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A review of environmental impact indicators of cultural heritage buildings: a circular economy perspective

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Abstract

This paper is the first in-depth review of the state of the art of environmental impact indicators for adaptive reuse of cultural heritage (ARCH) buildings from a circular economy perspective. Buildings are a necessary component of sustainability planning because they are significant consumers of natural resources, producers of construction and demolition waste, and contributors to greenhouse gas emissions. In addition, buildings, particularly ARCH buildings, are long lasting; therefore, measuring and managing their environmental impacts is crucial to achieving the universal vision of a sustainable, low-carbon economy. The research answers the questions, 'What are the environmental impact indicators used by individual ARCH building project analyses?' and 'Are the most commonly used indicators reflecting Circular Economy concepts?' It synthesizes and defines current practice in the field whilst highlighting the gaps between practice and policy. Although the term 'Circular Economy' is not explicitly and routinely used in the literature, related concepts such as life cycle analysis, energy consumption reduction, energy efficiency, and embodied carbon/energy are evident at the project level. Concrete and measured environmental indicators are not mainstream. However, narratives of environmental protection feature prominently in the literature, indicating an environmental motivation for repurposing cultural heritage buildings. Further, there is a gap between common indicators of circularity and the ARCH building project level indicators shown in the dataset.

1. Introduction

This paper reviews the state of the art of environmental impact indicators for adaptive reuse of cultural heritage (ARCH) buildings from a circular economy (CE) perspective. The city centers of Paris, London, Vienna, Berlin, New York, and Hong Kong are but a few examples of cultural heritage buildings' role in crafting the unique personalities of distinct communities around the world. Likewise, ARCH buildings anchored in rural landscapes such as windmills in Estonia or paper factories in Sweden are living connections to an impactful shared past. 'Cultural heritage is an expression of the ways of living, developed by a community and passed on from generation to generation, including customs, practices, places, objects, artistic expressions and values.' (ICOMOS 2002:21) There are 1,121 cultural properties on the UNESCO World Heritage List.[1] Listed ARCH properties are a tiny percentage of the culturally significant buildings that are not recognized by an international organization but are formally and informally recognized by their communities as forming the fabric of daily life across the world.

The number of listed and unlisted cultural heritage buildings is expected to grow. For example, about 17% of buildings in the United States were built before the end of World War II (Elefante 2007). In the Austrian capital, Vienna, an estimated one third of buildings were built before the First World War (Hatz 2008). While all old buildings are not listed, many are preserved because they are crucial to local cultural heritage and identity. In addition, preservationists 'will have to address a much larger building stock when modern-era buildings become more fully the stuff of preservation.' (Elefante 2007:28) Listed or not, the International Energy Agency predicts that about 60% of today's building stock in Europe, the United States and Russia will remain in 2050 (OECD/IEA 2013).

[1] UNESCO website. https://whc.unesco.org/en/list/?&type=cultural. Downloaded 14 January 2020.

The increasing stock of ARCH buildings holds unique significance to the past, present, and future of human communities—including their environmental impacts.

The widespread existence and importance of ARCH buildings demand that researchers, city planners, policymakers, and industry consider how the environmental impacts of ARCH buildings are managed in light of global environmental crises such as climate change, due to fossil fuel use and over-exploitation of natural resources. ARCH buildings, as a subset of the building sector, are significant greenhouse gas (GHG) emitters and consumers, while also possessing vast amounts of embodied energy (Akadiri *et al* 2012, Aksamija 2016, Assefa and Ambler 2017). Rapidly reducing the carbon emissions of the building sector is needed to support the Intergovernmental Panel on Climate Change (IPCC) objective of limiting global warming to 1.5 °C above pre-industrial levels (Rogelj *et al* 2018). In addition, ARCH buildings are often adaptively reused and refurbished or retrofitted to meet today's needs, rather than their original purpose, therefore, they present a unique opportunity for climate change mitigation, adaptation and other additional environmental quality improvements. In 2018, the Leeuwarden Declaration highlighted the economic, cultural, social, and environmental opportunities afforded by adaptive reuse of built heritage preservation (ACE 2018). The Leeuwarden Declaration supporters include the Architects' Council of Europe and Europa Nostra.

'Circular Economy is a production and consumption process that requires the minimum overall natural resource extraction and environmental impact by extending the use of materials and reducing the consumption and waste of materials and energy. The useful life of materials are extended through transformation into new products, design for longevity, waste minimization, and recovery/reuse, and redefining consumption to include sharing and services provision instead of individual ownership. A CE emphasizes the use of renewable, non-toxic, and biodegradable materials with the lowest possible lifecycle impacts. As a sustainability concept, a CE must be embedded in a social structure that promotes human well-being for all within the biophysical limits of the planet Earth.' (Foster 2020:2)

1.1. Circular economy and cultural heritage buildings

The concept of Circular Economy (CE) is central to the context of cultural heritage buildings because of the opportunities to adapt and reuse them. CE describes the aspirational and universal goal of transitioning to a sustainable and low-carbon economy that halts environmental degradation and climate change (Geissdoerfer *et al* 2017). Circularity contrasts with the 'extract, produce, consume, trash' linear economy model that is currently common all over the world (Bruel *et al* 2019). CE does not have a simple definition, rather it is a suite of strategies and definitions that describe an idealized state of human interactions with nature (Kirchherr *et al* 2017). CE is well-known for new closed-loop production and consumption patterns that aim to reduce and eliminate waste at every stage of the product life cycle. However, closed loops are not enough—a more comprehensive definition of CE is needed. This research frames CE according to Foster, who proposed CE strategies for reducing environmental impacts for ARCH in a related article (Foster 2020). A comprehensive concept of CE is important for the building and construction sector because it is not only an intense consumer of raw materials, but the sector also reflects humans' basic needs (shelter for living, socializing, and work (Max-Neef 1992) and basic desires (such as social inclusion/community, organization, and status (Reiss 2002, Schwartz 2012).

Several existing works establish the many links between buildings and CE (Pomponi and Moncaster 2016, Adams *et al* 2017, Leising *et al* 2017, Pomponi and Moncaster 2017, Fusco Girard and Gravagnuolo 2018, Mahpour 2018, Foster 2020). The goal of adopting a circular approach to buildings is mainly to reduce waste production and reduce resource consumption (Williams 2016). These environmental benefits are extensively researched.

The environmental benefits of ARCH are established in the literature (Pereira Roders and van Oers 2011, Melo 2012, Mahpour 2014, Mahpour 2018). In its most basic form, CE means using what is already there to maximize the use of embodied energy and materials in existing building stock. The challenge is that existing building stock, including cultural heritage buildings, must be refurbished and reused to meet the goals of a low-carbon economy.

The scope of the challenge is illustrated by recent statistics on energy sources and carbon emissions of buildings. First, globally buildings generate 28% of all energy-related CO_2 emissions in 2018[2]. Second, according to the latest European statistics, coal consumption in the European Union (EU) was 596 million tons for electricity and heating in 2018[3]. This statistic demonstrates that EU building stock is still reliant on a highly polluting fossil fuel. Coal emits more CO_2 emissions per unit of energy than natural gas, diesel fuel, gasoline, and heating oil.[4] Third and most important, at the global level, very little progress

[2] International Energy Agency 'Tracking Buildings'. https://iea.org/reports/tracking-buildings Downloaded 24 January 2020.

[3] Eurostat 'Coal production and consumption statistics'. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Coal_production_and_consumption_statistics Downloaded 24 January 2020.

[4] U.S. Energy Information Administration 'Frequently Asked Questions'. https://eia.gov/tools/faqs/faq.php?id=73&t=11 Downloaded 24 January 2020.

has been achieved and is even reversing. The International Energy Agency reports that, 'In absolute terms, global annual buildings-related carbon emissions appear to [have] risen again for a second year in a row, returning to their historical peak in 2013 of around 9.5 $GtCO_2$'[5]. Also, according to the Circularity Gap Report 2020, 'of all the minerals, fossil fuels, metals and biomass that enter the economy just 8.6% are reused'[6]. For these reasons, adapting and reusing ARCH buildings is an important part of a CE and low-carbon strategy in the built environment in urban and non-urban areas.

CE in the built environment is still in its infancy and has so far largely been limited to waste recycling and waste minimization of new buildings. From an environmental perspective, ARCH buildings:

- Extend the lifespan of the building whilst maintaining cultural heritage values;
- Reduce and avoid waste from demolition;
- Capture the energy expended in the original construction, thereby avoiding new energy use and greenhouse gas emissions;
- Retain building materials in use, thereby avoiding new materials extraction; and
- Provide opportunity for a variety of environmental enhancements such as improving energy efficiency, expanding outside green areas, reducing pollution, providing or restoring habitat for wildlife, or switching from fossil fuels to renewable energy sources.

There are many obstacles to adopting the CE concept in the building sector. Chief amongst these is a lack of information amongst clients, designers, architects, and subcontractors, especially in articulating the value of CE policies and environmental policies (Adams *et al* 2017). Transparency and better methods and tools for measurement and accountability would improve CE implementation in the future (Adams *et al* 2017). The lack of information and management tools specifically for the building sector and ARCH is particularly problematic given the rapid development of CE initiatives.

Nascent CE initiatives focus on high resource consumption industries such as building and construction in communities worldwide, at the regional, national, and city level. Some examples follow. China officially adopted CE in 2009. Finland began a national CE program in 2016. The European Commission's December 2019 European Green Deal builds on the 2015 European CE Action Plan. 'Circular City' initiatives are particularly relevant for ARCH because the cultural uniqueness of cities is related to features of the urban landscape including buildings (Bandarin and Van Oers 2012). The following cities, well known for cultural heritage of the built environment have announced Circular City initiatives: New York, Paris, Amsterdam, and Berlin. These examples are notable early entrants; however, preserving cultural heritage whilst pursuing CE is not limited to industrialized nations. This article aims to contribute to greater transparency and methods development by finding out what circular environmental indicators are commonly used in ARCH.

1.2. Present study and organization

Given the background described above, this article highlights environmental indicators for ARCH buildings in the context of CE. Environmental indicators for ARCH buildings can help to depict environmental data 'in a comprehensive and concise manner' and can be used to compare environmental performance over time, to highlight potentials for optimization, to derive and pursue environmental targets, to evaluate and compare the environmental performance of different case studies, to communicate environmental reports, to supply information feedback to the sector, and to motivate the workforce, amongst others (Jasch 2000:80). Further, environmental indicators are a management tool for the European Union energy and climate change policy objectives[7] and circular economy objectives.[8] Hence, environmental indicators are crucial for the implementation of CE strategies in ARCH buildings in urban and non-urban areas.

The new finding that environmental indicators are rarely applied in ARCH projects today is an impediment to progress towards the intertwined goals of CE and cultural heritage preservation. The research systematically reviewed the existing literature, 168 journal articles from 2008 to 2017, to answer the following questions: 'What are the environmental impact indicators used by individual ARCH building project analyses?' and 'Are the most commonly used indicators reflecting Circular Economy concepts?' The results are synthesized and presented in a summary table of key circular environmental indicators prevalent in this dataset. The present article contributes new knowledge on CE environmental indicators in the construction sector and ARCH.

Our research found that although the term 'Circular Economy' is not explicitly and routinely used in the literature, related concepts such as life cycle

5 International Energy Agency 'Tracking Buildings'. https://iea.org/reports/tracking-buildings Downloaded 24 January 2020.

6 Circle Economy 'World risks disaster as global resource consumption passes 100 billion tonnes a year'. https://aclima.eus/world-risks-disaster-as-global-resource-consumption-passes-100-billion-tonnes-a-year/ Downloaded 24 January 2020.

7 European Commission 'Energy union indicators webtool'. https://ec.europa.eu/energy/en/data-analysis/energy-union-indicators Downloaded 24 January 2020.

8 Eurostat 'Circular Economy Indicators'. https://ec.europa.eu/eurostat/web/circular-economy/indicators/monitoring-framework Downloaded 4 January 22020.

analysis (LCA), energy consumption reduction, energy efficiency, and embodied carbon/energy are evident at the project level. Concrete and measured environmental indicators are not mainstream. However, narratives of environmental protection feature prominently in the literature, indicating an environmental motivation for cultural heritage adaptive reuses. Further, there is a gap between common indicators of circularity and the ARCH building project level indicators shown in the dataset.

The remaining sections of the article are organized as follows. Section 2 reviews the relevant literature and discusses the contributions of this research. Section 3 provides an overview of how and why environmental indicators are used. Section 4 describes the study design and methods. Section 5 presents the results of the systematic literature review. Section 6 concludes with reflections, implications for the field and suggests avenues for future research.

2. Literature review

The recent academic and policy interest in the adaptive reuse of buildings, particularly in urban areas, has resulted in hundreds of individual adaptive reuse project studies. However, overviews and syntheses of the current work in the field are scant. This literature review identified six significant peer reviewed articles that conducted a structured literature review of secondary sources, developed a framework for environmental impact indicators, or reported on practice regarding environmental impact assessment (EIA). This section discusses the existing literature and notes how the current work contributes to the field.

In their study, Pomponi and Moncaster (2016) use the systematic literature review method to analyze 102 journal articles on how to mitigate and reduce embodied carbon in the built environment, identifying 17 mitigation strategies within the existing literature and conducting a meta-analysis of 77 LCA studies. The systematic review method, including a meta-study, allows the authors to make critical comments and suggestions about the way LCA studies are conducted. They note that the lack of end-of-life and occupancy consideration of embodied carbon is a critical problem with LCA methods as environmental indicators. Another article, Pomponi *et al* (2016), systematically conducts a meta-analysis of studies on the energy performance of Double-Skin Facades (DSFs) in temperate climates, noting the lack of embodied energy and LCA considerations, as well as the paucity of refurbishment-centered studies on DSF-use, which are very important for sustainability. The aforementioned studies report on one environmental aspect, embodied carbon and energy performance of DSFs, our research reports on all of the environmental indicators mentioned in the literature. The meta-analysis studies performed by Pomponi and Moncaster (2016) and Pomponi *et al* (2016) contributes to standardization and generalization of indicators. This paper also contributes to standardization of indicators in the field by reporting on the indicators used in practice.

Other authors in the adaptive reuse and cultural heritage literature also use the literature review method—for example Martínez-Molina *et al* (2016) use the systematic literature review approach to summarize and analyze different methods relating to achieving thermal comfort in historic buildings, to show the abundance of methods and approaches available and to systematize these by technique, country, area and type of building, etc Heidrich *et al* (2017) use the literature review method to analyze the development of and trends in the concept of building adaptability. These articles show the wide variety of possible adaptive reuses in cultural heritage buildings. The individuality of historic buildings partially explains the wide variety of environmental indicators revealed in this paper.

Ferreira, Pinheiro *et al* (2013) present a systematic review of papers focusing on decision-support tools and methods for building refurbishment, classifying the methods into five distinct groups: 'general methods,' 'improve energy and/or CO_2 emissions performance,' 'purely economic analysis,' 'LCA methods,' and 'sustainable assessment methods.' The indicators and metrics for energy and CO_2 emissions performance, as well as the sustainable assessment methods, are not expanded upon to specifically include metrics (Building Research Establishment Environmental Assessment Method (BREEAM) and Leadership in Energy and Environmental Design (LEED) assessment methods being considered as indicators). The authors note that in the reviewed works, the measurement of 'other environmental impacts' lacks rigor and comparability, since various aspects of environmental impacts (eutrophication, water use, waste and emissions) can be included. In general, these environmental impacts are mostly evaluated within the scope of LCA analyses amongst the reviewed papers. The authors consider the LCA approach promising for assessing environmental impacts, a welcome move away from the operational perspective focus. The critique of the wide and varied use and application of environmental measurement and impact assessment tools is touched upon by many other authors both in the adaptive reuse, cultural heritage as well as the EIA fields.

Dammann and Elle (2006) look at the case study of the Danish building sector to understand whether a common language for green building with a consensus on environmental indicators could be reached. Using the theory of the social construction of technology, they conclude that consensus amongst the different relevant stakeholders as to environmental indicators (specifically on the complexity of indicators needed as well as the need for LCA) is currently not likely. They assert that a lack of systematic environmental knowledge, even amongst people working in scientific fields such as architects and engineers, is a major barrier to the development of a common language for green building (Dammann and Elle 2006). Similarly, Dixit *et al* (2010) use the literature based discovery method to analyze and compare different methods and processes of embodied energy analysis, including process analysis, statistical analysis, input/output analysis, and hybrid analyses. The authors note that the results of the different and disparate embodied energy and life-cycle analyses vary widely, due to the inherent limitations of the different methods, making comparison and juxtapositions of the different measurements of embodied energy not possible. This paper is able to contrast and compare Dammann and Elle (2006) and Dixit *et al* (2010) conclusions against the new dataset analyzed herein.

Berthold *et al* (2015) review 25 case studies on 'sustainability indicators,' conceptualized as indicators overlapping in the spheres of the economy, society and environment (according to the sustainable development doctrine fashionable in the late 1990s). The authors note that 'indicators are generally recognized for their simple character and their analytical effectiveness' (Berthold *et al* 2015:25), but that the abundance of different sustainability assessment methods, as well as their applications and methodologies, has raised issues. The authors, like Dixit *et al* (2010), argue that using fewer and less explicit but consistent and easily regulated indicators would be preferable from the policy-making standpoint (especially in urban heritage management), although scientifically this is a compromise and necessarily involves value-judgments and political choices in the use of indicators and metrics. The authors observe a lack of consensus in the number and choice of sustainability indicators in the reviewed papers (with 70% of indicators only appearing in a single study, 21% in two different studies and 10% of indicators used in three different studies). The authors have a very broad understanding of indicators.

The above literature review shows that while there is an increasing awareness about the importance of environmental indicators as well as their choice, methodology, and policy application, as of yet there is little research focusing specifically on the use of and types of environmental indicators in the adaptive reuse and cultural heritage sectors. In summary, a number of individual environmental indicators appear in the literature discussed with varying levels of specificity. The following examples are not all-inclusive but illustrate the breadth of the indicators discussed in the literature:

1. *Indicators of reductions to new natural materials extraction*: timber use; water consumption; hazardous waste; construction and demolition waste; direct metering of water and energy use;
2. *Indicators of direct and indirect reductions to energy use and climate change*: CO_2 equivalent emissions; embodied carbon in the built environment; energy performance; electricity consumption; heat consumption; ozone precursors emitted;
3. *Indicators of other, often general, environmental improvements and pollution reductions*: environmental and ecological awareness; resources and materials consumption reduction; BREEAM and LEED assessment.

This study is more comprehensive geographically and has a wider scope of environmental impacts than previous studies. It also includes more articles than many past studies. The existing literature highlights that a common language and shared understanding for environmental indicators for ARCH buildings is needed. However, this task is complex and difficult to achieve because of the:

- wide variety of adaptive reuse strategies;
- lack of systematic environmental knowledge amongst practitioners in the field;
- lack of consensus on which indicators are most important; and
- wide variety of assessment methods including LCA.

Regarding environmental indicators, this article aims to contribute to finding a solution to the ARCH problem expressed in the Leeuwarden Declaration, 'It is essential to sensitise all stakeholders—local and regional public authorities, the financial sector, owners and heritage professionals—to the benefits and challenges inherent to such projects, and to foster peer-learning across Europe, as many good practices and solutions already exist' (ACE 2018:3).

3. Overview of environmental indicators

The main aim of environmental indicators is to make environmental impacts as well as benefits visible to the relevant actors, by focusing on specific relevant information (Dammann and Elle 2006). Radermacher (2005) explains that indicator-building requires extracting necessary and useful information from the less useful, by a process of knowledge finding, to allow us to reduce complexity and understand deeper processes at work—an inherently normative process. This cannot be a linear or positivistic process; the choice and methodologies of indicators must be part of an iterative decision-making process, where satisfactory solutions are found to specific problems and targets, while statistical measurability, scientific consistency and political relevance remain conflicting goals. Moldan and Dahl (2007) explain that since indices aim to indicate trends and reduce complexity,

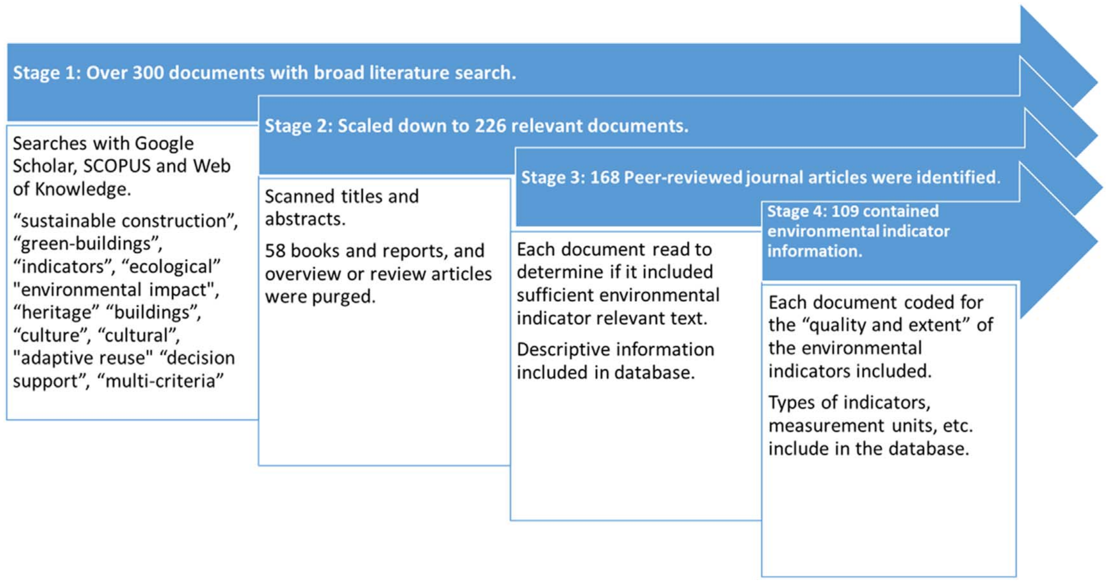

Figure 1. Systematic literature review process.

by their nature there are no perfect or recommended indicators, but different approaches that may be useful for specific needs. They explain that:

'Indicators are symbolic representations (e.g. numbers, symbols, graphics, colors) designed to communicate a property or trend in a complex system or entity. Traditionally, most indicators for decision makers have been numbers calculated by statistical services, including complex indices such as the gross national product (GNP) or percentages such as the unemployment rate' (Moldan and Dahl 2007:1).

Alfsen *et al* (1993) from the Norwegian Central Bureau of Statistics, in a much earlier article, look at the case of environmental indicators for Norway. They propose a hierarchical system of indicator sets, depending on the target group, the aim of environmental indication, and whether the indicators reflect causes or effects. The authors also undertake an international comparison of environmental indicators. The preliminary indicator set for environmental quality indicators they propose is specifically for Norway, including:

- a climate change indicator (changes in radiative forcing due to increased levels of CO^2 emissions);
- an ozone depletion indicator (change in total ozone column);
- urban environment indicator (exposure to air pollution);
- a eutrophication indicator (secchi disk depth measurement of turbidity and chlorophyll in Mjosa lake in Norway);
- an acidification (crown density of forests and area of lakes with extinct or badly damaged fish populations);
- a contamination indicator (thickness of Merlin bird egg shells);
- a recreation indicator (% of availability of undisturbed nature); and
- biodiversity indicators (% of endangered species, % of undisturbed river deltas).

While the paper focuses environmental indicators on a macro (country) level, rather than for the building sector alone, the discussion is relevant for the adaptive reuse and cultural heritage sectors.

4. Study design and methods

A systematic literature review is an approach that 'locates existing studies, selects and evaluates contributions, analyses and synthesizes data, and reports the evidence in such a way that allows reasonably clear conclusions to be reached about what is and is not known' (Denyer and Tranfield 2009:671). While popular in the medical sciences, the systematic review approach has also been gaining importance in other fields (Gough *et al* 2017), including organizational research and management (Tranfield *et al* 2003, Denyer and Tranfield 2009) as well as the built environment (Pomponi and Moncaster 2016, Pomponi *et al* 2016).

We use the comprehensive systematic literature review approach to achieve two primary goals: document the existing methods for evaluating the environmental impacts of adaptive reuse of cultural heritage buildings, and to create a new detailed dataset of the environmental impact indicator methods and tools applied by scholars and practitioners in the field. The literature review and data collection effort allowed the authors to characterize the literature in the field and

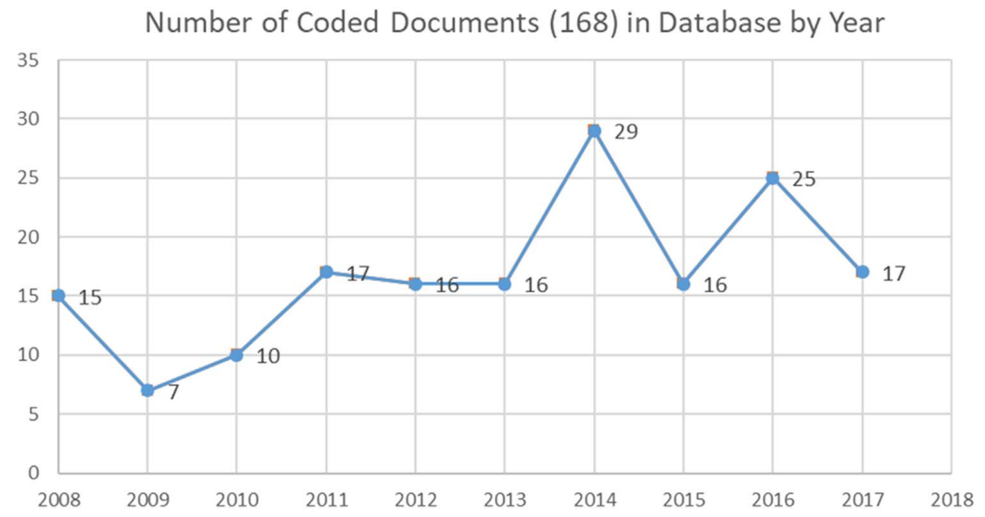

Figure 2. Distribution of documents in the dataset by publication date.

Table 1. Coding scheme for environmental impact indicators of cultural heritage buildings: a circular economy perspective.

1	Indicator(s) of environmental impact present. One or more indicators for a specific case study (building or group of buildings). For example, the indicator(s) are clear and measurable with quantitative units.
2	Aggregate indicator(s) of environmental impacts present. Ranking assessed according to LEED, BREEAM or similar for a specific case study (building or group of buildings or area). For example, the document reports that the building achieved LEED Gold Certification or BREEAM Very Good.
3	References specific quantitative indicators at the general or macro level (city, sector, nation, or global). For example, the CO_2 produced at the national level or the contribution of buildings to CO_2 at the national level.
4	Narrative reference to environmental impact, environmental benefits. No quantitative data at any level provided.
5	None.

synthesize, evaluate, and interpret the data presented in the literature to build a deep understanding of practices in this field.

Dataset—Keeping in mind that adaptive reuse of cultural heritage buildings is a subset of rehabilitation of existing buildings and is practiced world-wide, very often without any environmental motivation, it was necessary to hone in on a specific group of documents within a broad group. The document search followed a funneled process that was explicitly iterative. See figure 1.

At the first stage, documents were identified using reference and citation search engines and databases Google Scholar, SCOPUS and Web of Knowledge. These documents were identified using key word searches combining relevant terms (with many combinations) 'sustainable construction,' 'green-buildings,' 'indicators,' 'ecological' 'environmental impact,' 'heritage' 'buildings,' 'culture,' 'cultural,' 'adaptive reuse' 'decision support,' 'multi-criteria.' The first stage consisted of over 300 published works including journal articles and reports from industry and organizations worldwide. The titles and abstracts of each of these documents was scanned to determine if they fit into the scope of the research. At the next stage, 226 documents were selected as relevant. This list was culled further when books, reports and overview articles were purged. Finally, 168 articles were selected for in-depth analysis. A deductive list of codes for methods, tools and indicators was assembled and applied to the 168 articles. Figure 2 provides a timeline of the distribution of the documents comprising the dataset by their publication dates. Of these, 59 documents did not include enough indicator information to be coded. More detailed reading and coding of the quality and extent of indicators in the text applied to 109 documents that met the minimum of environmental indicators (see table 1(above)).

A limitation of this research is that the dataset is comprehensive but not all-inclusive. The search engine methodology was applied only for the ten year period between January 2008 and December 2017. This period includes current techniques and developments in the field. This period also follows a broadening of the cultural heritage preservation discipline to reuse and sustainability. In the United States, for example, this broadening is marked by Carl Elefante's frequently referenced article, 'The greenest building is… one that is already built.' in the journal of the National Trust for Historic Preservation (Elefante 2007:32). Although, the dataset is relatively large and comprehensive, it is possible that relevant case studies were missed.

Coding Process—The *in vivo* coding process identified the environmental indicators applied in the document, units of measure, methods of assessing environmental impacts and other relevant information. According to suggestions by Saldaña (2013), Microsoft Excel was used as a repository for the database, with each article represented by a row. Excel was preferred to other software because of its accessibility, the large number of research articles, the ability to have individual cells holding thousands of entries and their accompanying codes (with color-coded cells), the familiarity of both researchers with the software, the ease of importing bibliographic data in a tab-lineated manner, as well as the ease of displaying 'quantitized' qualitative data (Saldaña 2013:6–27, 63, 255). As researchers Meyer and Avery (2009:110) have argued, while Excel might be known as a number-crunching tool, its abilities 'extend to qualitative analysis applications' extremely well, in part because of the software's ability to organize data in a meaningful way, although this has been largely overlooked.

During the first cycle of coding, the texts were coded *in vivo*, according to attributes, and additionally sub-coded according to 'magnitude,' with the articles being numbered according to the methods, tools and metrics of environmental assessment (Saldaña 2013). The textual material, codes and memos were processed several times. In the second cycle of coding, the methods and tools were further divided by categories (energy use indicators, emissions, water use, and so forth) and coded by a second coder, to ensure inter-code reliability (Mayring 2014).

The coding scheme ascribed five levels to describe the environmental indicators included in each paper. Following the purpose of environmental indicators as described in section 4, indicat ors were considered when relevant, clear, specific, measurable, and actionable. Table 1 provides the coding scheme used to assess the quality of the environmental indicators identified in the literature.

5. Results and discussion

This section presents the main findings of the analysis. First, the overall results of ranking the environmental indicator information per table 1 are discussed. Second, the discussion turns to the synthesis of the environmental indicators most prevalent in the dataset.

An early finding is shown by the timeline of publications (see figure 2 above). The academic interest in adaptive reuse projects has a slightly increasing trend over the study period, 2008–2017. There are two unexplained upticks in publications in 2014 and 2016. The dataset is international and global, including case studies in Austria, the United States, the United Kingdom, Australia, the Netherlands, China, and Iran, for example. Twenty-seven countries are included. The authors' general assessment of the dataset is that it is representative of the field and it is not skewed by year of publication or region. However, there is a strong representation of Australia, which seems to be a leader in environmental indicators of adaptive reuse projects. Figure 3 provides a world map indicating the countries present in the data set. This research has a global focus, no regions were excluded. However, the preponderance of studies from advanced industrial economies reflects the general unevenness in research and academia (Altbach 2009). ARCH buildings and sites exist in every country; therefore, placing them within a CE framework is relevant everywhere.

5.1. Results of ranking the documents in the dataset

The overall results of the analyses are presented in graphic formats whilst discussed below. In summary, as shown in figure 4:

- The majority of ARCH documents in the dataset (65%) make reference to environmental impacts.
- Only 17% of the documents in the full dataset were ranked at level 1, 'Indicator(s) of environmental impact present. One or more indicators for a specific case study (building or group of buildings).'
- Of the 109 documents that reference environmental impacts, the majority (54%) include them in a narrative form when describing adaptive reuse, without specific indicators. These were ranked at level 4, 'Narrative reference to environmental impact, environmental benefits. No quantitative data at any level provided.'

It is an important finding that the majority of ARCH documents mentions environmental impacts, and that only 35% do not reference the environment. This shows that ARCH practitioners believe that environmental impacts are relevant to their work. Alternatively, the low level (17%) of analyses at level 1 show that there is a knowledge gap. This finding corresponds with previous research that a lack of systematic environmental knowledge amongst architects and engineers is a major barrier (Dammann and Elle 2006).

Another finding derived from the results of the analysis is that reducing environmental impacts is a shared norm and value in the field of ARCH. The results show that 54% of all documents note environmental impact as part of the narrative rather than as measured and reported indicator. This highlights the role of defining the 'story' of a discipline to convey shared knowledge, including shared norms and values in this field. Storytelling is 'Sharing of knowledge and experience through narrative and anecdotes in order to communicate lessons, complex ideas, concepts and causal connections' (Sole and Wilson 2002:6). Today's

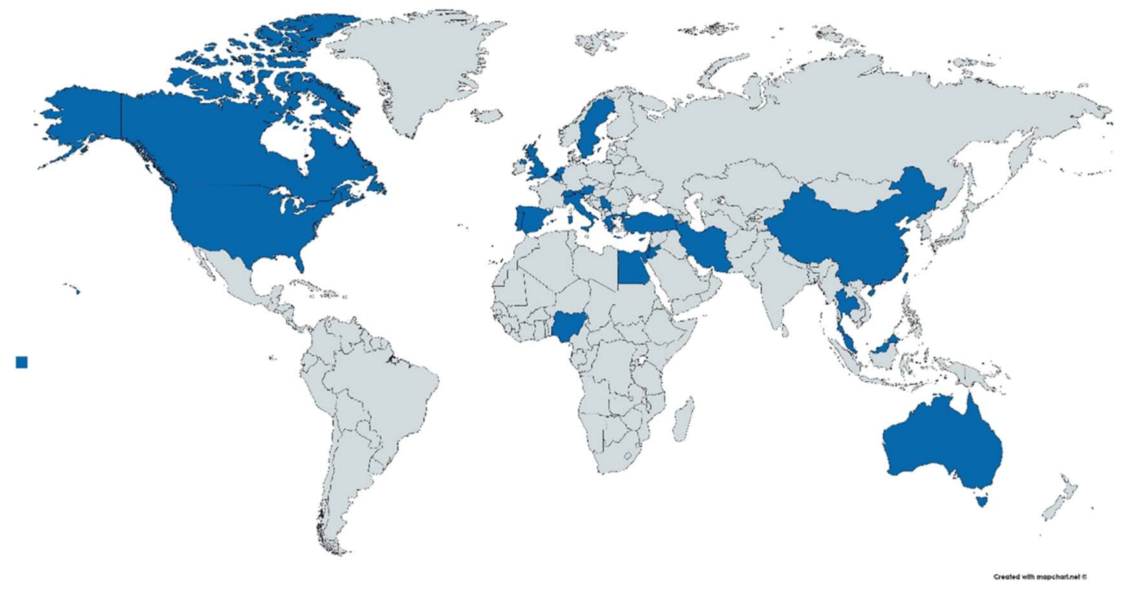

Figure 3. World map of countries present in the dataset.

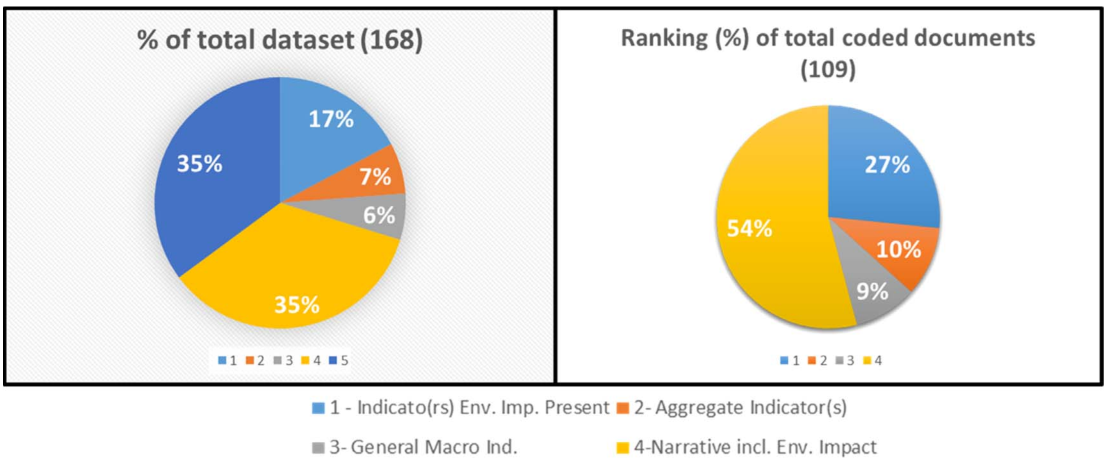

Figure 4. Overview of the results of ranking the quality of environmental indicators present in the dataset.

narrative of ARCH includes reducing environmental impacts.

There are both negative and positive aspects raised by the narrative perspective in this case. A negative aspect of the environmental narrative is the presumption that environmental benefits of adaptive reuse will occur *a priori*. Hence, there is little need to diligently measure and manage these outcomes, for example by using detailed environmental indicators. Perhaps, this perspective could partially explain the current low level of detailed indicator use as well.

Positively, embedding reducing environmental impacts as part of the story of ARCH adaptive facilitates 'unlearning and change' (Sole and Wilson 2002:7). Unlearning and change are needed to transition from linear to circular economy models in the building sector. Figure 5 presents the data over time allowing for observation of change during the period. The drive to reduce environmental impacts represented in the dataset shows a concerted shift in the ARCH field over time. High quality indicators (ranking of 1 & 2) were found in 38% of the documents published in the first five years of the dataset (2008–2012). The second five years of the dataset (2013–2017), showed an increase in the prevalence of specific indicators to 49% of the documents. There is a clear trend towards more inclusion of environmental indicators.

The positive aspects of the current narrative approach to reducing environmental impacts outweigh the negatives as it points towards a new direction in the field. Addressing environmental impacts as a key motivator of ARCH promotes new thinking and potentially better environmental outcomes.

The emergent and increasing use of environmental indicators in the ARCH field shown by this analysis furthers the need for better understanding and potential

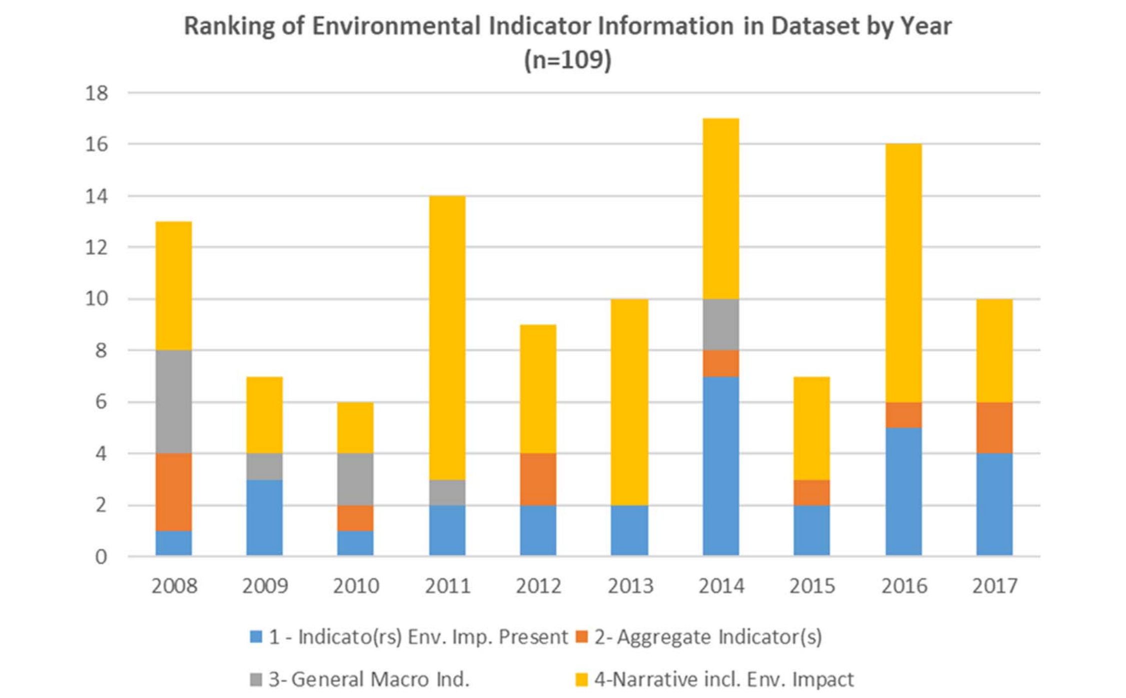

Figure 5. Observing change over time: ranking documents in dataset by year.

standardization of environmental indicators in general and specifically circular environmental indicators.

5.2. Circular environmental indicators in the dataset

Having established the prevailing trends above, this section reports the results of the analysis based on the article's two main research questions, 'What are the environmental impact indicators used by individual ARCH building project analyses?' and 'Are the most commonly used indicators reflecting Circular Economy concepts?' The results derive from the 51 documents whose indicators were ranked at level 1, 2, or 3. As discussed in section 2, there are many common CE indicators that capture the main principles of CE. Briefly , extending the lifespan of material resources and energy in a non-polluting way thereby reducing the need for new virgin material, reducing waste, and enabling regeneration of resources in nature (EMF 2013, Figge *et al* 2018). The analysis of the indicators in the dataset is based on these principles.

The indicators noted in the database include the categories one would expect to be associated with ARCH projects. The top six categories of environmental impact observed in the data and collated from the database are presented (in order of prevalence) as follows:

1. Air emissions including CO_2, nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter;
2. Energy efficiency/consumption and proportion of renewables versus non-renewable energy consumed;
3. Embodied energy calculated as tons of carbon dioxide (CO_2) or CO_2 equivalent greenhouse gasses avoided;
4. Construction & Demolition (C&D) waste to landfill;
5. Land use change; and
6. Water efficiency/consumption and water quality measured as eutrophication potential based on nutrient loads and ecotoxicity.

There were two surprises in the results. First, the documents ranked as actual indicators (1–3) for C&D waste to landfill and land use change were scant. Only twelve documents mentioned C&D waste to landfill. Only eleven documents mentioned land use change. Only thirty percent of these documents included quantitative data. This is a surprising result because C&D waste to landfill and land use change are long-standing core circular practices of the building sector and are often stated as municipal/national policy goals (Chini and Bruening 2003, Ding 2013, Ferreira *et al* 2013). Both indicators are easily quantifiable. Further, because C&D waste to landfill usually involves paying for disposal based on volume, projects often quantify these costs. Reusing materials and reducing C&D waste to landfill is a cost savings and would be part of a project's documentation. This finding highlights not only the lack of publicly available data but also an anomaly between practice and policy.

Second, most water indicators in the dataset focus on water quality defined as eutrophication potential based on nutrient loads. These outnumbered water efficiency/consumption measures. Although the sample of water quality indicators is low (10), this outcome is surprising as generally water consumption along with energy consumption are common CE indicators (Moraga *et al* 2019). Further, a building refurbishment could change the use of water at the site, for example through increased occupancy and/or modernized plumbing. Water efficiency/consumption indicators are theoretically easier to measure than the adaptive reuse's contribution to eutrophication. Therefore, it is surprising to see more emphasis on water quality indicators instead of water quantity indicators in the dataset.

The circular environmental impact indicators most used in individual ARCH building analyses are embodied energy of the building materials and CO_2 emissions during the construction and operating phase. In fact, energy is the most reported category overall with 44 documents ranked at levels 1–3. Also, the most detailed indicators are related to energy. Measuring energy and greenhouse gas impacts is needed for addressing global climate change, a prevalent policy objective in the building sector today.

While energy was represented, materials were not adequately represented. For example, decreasing construction and demolition waste reduction is a common waste management goal, yet little data was included. Also, the recovery of materials for reuse during the construction phases and end of life phases lacked detailed indicator data. Except as related to embodied energy of the main components of the building, the recycled/reused content of the project remained in the realm of narrative. This finding indicates that knowledge building on materials recovery, particularly specific waste streams such as wood waste, electronic waste, etc is needed to improve practice in this area.

Finally, the field of ARCH buildings is heavily influenced by green building rating and certification schemes (GBRCs). BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design) are two well-known example of GBRCs. There are many international, regional and national GBRCs. In general, these schemes are an aggregate measure of disparate environmental indicators. There is some criticism in the literature that aggregate rating schemes can be achieved without covering all environmental and energy elements equally. In particular, energy and materials can be rated at a low level without compromising certification (Obata *et al* 2019). A LEED Gold, Silver, or Platinum certification level indicates a certain number of points rather than a specific indicator of material or energy throughput reduced, increased longevity, or pollution abated or regenerative capacity. These are core CE objectives (EMF 2013). Therefore, these aggregate measures of building sustainability are problematic from a CE perspective and do not readily translate to common CE objectives.

In summary, three commonly used CE indicators, water efficiency; C&D waste to landfill; and land use change are poorly represented in the dataset. On the other hand, carbon emissions and air pollution, energy efficiency, and embodied energy are the top three reported indicators. Finally, rating systems heavily influence reporting but do not adequately capture circularity.

5.3. Synthesis of circular environmental indicators in the dataset

As discussed in the introduction, CE in the building sector refers broadly to increasing the longevity of natural resources by reducing waste and increasing the recovery/reuse of materials. The indicators in the literature are inconsistent regarding the construction phase or the operation phase, or demolition/reuse phase of the building's lifecycle. So, no distinction between the phases of the building lifecycle are made in this analysis. Additionally, this article reports what indicators were applied in practice rather than the indicators that should or could be applied.

Please note that the synthesis is drawn from the wide variety of indicators and units of measure in the data. The wide variety shown in the dataset corresponds to the findings of Dixit *et al* (2010). For this synthesis, indicators of CE are clustered in the following groups:

1. Indicators of direct reductions to new natural materials extraction due to the adaptive reuse;
2. Indicators of direct reductions to energy use due to the adaptive reuse;
3. Indicators of direct environmental improvements due to the adaptive reuse; and
4. Indicators of indirect reductions to energy use or pollution due to the adaptive reuse.

The groups were developed inductively as a way to categorize the different indicators. Groups 1, 2, and 3 focus on direct impacts on materials, energy, and environment, due to the adaptive reuse respectively. Group 3 includes reductions to pollution, but also includes varied environmental improvements due to the adaptive reuse. An example of an improvement that is not a 'reduction' is new green areas with wildflowers that provide insect habitat and reduces the heat island effect of formerly paved areas. Group 4 encompasses indirect reductions to energy or pollution. An example of a Group 4 indicator would be the reduction of vehicle miles due to features of the adaptive reuse and the concomitant reductions in fuel use and related greenhouse gases. For example, repurposing an abandoned factory into a supermarket could reduce the distance that residents travel to purchase

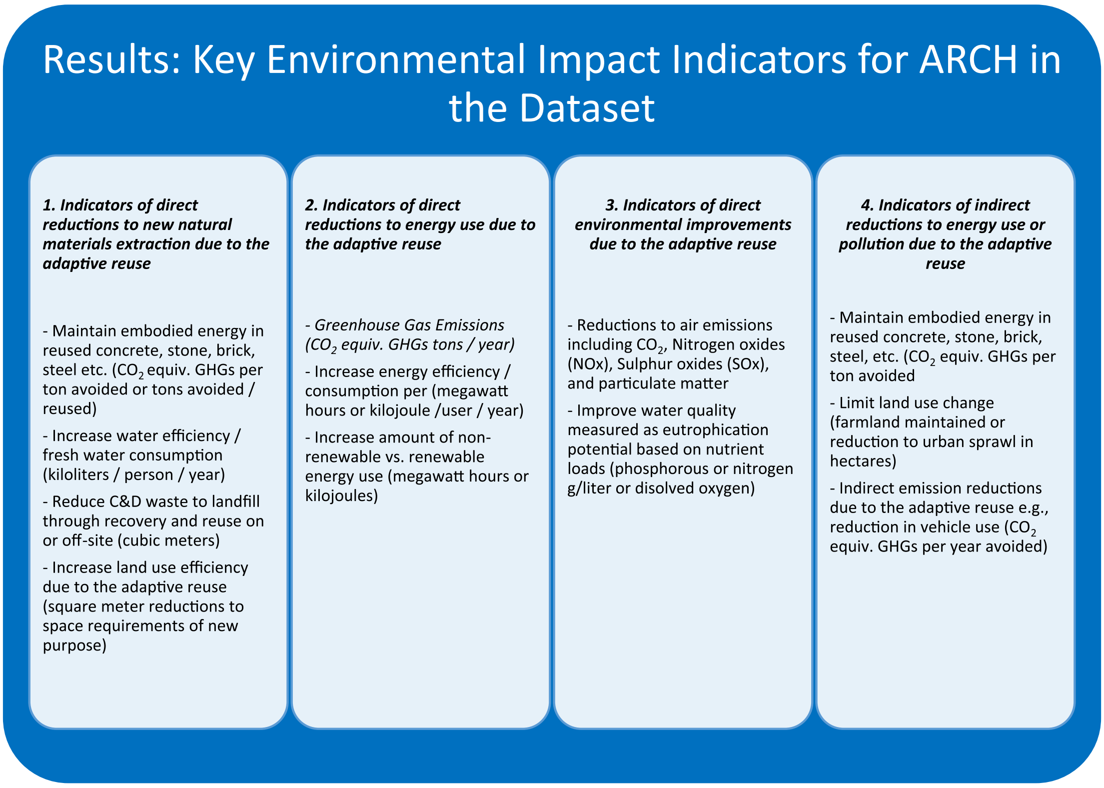

Figure 6. Synthesis of key circular environmental indicators prevalent in the dataset.

food. The direct versus indirect environmental impact groupings are proposed because separating indicators in this way aligns with LCA boundary setting norms and International Organization for Standardization recommendations. These, along with GBRCs, are the major governance frameworks that are currently applied to existing buildings. Therefore, this rubric is easily understood by practitioners from many disciplines.

The synthesis presents the key indicators in line with the stimulus for all environmental indicators, which is decision making. The desired direction of the trend shown by an indicator is guiding information for decision making. Therefore, each indicator is posed with its corresponding management objective. This also corresponds to how indicators are discussed and used in the dataset. For example, an indicator 'Limit land use change (farmland maintained or reductions to urban sprawl in hectares)' is not only referring to 'hectares' but hectares as a trend with the objective of limiting land use change. The synthesis of key Circular Environmental Impact Indicators for ARCH, with units of measure, in the database are organized by group in figure 6 (above).

6. Conclusions

CE initiatives are expanding at the global, European, country and city levels. Circularity is cited as a strategy to achieve several Sustainable Development Goals of the United Nations' 2030 Agenda through sustainable consumption and production. For example, see SDG 12 'Ensure sustainable consumption and production patterns.' (UN 2018:1) The European Commission adopted a Circular Economy Action Plan in 2015 with the aim of 'transition[ing] to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized… an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy.' (EC 2015:2) An institutional, governmental and multi-level policy framework of support for environmental CE measures is crucial to maintain focus on the core objectives of CE.

This article contributes an up-to-date synthesis of the key environmental indicators applied in the field, which heretofore was missing. It identified the key circular environmental indicators that are commonly used in ARCH over the ten-year period 2008–2017. The main conclusions of the review are that there is a gap between policy and practice and a gap between CE theory and common indicators. The findings and implications are summarized below.

- Concrete and measured environmental indicators are not mainstream, despite the pro-CE policy landscape. While narratives of environmental protection feature prominently in the literature, this has not yet translated into widespread use of environmental indicators. The findings indicate the existence of an environmental motivation for ARCH. This study provides a baseline. Repeating it in future would gauge progress when compared to today's baseline.

- LCA, EIA, and GBRC are prevalent environmental management frameworks that influence environmental indicators for ARCH. Future versions of LCA, EIA, and GBRC guidance could become explicitly CE through inclusion of additional indicators. The Dutch Green Building Society has already begun with its BREEAM proposal (Kubbinga *et al* 2018).
- The current ARCH environmental indicators do not routinely capture many of the basic materials reduction indicators of a CE approach. The practice of CE indicators for ARCH should be significantly expanded and standardized to better capture materials reduction. The findings indicate that governments can support training for ARCH architects, planners, and others to include CE environmental indicators in project scoping and design.
- CE is gaining importance on the local, national, regional, and global levels; however, many barriers to the implementation of CE policies for ARCH buildings at the project-level remain. Future practical research can explore how governments may encourage indicators to accelerate CE. For example, experiments may test implementing CE environmental indicators in government procurement criteria.

In summary, this study demonstrates that very few ARCH projects include adequate environmental indicator data. The major implication of the findings is that better CE indicators are needed by ARCH in the building and construction industry. At present, the quality and content of current indicators is insufficient for realizing the sustainability promises of CE.

In the future, ARCH buildings can contribute to sustainability with better environmental indicators as CE management tools. Examining the rapidly developing area of CE governance frameworks and industry frameworks, and filtering them for application to ARCH, will be the next step in this research thread, which ultimately seeks to encourage and support adaptive reuse of cultural heritage sites and buildings.

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Declarations of interest

None.

Data availability statement

The data that support the findings of this study are available upon request from the authors.

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