—	—	—	Yes	Yes	—
Brian	38	Texas	—	—	—	—	—	—	—	—	—	—
Luke	6	Washington	—	—	—	—	—	—	—	—	—	—
Will	20	Iowa and Wisconsin	Yes	Yes	Yes	Yes	—	Yes	—	—	—	—
Total			4	1	5	10	2	3	4	3	4	2

- The inventory of barriers was divided into seven categories: economic, educational, cultural, technical, environmental, regulatory, and technological. The categories are explained in the "Results" section, and the list of barriers is reported in Table 3.
- The interview transcripts were thematically coded based on the barriers found in the literature. Similarities, differences, and statements that reinforced or contradicted the barriers were documented. Similar responses were grouped under each theme.
- Barriers that emerged from the data and were new to the literature were documented and added to the inventory of barriers. The new barriers are highlighted in Table 3. Potential enablers that emerged from the data were also documented and are discussed in the "Results" section.

Table 3. Barriers for circular building design in the US

Code	Barrier
Most mentioned barriers	
EC2	Cost and schedule constraints ($n = 9$)
RE1	Existing regulations and codes hinder reuse and repair ($n = 6$)
CU1	Competitive and fragmented nature of the construction sector ($n = 6$)
ED3	Lack of clarity on what CE entails ($n = 6$)
CU8[a]	Belief that DfD compromises building durability and resiliency ($n = 5$)
Barriers new to the literature	
EC8	Market for prefabrication heavily dependent on imports
ED6	Lack of leadership, cost, and schedule considerations in the university curriculum for building design
ED7	Lack of public awareness on life cycle costs and benefits
CU7	Lack of leadership from designers
TE13	Lack of standardization and transportability of building components
TE14	Conflicting goals between pre-engineered structures and future reuse
TE15	Matching the old to the new
TE16	Walmart effect
EN5	Tradeoffs between different sustainability strategies may hinder CE

Note: This table lists the barriers that were most mentioned by the participants in this study (n = number of responses), and the barriers that are new to the literature. The complete list of barriers found in the literature and in this study can be found in the Appendix.
[a]This barrier was both highly mentioned and new to the literature.

- The number of barriers per category identified in this study was calculated and compared against the empirical studies in other countries.

The results of a prior analysis of the same data following a constructivist grounded theory approach (Charmaz 2014) were previously published (Cruz-Rios and Grau 2020). The first analysis was concluded in 2017, simultaneously with the data collection and preceding the publication of the studies that generated the inventory of barriers reported in this paper. Thus, the transcripts were not analyzed for specific barriers and enablers as in this study. Instead, the prior effort explored core categories that have emerged from the data.

After analyzing the interview data to identify barriers, the authors proposed enablers for each barrier. A few enablers have emerged from the interviews, but most enablers suggested in this paper are based on the literature and on the authors' professional experience. For example, two of the authors (Bilec and Cruz Rios) are part of a transdisciplinary research project called *Convergence around the Circular Economy* [National Science Foundation (NSF) Award No. 1934824]. As part of this project, the authors facilitated discussions with anthropologists, economists, engineers, and political scientists around enablers for CE. Additionally, the three authors were part of a NSF-sponsored workshop for CE experts called *Designing for the CE: From Molecules to the Built Environment* (Bilec et al. 2020) that aimed at identifying enablers and future areas of research for CE in different sectors and scales, including a track dedicated to the built environment.

Thus, although there was not a systematic data collection for the enablers, the authors relied on their expertise to propose them, alongside with the stakeholders involved in each enabler. Most importantly, the list of enablers and stakeholders is not meant to be comprehensive, and therefore there are likely enablers missed by the authors. Similarly, it is possible that stakeholders who are not listed as responsible for a given enabler may also have a role in promoting it. The barriers and enablers are presented in the next section.

Results

In this section, the authors present and discuss the barriers for circular building design as perceived and experienced by the participants of this study. In this paper, the authors focused on the barriers that were most mentioned by the participants and on the barriers that are new to the literature. The nature of the barriers identified in the US is compared with the findings from empirical studies in European countries. Finally, the authors propose enablers for each barrier. The complete list of barriers (including barriers identified in other studies but not mentioned in the interviews) and respective enablers can be found in the Appendix.

What Are the Barriers and Enablers for Circular Building Design in the US?

The barriers found in the literature and gathered from the interviews were divided into seven categories according to their nature: economic, educational, cultural, technical, environmental, regulatory, and technological. Some of these categories are consistent with prior studies [e.g., cultural, regulatory, and economic barriers in the work of Hart et al. (2019)], and others were proposed by the authors. Economic barriers correspond with issues of market and costs; educational barriers are related to stakeholders' awareness, knowledge, and skills; cultural barriers include cultural, social, and behavioral aspects in sectors, organizations, and individuals; technical barriers are concerned with design, manufacturing, and construction aspects; environmental barriers include environmental aspects of CE like metrics and environmental benefits; regulatory barriers include regulations, codes, standards, and contractual issues; and technological barriers include challenges related to technologies and infrastructure (e.g., sorting and processing technology and infrastructure for salvaged materials).

After the taxonomy was complete, a noticeable difference was found in the nature of the barriers in the literature when compared with the ones reported by architects in this study. For example, the average share of regulatory barriers found in the literature (Table 1) was 18% per study. In this study, only 6% of the barriers identified by the architects were regulatory in nature. The same applied to educational barriers: an average share of 9% in prior studies against 18% in this study. The largest difference was related to technological barriers. Whereas 19% of the barriers identified in the literature were related to technology and infrastructure, technological barriers were only 3% of the challenges mentioned by architects in this study. Most of the barriers perceived by the architects interviewed were technical (29%), cultural (21%), economic (18%), and educational (18%). Fig. 2 illustrates a comparison among this study, the average of the other 10 studies listed in Table 1 (including systematic literature reviews), and the average of the empirical studies only.

The nature of the barriers found in the literature highly correspond with those found in the empirical studies. The empirical studies included in the analysis were all conducted in European countries, mostly in the UK. In contrast, the barriers perceived and experienced by architects in the US were different in nature and higher in number (e.g., a total of seven cultural barriers were identified, against an average of 2.25 in the European empirical studies). Such a difference can be explained by several factors. For example, although this study selected only architects to participate in the interviews, designers represented only 9% of the sample in the study by Adams et al. (2017) and 15% of the sample in the study by Densley Tingley et al. (2017). The data collection methods also varied from surveys (Adams et al. 2017) to focus groups (Akinade et al. 2020) to interviews (Densley Tingley et al. 2017; Kanters 2020).

However, the main explanation for the divergences found are likely due to the different contexts in which the design practices are situated. That is, the regulatory, economic, cultural, and educational contexts of CE in Europe differ from those in the US.

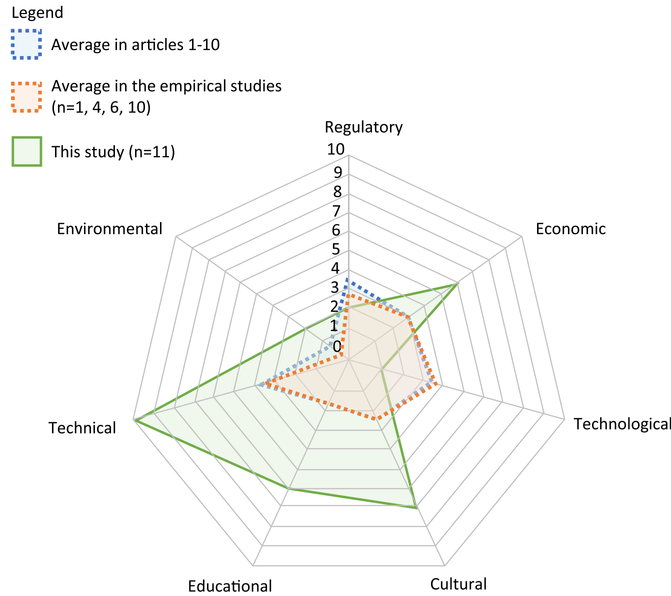

Fig. 2. Types of barriers to applying CE strategies in the built environment. The scale 0–10 represents the number of barriers of each category as identified by the authors. Article numbers (n) correspond with Table 1.

For example, European regulations like the CE Action Plan, the Ellen MacArthur Foundation (EMF), and European green building rating systems (GBRS) like the Building Research Establishment Environmental Assessment Method (BREEAM) and the German Sustainable Building Council Certification System (DGNB) have contributed to raise awareness and knowledge around CE for the last few years. Conversely, there are no CE-specific regulations in the US, and CE is not explicitly mentioned in American GBRS.

For example, buildings can get leadership in energy and environmental design (LEED) credits for building life cycle impact reduction through adaptive reuse of buildings or through using salvaged building materials. However, LEED offers the alternative of doing a whole building life cycle assessment (LCA) to gain the same credits. LBC's "Materials Petal" requires net positive waste and aggressive diversion rates for different building materials and includes considerations for material durability and future deconstruction in the design phase. However, LBC does not differentiate between reuse and recycling in terms of landfill diversion. In contrast, the German DGNB assigns different credits to the end-of-life paths: higher credits (called CE bonuses) are given to dematerialization, reuse, and remanufacturing when paired with circular business models, and lower credits are assigned to recycling or waste-to-energy paths.

Finally, barriers found in Europe may be enablers in the US, and vice-versa. For instance, storing salvaged materials in European countries is often cost-prohibitive (e.g., Densley Tingley et al. 2017; Akinade et al. 2020; Kanters 2020; Cruz Rios et al. 2015). However, the larger availability of land in the US means more opportunities for accommodating storage infrastructure, which is likely to result in more economic storage solutions.

The next sections present and discuss the barriers perceived and experienced by the architects in this study, including the barriers that were most mentioned during the interviews, and the barriers that are new to the literature, as listed in Table 3.

Table 4. Enablers for circular building design in the US

Enabler	Link
Exercising leadership and educating stakeholders	CU7; CU8
Integrating CE in contractual requirements for design	CU7
Assigning CE consultants to assist design	ED3; ED6
Seeking opportunities to use prefabrication and modular design	EC2
Developing and implementing material tracking technologies	CU1; TE15
Creating databases for reusable components; urban mining	EC2; TE15
Enforcing sustainable procurement aligned with CE (civic and institutional projects)	CU7
Creating tax deductions for CE design strategies	EC2
Establishing landfill diversion targets and zero-waste policies that differentiate between reuse and recycling	ED2; CU7
Establishing targets for salvaged components	ED2; CU7
Establishing targets for reducing building embodied energy	CU7
Increasing demolition taxes	EC2
Increasing landfill fees	EC2
Promoting carbon taxes	EC2
Incorporating CE in building codes (e.g., mandatory plan for building disassembly)	RE1; CU7
Developing more life cycle cost case studies on short-, medium-, and long-term savings promoted by CE strategies	EC2; TE16
Choosing IPD and other collaborative project delivery methods	CU1; CU7
Educating designers and building owners on life cycle cost	EC2; TE16
Integrating client demands into architecture education	ED6
Integrating CE into university curricula in all sectors	ED3; ED7; CU8
Raising public awareness of CE through public campaigns	ED3; ED7; CU8
Incorporating CE training into the professional license renovation requirements for architects, engineers, and contractors	CU8
Raising taxes on virgin materials	EC2
Allocating public funding to offer financial aid to SMEs and individuals that want to engage in circular design and construction	EC2; TE16
Offering subsidies, tax credits, and low-interest loans for companies that want to engage in CE practices, like circular design and circular business models (CBMs), and building disassembly and EOL management	EC2; TE16
Raising taxes on foreign prefabricated components to strengthen national market	EC8
Raising awareness about the difference in environmental impacts between reuse and recycling and between recycling and downcycling	ED3
Integrating LCA into design tools to aid case-by-case decision making about CE strategies	EN5; TE14
Integrating CE into the K–12 education	ED3; ED7
Reaching consensus around the concept of CE and creating explicit guidelines about different CE strategies in all sectors	ED3
Increasing taxes on new construction and reducing taxes for building adaptive reuse	RE1
Develop guidelines for transportability of building components	TE13
Enforcing a construction regulation reform to eliminate burdens to material reuse and building renovations and to promote CE in the construction sector	RE1
Integrating CE strategies to ICT (e.g., DfD to BIM)	CU1
Promoting existing salvaged yards through funding, economic and fiscal incentives, and partnerships with technology companies to integrate their inventory to digital databases	TE15

Note: This table lists the enablers that correspond with the barriers in Table 3. The complete list of enablers to all barriers found in the literature and in this study (and respective stakeholders) can be found in the Appendix.

In each section, potential enablers are discussed. The enablers are listed in Table 4.

Cost and Schedule Constraints

Cost and schedule constraints were the most mentioned barrier by the participants. The architects reported having rushed schedules to complete a building design, which affects their ability to incorporate circular design strategies like creating a deconstruction plan and taking the time to "go around looking for [salvaged] materials." In cases when an existing building was demolished and replaced with a new construction, the projects' constrained schedule also hindered the ability to deconstruct the existing building and sort components for reuse.

Besides schedule constraints, the higher cost associated with circular design strategies were mentioned by several participants. One participant mentioned that, to his knowledge, the US federal government has been over cladding several office buildings across the country because adding a second layer of cladding is faster and less expensive than replacing a roof or façade. An anecdote told by another participant illustrates how the costs of storage and processing of building components often prohibits reuse, a common problem faced by a few interviewees:

> I came across an issue where it'd be much more costly to have taken all these tiles down, up and down a ladder, packaged and stored, than it would be for them to just throw them from the roof straight into a dumpster. So it's gonna cost almost 10 thousand dollars more to take it down and salvage for a potential reuse in the future. And then there was storage fee versus just taken to a dumpster and hauled off to the dump. Which is very disconcerting. (Charlie)

Another challenge highlighted in the interviews was the hurdle of the life cycle cost versus the first-time cost. The architects found hard to convey the long-term economic benefits of circular design strategies like flexible design and building adaptability. One participant was admittedly pessimistic about the financial case for CE: "...and I think you'll probably find that even as you start talking about circular economy that there's no real economic incentive for a circular construction system" (Carol). Examples of enablers for this barrier are (1) using prefabricated systems to lower costs and optimize schedule in states where the market for off-site construction is well-developed; (2) develop more life cycle cost case studies on short-, medium-, and long-term financial savings from CE strategies like building adaptability and disassembly and the use of salvaged components; and (3) educating designers and building owners on life cycle cost, creating databases for urban material stocks, and creating fiscal incentives like tax deductions, public funding, and subsidies to offset the higher initial costs associated with circular design strategies.

Existing Regulations and Codes Hinder Reuse and Repair

Participants have mentioned examples of current regulations that pose barriers to reuse. Two participants mentioned underwriter laboratories (UL) testing requirements as a hindrance to reuse or repair existing fixtures:

> The building codes are a huge barrier [to reuse] because so many of our products have to be UL-listed for fire, smoke, sound, so many other ways . . . FRC, red doors, windows . . . It adds layers of complexity to the project. (Will)

One respondent who worked with health care clients, research laboratories, and government buildings stated that these types of buildings are "very heavily code-driven," which makes it "very hard to reuse things and keep that piece of the work."

Some regulations may have tradeoffs with different dimensions of CE. For example, a regulation in place for equity reasons has negatively affected environmental benefits of reuse or repair:

> ". . . there's a funny catch 22 with might just be about Massachusetts, there's a state law if you spend a certain amount of money in an existing building, you must by law make it fully accessible, which include changes in the exterior and the interior. And those can be extraordinarily expensive, and we have seen clients, very high-end clients who avoid working on their buildings because they don't wanna trigger that. And then the building deteriorates and deteriorates and deteriorates, and at a certain point it's less expensive to replace their building than to repair. It's easier than to make the building compliant to the codes. (Carol)

Carol's example illustrates another situation that is characteristic of the US: states may have specific examples of codes and regulations that hinder reuse or repair, which requires special attention from architects who are licensed in different states. Possible enablers for this barrier are incorporating CE in building codes (e.g., mandatory plan for building disassembly), increasing taxes on new construction and reducing taxes for the adaptive reuse of buildings, and promoting a construction regulation reform to eliminate burdens to material reuse and building renovations.

Competitive and Fragmented Nature of the Construction Sector

A few participants reported a lack of leverage in the decision-making process for circular building design strategies like the use of demountable joints, prefabricated elements, and salvaged building components. One participant stated:

> I think the only time the structural engineers are willing to listen to us in terms of if something is welded or bolted if it's going to be exposed and we have concerns about how it looks. I think if it's concealed construction they don't necessarily even ask us. (Kody)

Other decisions were attributed to contractors, who often have competing interests like lower costs and faster schedule. For example:

> . . . if it's a smaller contractor that's not accustomed to reducing waste, they'll pass those costs to the client and depending on what premium client has to pay they'll have to make the decision if they think it's worth it or not. So we do what we can but it can be challenging and most of the times it comes down to the contractors. (Charlie)

Finally, one participant acknowledged that the lack of closer collaboration with contractors hinders DfD because architects need the contractor's input on the logistics of disassembly. Potential enablers include developing and implementing material tracking technologies like blockchain to share data on building components among construction stakeholders and inform decision making; integrating CE strategies into information and communication technologies (ICT) like BIM; and promoting integrated project delivery (IPD) and other collaborative project delivery methods.

Belief that DfD Compromises Building Durability and Resiliency

Some participants associated DfD with temporary buildings and believed that the ability to disassemble a building and reuse its components is "trumped by permanence." One participant stated, "So, if I'm doing a project at the University, I'm not really thinking about taking it apart, that's probably not gonna happen, it's a hundred-years building" (Kevin). His concerns were echoed by another respondent: ". . . typically when we design buildings, we design buildings to be there permanently . . . So we try to build the building as strong as possible so that doesn't really lend itself to being able to take it apart" (Charlie).

In contrast, other architects acknowledged the value of DfD to promote building adaptability and resiliency, especially given fast-paced technology changes in buildings like hospitals, laboratories, and classrooms. One interviewee admitted that, as an architect, he strived to create designs that would last but needed to acknowledge that buildings transform over their service life. Potential enablers include exercising leadership and educating stakeholders (in this case, building owners or contractors would educate architects on the benefits of DfD); integrating CE into university curricula in all sectors; raising public awareness on CE through public campaigns; and incorporating CE training into professional license requirements for architects, engineers, and contractors.

Lack of Clarity on What CE Entails

Many respondents demonstrated a lack of clarity on CE goals and strategies. Although that is expected given the lack of a consensus around the definition of CE, the architects' confusion around commonly used terms like reuse, recycling, and salvaged materials was concerning. When asked about their experience with salvaged materials, three architects mentioned grinding concrete or asphalt to use as underlayment for buildings. Another architect answered:

> We're doing a project here in the upstate of South Carolina that's in a greenfield, previously undeveloped site and we're gonna be cutting down some of the trees and milling them and using them as design elements on the inside of the building. I'd classify that as salvage because otherwise they'd end up becoming paper somewhere. (Jack).

Similarly, other three respondents have used the word recycle when describing reuse of building components. The lack of clarity on terminology reflects a lack of understanding of the environmental benefits of CE strategies. For example, by thinking that reuse and recycling are similar strategies, one ignores that reuse has usually higher environmental benefits than recycling and thus should be prioritized when possible. Similarly, salvaging materials in their original state to be reused in new construction is environmentally superior compared with cutting down trees from a greenfield and turning them into design elements. Examples of enablers, in addition to the enablers listed for the previous barrier (CU8), are assigning CE consultants to assist design; integrating CE into educational curricula from kindergarten to 12th grade (K–12) education; and reaching consensus around the concept of CE and creating explicit guidelines about CE strategies in all sectors.

Market for Prefabrication Heavily Dependent on Imports

A respondent from Arizona pointed out that geographical factors influence the market for prefabricated building components in the US. Because most prefabricated components come from Europe, coastal states with connections to ports have an advantage, and the market for off-site construction in these regions are "more sophisticated." As a result, prefabrication is not always cost-effective in states with a less developed market for off-site construction. A potential enabler is raising taxes on foreign prefabricated components to strengthen the national market.

Lack of Leadership, Cost, and Schedule Considerations in the University Curriculum for Building Design

Respondents highlighted a gap in the educational curricula for architecture schools. According to them, topics like leadership, life cycle cost, and scheduling were lacking from the architectural curricula. One architect, who was also a professor of practice, stated:

> I think that part of the problem, I think some of it is due to the disconnect that much of our education process doesn't involve a client. . . . And I think that one of the skills that we should be trying to help the architects of tomorrow is how to promote these new ideas to clients and how to be advocates for the environment, for modularity, and disassembly. (Luke).

The youngest respondent, who had graduated recently from architecture school, admitted that she found it hard to estimate and convey life cycle costs to clients. Potential enablers are assigning CE consultants to assist design; and integrating client demands like cost and schedule into the educational curricula in architectural schools.

Lack of Public Awareness of Life Cycle Costs and Benefits

Besides architects and building owners, the need for public awareness of long-term costs and benefits of CE strategies was identified by one architect. In his experience, the public lacks understanding of life cycle costs and often pressures municipalities to lower the initial investment on civic buildings. The respondent pointed out:

> For a lot of municipalities around Arizona, some small towns, some big, everything in between, it's always interesting how it's always about that first capital cost because that's what the public sees. And the public is thinking about, you know, 'why you spent so much money on this building?', 'the building down the street only cost this much' or 'my house only cost this much to build.' (Kevin)

Enablers for this barrier are integrating CE not the education curricula from K–12 to universities and raising public awareness of CE.

Lack of Leadership from Designers

When reflecting upon the drivers for sustainable design in his practice, one respondent blamed the lack of leadership of architects that did not enforce sustainable design solutions as part of every project. He stated:

> I think that those guiding principles [of sustainable design] outta be established upfront and then I think the firm outta follow those and outta provide leadership to their clients so then it's not even a discussion. This is just the way it should be. This is the way we do things, this is how we build a building. And I think that when we give the client the option, what we are telling them is 'it's your choice and it's ok if you do it, and it's ok if you don't do it.' And I think that's where the lack of leadership comes in. And I believe that the lack of leadership comes in mostly because of the lack of education. When architects are not informed properly, they don't know where they get materials, they don't familiarize themselves with these types of systems and questions . . . Then they are not able to provide good leadership and they don't usually incorporate it into design. (Brian)

Architect leadership was a common theme in many interviews, but often mentioned as an enabler for the clients' lack of interest in sustainable or circular building design solutions. Five other respondents stated at some point during the interviews that they believed architects should drive the decision making for sustainability solutions, including CE. The respondents pointed out that architects should "not ask permission to design a sustainable building," and that it is incumbent on the architects to "find opportunities to use salvaged materials," to "integrate disassembly into design," and to "educate the clients" on circular building design strategies. Examples of enablers include enforcing procurement practices align with CE for civic and institutional projects (so that circular building design would be a requirement from building owners); integrating CE in contractual requirements for design; and establishing targets for salvaged components and reducing the embodied energy in buildings.

Lack of Standardization and Transportability of Building Components

Three architects brought up the need for manufacturing building components in standard and transportable sizes or modules. Two architects reported that they have missed opportunities to reuse building components because they would not fit on a truck or in a container. As an enabler, guidelines for transportability of building components must be developed by researchers, contractors, and manufacturers alike.

Conflicting Goals between Pre-Engineered Structures and Future Reuse

Two respondents reported that specifying pre-engineered structures to reduce material use can negatively affect future reuse. Pre-engineered structures are custom-design for each project so that they only use the amount of resources (e.g., steel) needed for a specific building. Although this strategy is a means to

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dematerialization, custom-made structures make future reuse difficult. One architect explained:

> ...right now there's some much customization. If we have a transfer beam in the floor or we optimized the size of columns for the loads that they're carrying ... So on one hand the more you optimize the design, less usable it is in the future, when it comes to disassembling that building and using it again. ...I think they're conflicting goals: optimizing design and reuse. I think they're both good, but they may be an obstacle for one another. (Jake)

A potential enabler for this barrier is integrating LCA into design tools to aid case-by-case decision making on circular building design strategies.

Matching the Old to the New

Issues in matching the old to the new were identified in two different stances. First, when working with prefabricated components: because of the rigidity of precast systems, one respondent reported the challenge of "make sure that the precast solution could meet our design," which led to a prolonged "onsite investigation to understand the existing conditions."

Second, matching the old to the new was mentioned when trying to use salvaged components in new construction. One respondent pointed out that ideally there would be enough salvaged components available to use in the whole building (e.g., salvaged doors). However, there is not enough quantity of a salvaged component in the dimensions needed for the project. He concluded, "So I'd say that integrating the old and the new both in size and quantity is always an issue" (Brian). Potential enablers include developing material tracking technologies and databases for urban material stock so that architects can locate salvaged components in adequate quantity and dimensions.

Walmart Effect

One architect described a phenomenon that, in his perception, is characteristic of the US:

> ...in this country at least there is a continuous–I call it the Walmart effect–there is a continuous drive to make things as inexpensive and nondurable as possible. So a commercial door that's put in a commercial building 5 years ago probably isn't worth to pulling out of a building and reusing. (Jake)

His concern with the widespread use of nondurable building components was echoed by other respondents. For example, one architect stated that she often replaces durable materials with short-life materials by owners' request. According to her, these clients are concerned about the initial investment and often do not plan to retain the ownership of the building for long (e.g., real estate developers). Examples of enablers are developing more life cycle cost case studies around circular building design strategies; and offering subsidies, tax credits, low-interest loans and other economic and fiscal incentives to stakeholders who aim at investing in circular building design strategies.

Tradeoffs between Different Sustainability Strategies May Hinder CE

One architect reported finding it difficult to consider tradeoffs between different sustainability strategies. As an example, she described the difficulty of choosing a cladding material for a student housing project that was supposed to last for 50 to 100 years. On the one hand, brick has a high embodied carbon but is a very durable material; on the other hand, wood is less carbon intensive but less durable in that situation. At the end, brick was the chosen material:

> ...we were caught by the economics that supported a material which has great durability but also has a very high carbon footprint. I try to comfort myself with the durability, but I think that the urgency of the moment makes carbon much more important. (Carol)

Similar to TE14, integrating LCA into design tools to aid decision making is a potential enabler for this barrier.

The next section discusses the role of different stakeholders in creating the enablers mentioned above.

Discussion: Role of Stakeholders

Although only two regulatory barriers were identified by the participants, policymakers were responsible for most of the enablers listed in Table 4 ($n = 18$). Regulatory enablers can help overcome a variety of barriers, from educational to cultural to technical barriers. In this paper, the authors proposed more incentives than mandates given the market-based nature of US society. Following policymakers, the stakeholders responsible for the largest share of enablers were non-governmental organizations (NGOs) and industry associations ($n = 12$), designers and contractors ($n = 10$ each), and researchers ($n = 9$). Designers include all the professionals involved in the design team (i.e., architects, engineers, and consultants). Fig. 3 illustrates the number of enablers by their respective stakeholders, as described below.

Designers, Contractors, and Building Owners

The design team can help overcome significant cultural and educational barriers. Architects can exercise leadership and educate building owners and other stakeholders on circular building design strategies. Architects, contractors, and building owners can

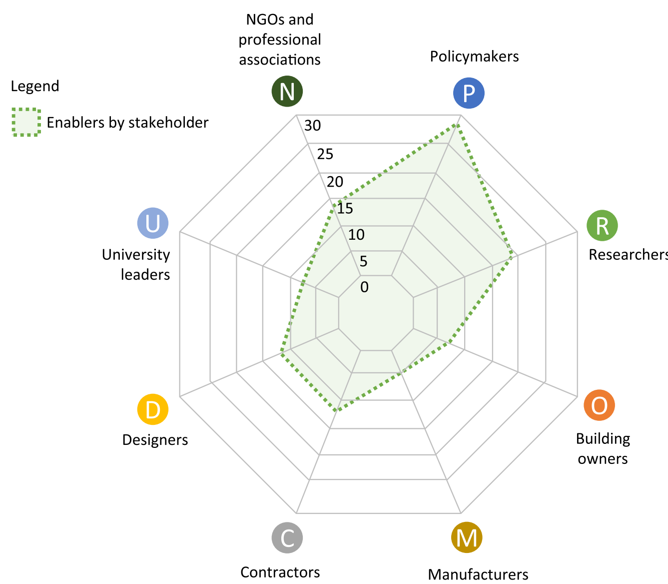

Fig. 3. Number of enablers by each stakeholder. The scale 0–20 represents the number of enablers that fall under the responsibility of each stakeholder as proposed by the authors. These numbers are consistent with the enablers listed in Table 4. The complete list of enablers and respective stakeholders can be found in the Appendix.

incorporate CE strategies into design contractors (e.g., requiring a plan for disassembly or establishing targets for salvaged materials). CE consultants can help guiding the design team, contractors, and building owners through circular building design and explain CE environmental, economic, and societal benefits and tradeoffs. Several architects in this study mentioned taking advantage of off-site construction to save time and lower construction costs, thus seeking opportunities to use prefabricated building components can help overcome economic barriers. Finally, designers, contractors, and building owners should opt for integrated project delivery (IPD) and other collaborative project delivery methods when possible. Closer collaboration between construction stakeholders from early stages of the project is needed to overcome the competitive and fragmented nature of the construction sector.

Policymakers

The most important contributions from policymakers to circular buildings are raising public awareness on CE, promoting a regulatory reform to eliminate burdens to circular building design strategies like reuse and repair, establishing targets that emphasize the benefits of reuse and lower embodied energy in buildings, and creating fiscal and economic incentives to circular building design. Examples of fiscal and economic incentives are tax deductions for CE strategies, offering subsidies to construction stakeholders who want to invest in circular buildings, and raising taxes on demolition, disposal, virgin materials, and new construction to encourage CE in the built environment. Finally, policymakers should invest in existing infrastructure to support CE, like salvage yards, deconstruction companies, and companies that perform maintenance and repair of building components.

Researchers and Manufacturers

Researchers and manufacturers must work together to develop and implement material tracking technologies to building components, like material passports. These technologies will help map the available stock of reusable materials in the urban environment and match demand and supply for salvaged materials. Future research agendas should also include the development of LCA methods integrated to CE strategies (e.g., cradle-to-cradle LCA) and the integration of such methods into design tools like BIM to aid decision making during early design. Finally, researchers from different disciplines and sectors must work toward convergence around CE definition and strategies and create clear guidelines for industry stakeholders.

University Leaders, NGOs, and Industry Associations

Universities, NGOs, and industry associations can work together to educate stakeholders on CE. For example, universities should include CE principles in the educational curricula of all disciplines and create multidisciplinary spaces to discuss the CE agenda moving forward. Industry associations should incorporate CE strategies into the training required to renew the professional license of designers (architects and engineers) and include CE-specific considerations in GBRS. NGOs can help raise public awareness on CE through educational campaigns.

Finally, universities were mentioned several times by the participants in this study as being at the forefront of sustainable building design. Architects pointed out that university buildings are usually required to meet GBRS certification standards like LEED Silver, and designers often exceeded the requirements to meet higher standards like LEED Gold or Platinum. That sheds light on an opportunity for universities in the US for incorporating CE targets and principles in their procurement policies. Universities have the potential to experiment and create exemplars of circular building designs that can influence and inspire building owners in all sectors and boost the market for circular solutions in the built environment.

Limitations

This research had some important limitations. First, only architects from large design firms were interviewed, and their experiences were mostly focused on institutional buildings (Table 2). The findings may have been different if architects from other market sectors have been interviewed (e.g., single-family residential sector or retail). Additionally, the authors recruited architects to participate in the interviews because of their central role in the building design process and decision making. As a result, some of the new barriers identified in this study may be linked to the unique perspective of architects (e.g., barriers ED6 and TE15 in Table 3), and recruiting a different mix of construction stakeholders could have altered the results. That said, although there were clear differences in the nature of the barriers identified in US and European countries, one cannot claim that such a disparity is caused exclusively by the different geographical context in which the interviewees were situated. The primary contribution of this study is to identify barriers that hinder CE in the US built environment, and identifying causal relationships between each barrier and their geographical context is out of the scope of this research.

Conclusions

Among the limited body of literature devoted to identifying barriers and enablers for circular building design strategies like DfD, all empirical studies were conducted in European countries. These barriers and enablers were highly influenced by the regulatory, cultural, and technological contexts where they are situated (e.g., the presence of top-down efforts toward CE such as CE-specific legislation and incentives). Despite the US context differing from its European counterparts, no studies were found that investigate the challenges and opportunities for circular built environments in the US. This paper aimed at filling this knowledge gap. Interviews with architects across the country have resulted in a variety of barriers and enablers for strategies like DfD, reuse, modular design, and prefabrication, including 10 barriers that were new to the literature. Most of the barriers perceived and experienced by the architects were technical, cultural, economic, and educational, and they have identified fewer regulatory and technological barriers than European counterparts. Understanding the challenges and opportunities of circular building design in the US and how they differ from the European context is key to implementing CE in the US building sector.

Finally, the authors have discussed the role of policymakers, researchers, designers, contractors, manufacturers, building owners, NGOs and industry associations, and university leaders in creating enablers for a circular built environment. The stakeholders that must be engaged in each enabler were identified, which will help establishing research and policy agendas, and forming new partnerships within the US construction sector.

Appendix. List of Barriers for Circular Building Design

The complete list of barriers (including barriers identified in other studies but not mentioned in the interviews) and respective enablers can be found in Table 5 and Fig. 4.

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Table 5. Barriers for circular building design

Category	Code	Barrier
Economic	**EC1**	**Underdeveloped market for salvaged components**
	EC2	**Cost and schedule constraints**
	EC3	**Limited viable CBMs for construction**
	EC4	**Unclear financial case for CE (cost benefits)**
	EC5	**Short-termism of clients who expect a quick ROI**
	EC6	Low virgin material prices
	EC7	Limited funding
	EC8[a]	**Market for prefabrication heavily dependent on imports**
Educational	**ED1**	**Lack of stakeholders' knowledge and awareness of CE strategies and benefits**
	ED2	**Confusion between reuse and recycling**
	ED3	**Lack of clarity on what CE entails**
	ED4	**Stakeholders' lack of experience and skills about CE strategies**
	ED5	Lack of empirically based literature on CE barriers
	ED6[a]	**Lack of leadership, cost, and schedule considerations in the university curriculum for building design**
	ED7[a]	**Lack of public awareness on life cycle costs and benefits**
Cultural	**CU1**	**Competitive and fragmented nature of the construction sector**
	CU2	**Conservative sector; risk aversion**
	CU3	**Perceived lack of aesthetics, quality, and safety of salvaged components**
	CU4	**Lack of trust to the supplier of salvaged components**
	CU5	**Skepticism about the future resale of used building components**
	CU6	**Stakeholders' lack of interest in CE**
	CU7[a]	**Lack of leadership from designers**
	CU8[a]	**Belief that DfD compromises building durability and resiliency**
Technical	**TE1**	**Current buildings were not designed for disassembly**
	TE2	Damages during deconstruction
	TE3	**Hazardous or contaminated materials**
	TE4	Difficulty in identifying the content of salvaged components and materials
	TE5	Split incentives
	TE6	**Uncertainty about future spatial needs**
	TE7	**Uncertainty about EOL (long life span)**
	TE8	**Industrialization of natural materials (e.g., timber products) hinders biodegradability**
	TE9	**Complexity of building design**
	TE10	Composite structures hinder reuse
	TE11	Structural overdimensioning when using salvaged materials
	TE12	Lack of bio-based construction materials and components
	TE13[a]	**Lack of standardization and transportability of building components**
	TE14[a]	**Conflicting goals between pre-engineered structures and future reuse**
	TE15[a]	**Matching the old to the new**
	TE16[a]	**Walmart effect**
Environmental	EN1	Environmental benefits of reuse are not guaranteed
	EN2	Downcycling of building components
	EN3	Not all materials can be environmentally effectively recycled
	EN4	Environmental case of CE is poorly understood
	EN5[a]	**Tradeoffs between different sustainability strategies may hinder CE**
Regulatory	**RE1**	**Existing regulations and codes hinder reuse and repair**
	RE2	Lack of CE-specific regulations
	RE3	Ambiguous or inadequate EOL policies
	RE4	Policies ignore resource extraction and demand
	RE5	Policy focus on recycling leads to downcycling
	RE6	Warranty issues of using reused materials
	RE7	Anti-trust legislation impedes collaboration
	RE8	**Lack of fiscal and regulatory incentives for CE**
	RE9	Lack of standards for reused and recycled building products
	RE10	Low GBRS points for CE strategies
Technological	**TO1**	**Lack of data about availability, quality, and quantity of salvaged building components**
	TO2	Lack of sorting and processing technologies for salvaged components
	TO3	Lack of collection, storage, treatment, and transportation infrastructure for salvaged components
	TO4	Lack of technology and infrastructure to assess quality and performance of salvaged components
	TO5	Lack of circularity metrics and EOL information in existing design tools
	TO6	Existing DfD tools are not BIM-compliant
	TO7	Lack of tools to identify and classify salvageable materials
	TO8	Limited visualization capability for DfD
	TO9	Fast-paced technology adds uncertainty to future reuse

Note: ROI = return on investment; and EOL = end of life. Barriers that were echoed by the participants of this study are in bold.
[a]Barrier new to the literature.

Enabler	Respective barriers (codes)	Stakeholders involved/responsible
Exercising leadership and educating stakeholders	CU2; CU6; CU7; CU8	D O C N
Integrating CE in contractual requirements for design	CU2; CU6; CU7	D O C
Assigning CE consultants to assist design	TE9; ED1; ED3; ED6	D O C
Seeking opportunities to use prefabrication and modular design	EC2	D O C M
Developing and using biobased materials	TE8; TE12	R M D
Developing and implementing material tracking technologies	EC1; CU1; CU4; TE4; TO1; TO7; TE15	R M
Creating databases for reusable components; urban mining	TO1; EC1; EC2; TE15	R
Enforcing sustainable procurement aligned with CE (civic and institutional projects)	EC1; CU6; CU7; RE2; RE3; RE8	P U
Creating tax deductions for CE design strategies	EC1; EC2; EC3; EC4; EC5; EC6; CU2; CU6	P
Establishing landfill diversion targets and zero waste policies that differentiate between reuse and recycling	EC1; ED2; CU6; RE3; RE5; RE8; CU7	P D C U O N
Establishing targets for salvaged components	EC1; ED2; CU6; RE3; RE5; RE8; CU7	P D C U O N
Establishing targets for reducing building embodied energy	RE4; CU7	P D C U O N
Increasing demolition taxes	EC2; RE8	P
Increasing landfill fees	EC2; RE8	P
Promoting carbon taxes	EC2; RE4; RE8	P
Incorporating CE in building codes (e.g., mandatory plan for building disassembly)	RE1; CU6; CU7	P
“Selling” adaptability	CU6; TE6; TE7	D
Developing more life cycle cost case studies on short-, medium-, and long-term savings promoted by CE strategies	EC2; EC3; EC4; EC5; CU2; CU6	D R C N
Choosing IPD and other collaborative project delivery methods	CU1; CU7; TE9	D C
Educating designers and building owners on life cycle cost	EC2; EC4	D R C N
Integrating client demands into architecture education	ED6	U N
Integrating CE into university curricula in all sectors	ED1; ED2; ED3; ED4; ED7; CU8	U
Raising public awareness of CE through public campaigns	ED1; ED2; ED3; ED7; CU8	P N
Incorporating CE training into the professional license renovation requirements for architects, engineers, and contractors	ED1; ED4; CU8	N
Raising awareness of construction stakeholders about successful examples of CBMs in the sector	EC3; CU6	P N R
Raising taxes on virgin materials	EC1; EC2; EC6	P
Allocating public funding to offer financial aid to SMEs and individuals that want to engage in circular design and construction	EC7; TE5	P
Offering subsidies, tax credits, and low-interest loans for companies that want to engage in CE practices, like circular design and CBMs, and building disassembly and EOL management	EC2; EC3; EC4; EC5	P
Raising taxes on foreign prefabricated components to strengthen national market	EC8	P

Fig. 4. Enablers for circular building design: enablers for the barriers listed in Table 5.

Developing standards and improving current methodologies for environmental assessments of CE strategies	EN1; EN4	P R
Developing empirical research studies on CE barriers in different regions	ED5	R
Raising awareness about the difference in environmental impacts between reuse and recycling; and recycling and downcycling	EN2; EN4; ED2; ED3	P R U N
Integrating LCA into design tools to aid case-by-case decision-making about CE strategies	EN1; EN3; EN5; TO5; TE14	R
Integrating CE into the K-12 education	ED1; ED2; ED3; ED7	P
Allocating more weight to CE strategies in GBRS and ecolabels	RE10	N
Reaching consensus around the concept of CE and creating explicit guidelines about different CE strategies in all sectors	ED1; ED3	P R N
Developing and enhancing technologies to assess the quality and safety of salvaged components	CU3; CU4; TE11; TO4	R
Offering contractual warranties on the quality and safety of salvaged components	CU4; RE6	C
Promoting deconstruction training to demolition workers to avoid damages during deconstruction and preserving the quality, safety, and aesthetics of salvaged materials	CU3; TE2	C
Developing and enhancing technologies to decontaminate building materials	TE1; TE3	R
Avoiding hazardous and toxic materials during design (e.g., Red List from LBC)	TE3	D
Creating content labels for building materials and components	TE4	R N M
Enforcing polluter-pays taxes for building's embodied energy	RE4	P
Increasing taxes on new construction and reducing taxes for building adaptive reuse	RE1	P
Developing technologies to connect supply and demand for salvaged components	TO1	R
Developing technologies to disassemble composites and separate biodegradable, reusable, and recyclable materials	TE8; TE10	R
Develop guidelines for transportability of building components	TE13	R C M
Enforcing a construction regulation reform to eliminate burdens to material reuse and building renovations and to promote CE in the construction sector	RE1; RE2; RE3; RE4; RE5	P
Creating national and regional CE action plans	RE2	P
Creating incentives for collaboration between companies (e.g., funding for collaborative initiatives towards CE)	RE7	P
Developing standards for reused and recycled building components	RE9	P
Developing and enhancing technologies for sorting and processing of CDW (e.g., integrating machine learning and automated sorting systems)	TO2	R
Allocating federal funding for R&D initiatives focused on CE	TO1; TO2; TO3; TO4; TO5; TO6; TO7; TO8	P
Promoting existing salvaged yards through funding, economic and fiscal incentives, and partnerships with technology companies to integrate their inventory to digital databases	TO1; TO3; TE15	P N
Integrating CE strategies to ICT (e.g., DfD to BIM)	TO6; TO8; CU1	R

Legend:

D Design team; C Contractors; R Researchers; N NGOs and industry associations; O Building owner; P Policymakers; U University leaders; M Manufacturers

Fig. 4. (*Continued.*)

Data Availability Statement

Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions. As per IRB requirements, identifying information about the interviewees are confidential.

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Supplemental Materials

Interview questions are available online in the ASCE Library (www.ascelibrary.org).

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