Circular economy for the built environment: a research framework

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Abstract

The built environment puts major pressure on the natural environment; its role in transitioning to a circular economy (CE) is therefore fundamental. However, current CE research tends to focus either on the macro-scale, such as eco-parks, or the micro-scale, such as manufactured products, with the risk of ignoring the additional impacts and potentials at the meso-scale of individual buildings. This article sets out to unpack the fundamental defining dimensions of a CE and frame them for CE studies for the built environment. A critical literature review forms the basis for identifying and framing such fundamental dimensions. Our contribution highlights the key roles of interdisciplinary research and of both bottom-up and top-down initiatives in facilitating the transition to 'circular buildings'. The frame for reference has been used to capture current discourse on the sustainability of the built environment and has proved to be a valuable tool to cluster existing initiatives and highlight missing links for interdisciplinary endeavours. The article represents a contribution to the theoretical foundations of CE research in the built environment and a stepping stone to shape future research initiatives.

1. Introduction

In the 1990s buildings were responsible for 40% of the material and a third of the energy consumed globally (Rees, 1999). Two decades later, the construction sector is still the world's largest consumer of raw materials, and accounts for 25-40% of global carbon dioxide emissions (WEF, 2016). In the interim period there have been numerous attempts to improve from this position, carried out with genuine fervour and heartfelt good intentions. 'Green buildings' were believed to be a panacea but it was later found that the sole focus on the operational stage of a building would not suffice to reduce its environmental impact. Whole life approaches were then put forward as the right pathway to sustainability[1], but despite the admirable intention to look at ecological threats and environmental impacts (ISO, 2006), the focus in the day-to-day practice within the construction sector has been rather circumscribed and most often limited to energy consumption and carbon emissions (Pomponi and Moncaster, 2016) without considering the risk of just shifting environmental impacts from one category to another (Pomponi et al., 2016). In spite of these efforts

[1] Sustainability in this article is intended as the consequence or manifestation of the concept of sustainable development – whose most common definition is that of the World Commission on Environment and Development: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland et al., 1987 p.43). It is worth remembering though that over time many more definitions of sustainability as well as sustainable development have arisen, which can also be contrasting with one another (Elliott, 2012).

building-related CO_2 emissions are continuing to rise, with the International Energy Agency (IEA) suggesting that emissions are on track to double by 2050 (IEA, 2014).

A new paradigm, circular economy (CE), is now gaining momentum, and it promises to overcome the contradiction between economic and environmental prosperity. There are many different schools of thought on the CE (Ellen MacArthur Foundation, 2016); however the shared founding principles lie in the better management of resources. The role of the built environment is therefore crucial, due to its high environmental impacts, which also conversely offer significant opportunities for reductions in energy use, greenhouse gas emissions and waste production.

Buildings are unique entities, as they are often the results of one-off projects. This feature adds to their inherent complexity, where each of the materials used has its own specific life cycle and all interact dynamically in space and time. Furthermore, their long lifespan, and changes of use during their service life, lead to increased uncertainty about future scenarios. Therefore, although buildings are made up of components which are manufactured products, when assembled together those products create an entity which no longer fits into the logic of manufacturing. From a CE perspective, current research tends to focus mainly on short-lived manufactured products (e.g. Singh and Ordoñez, 2016), and therefore the complexities that are inherent within buildings are often neglected.

This article aims to address such a gap, by providing a frame of reference for built environment research that is in harmony with the theoretical underpinning of a CE in order to achieve 'circular buildings'. This term is used to define a building that is designed, planned, built, operated, maintained, and deconstructed in a manner consistent with CE principles. A schematic view of the methodological approach used for this research is shown in Figure 1.

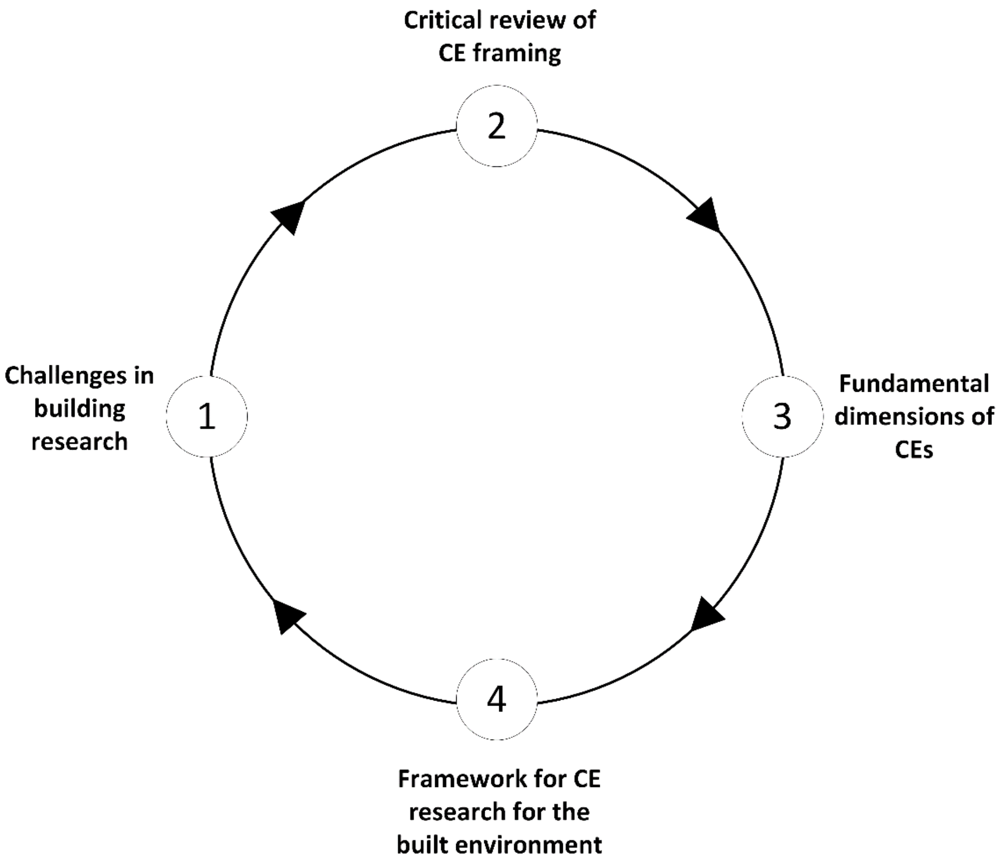

Figure 1 – Methodological approach of the research

The article is organised as follows. Section 2 frames the problem of assessing 'circularity' in buildings. We then move on to investigating the available tools and techniques to assess circularity (Section 3) and reviewing seminal literature to unravel fundamental dimensions of circular economies (Section 4). This represents the underlying basis we use to propose and discuss our frame of reference for CE studies for the built environment (Section 5). Section 6 concludes the article.

2. Building research and circular economies

Although literature on CE in the built environment is still in its infancy, the concept is gaining momentum in the construction sector. Some examples are the EU action plan on closing the loops (EC, 2015) which focuses on construction and demolition, and the UK Green Building Council work on materials, waste, and water (UKGBC, 2016). If on the one hand such initiatives promote the idea of a CE and spread the message to as wide an audience as possible, on the other they do not seem to represent a huge leap forward from existing research on construction and demolition from a mere LCA perspective (e.g. Carpenter et al., 2013). Focusing on resource consumption and efficiency as well as increasing rates of recycling or reuse might well not be sufficient to bring about 'circular buildings'.

Two aspects are worth considering when framing building research from a CE perspective. Firstly, solutions devised and engineered for short-lived products are unlikely to be applicable to buildings. The 'manufacture' and useful life phases of a building extend over a significant time span. Evidence of this can be found in figures about the existing building stock. In northern hemisphere countries, 75-90% of the existing building stock will be still be standing in 2050 (IEA, 2014). Data from comparable geographical areas (BPIE, 2011) report that, on average, more than 80% of existing buildings were built before 1990, and half of those before 1960. These numbers indicate average lifespans for buildings of at least 60-90 years, in line with those reported by Ma et al. (2015). If we are to bring about circularity in buildings, focusing on the new ones will not suffice. Secondly, buildings are constructed of standard manufactured products, but when these are assembled they create a unique, complex, long-lived and ever-transforming entity. The work of Frank Duffy and Stewart Brand (1994) on the shearing layers of buildings qualitatively highlights this aspect particularly well.

From a systemic point of view, buildings can be seen as a meso-level, the macro-level being urban agglomerates and the micro-level as building components (Figure 2). For the macro-level, research in terms of CE (although mainly limited to industrial symbiosis and urban metabolism) is more advanced within the concept of eco-cities (Roseland, 1997; Van Berkel et al., 2009), whereas for the micro-level current research on the material dimension (Braungart et al., 2007; McDonough et al., 2003) and circular Supply Chain Management (SCM) (e.g. Lacy and Rutqvist, 2015; Singh and Ordoñez, 2016) could suffice to bring circularity about. One such example is the use of sewage sludge ash (SSA) as a by-product for the construction industry at material level (Smol et al., 2015). Eco-cities and material/product-level research have one trait in common: both look ahead, which is to say that new solutions, which often rely on substantial use of new and high technologies, are proposed to improve the *status quo*. Such technological freedom and the wide use of new techniques becomes less relevant when the focus switches to buildings, where the high levels of existing stock require us to incorporate significant constraints.

A level of analysis which is currently lacking is the building as an entity per se. This is in stark contrast with the more standard practice of environmental impact assessment research, most often in terms of embodied energy and carbon[2], for which buildings rather than cities or materials are the most common level of analysis in current literature (Pomponi and Moncaster, 2016).

[2] Defined as the sum of CO_{2eq} emissions related to all activities and components other than the operational energy consumption related to a building's life. More generally, embodied costs or impacts may refer to different units such as energy, carbon, water, natural resource depletion, etc.

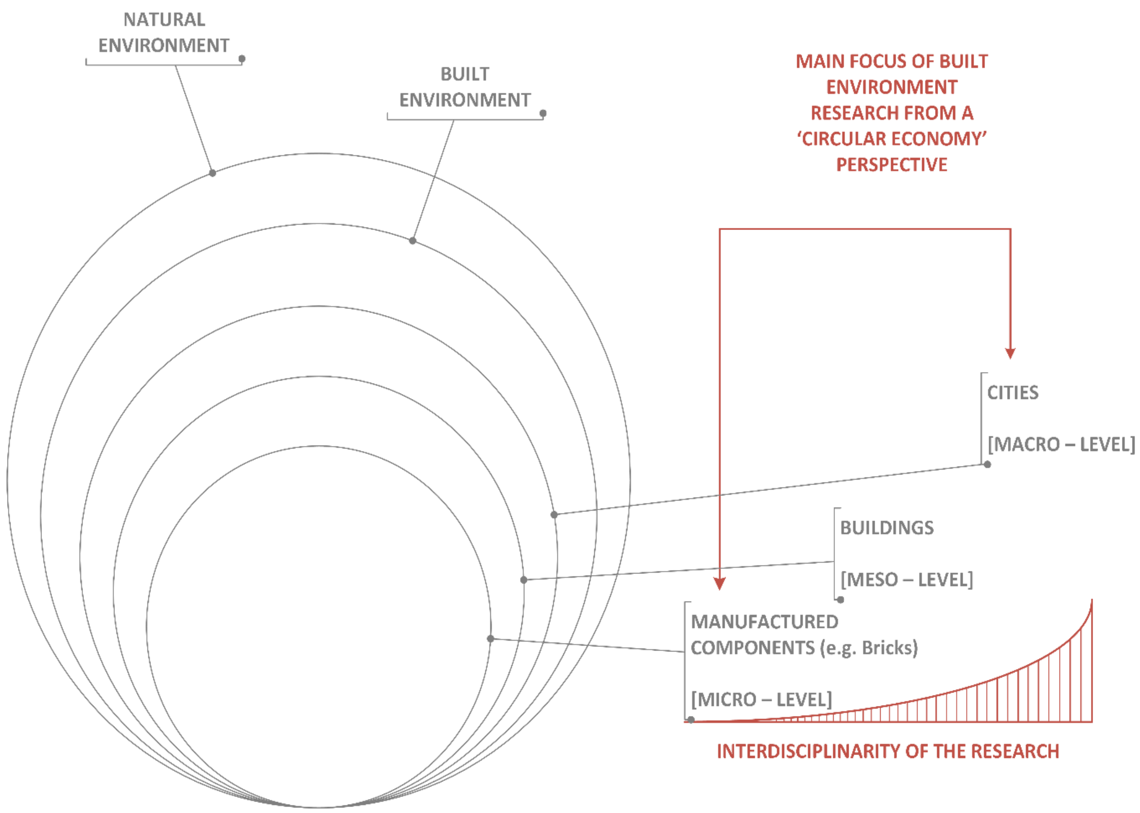

Figure 2 – Framing of built environment research

Figure 2 also shows a qualitative trend of interdisciplinarity in built environment research. From a methodological point of view, an interdisciplinary, if not a transdisciplinary, approach could be seen as essential. Built environment research is not a "discrete discipline with its own standard approaches to philosophy, methodology, and methods" (Knight and Turnbull, 2008 p.72); rather, built environment researchers often deal with blurry theoretical boundaries and draw their methods from across the spectrum of more well-defined disciplines, such as mathematics, social, natural and physical sciences, and arts and humanities (Knight and Turnbull, 2008).

In fact, however, only research at macro-levels (i.e. cities, neighbourhood, built environment) tends to acknowledge multiple disciplines. One example in this respect is the huge, though UK-centric, Sustainable Urban Environments programme (EPSRC, 2013) which aimed from the outset to have an interdisciplinary focus.

At the meso-level (building), the interdisciplinarity of sustainability research is more moderate, and three main strands are identifiable:

1. post-occupancy evaluation (POE) which considers the effectiveness of occupied environments for humans as users (Zimring and Reizenstein, 1980),

2. life cycle assessment (LCA) which could be seen as almost entirely techno-numerical although it aims to understand the impacts of human activities on the environment (Crawford, 2011), and
3. recent research trends on operational energy which has started moving from technical to techno-social, by including some thoughts about how people actually live in and use the buildings (Janda, 2011).

At the micro-level (component), interdisciplinary research is an exception with extremely few cases (e.g. Forman and Tweed, 2014) where the study goes beyond a mere technical point of view.

Therefore we see that at the fundamental level of the built environment, that of buildings, there is a lack of the interdisciplinary research which is critical for understanding and applying the Circular Economy.

3. Tools and techniques for building research in a circular economy

Life cycle assessment (LCA) and material flow analysis (MFA) are well established techniques for sustainability studies in the built environment which could both be extended to CE research. Genovese et al. (2015) adopted a hybrid LCA methodology in a study on sustainable SCM and CE whereas Chen (2009) promoted the key role of MFA to enhance the understanding of the economic dimension of a CE. Allwood and Cullen (2012) used MFA to map global flows of key materials, energy, and emissions, which allow greater confidence in exploring opportunities for efficiency and recovery. Wen and Li (2010) used MFA to explore possible measures to promote CE, and Wen and Meng (2015) utilised MFA to assess the impact of employing industrial symbiosis to achieve circular economies.

Ghisellini et al. (2016) reported the use of life cycle analysis to frame and assess the environmental performance of supply chain symbiosis in eco-industrial parks, and – already almost two decades ago – Fischer-Kowalski and Hüttler (1998) identified MFA as a powerful and indispensable tool for the analysis of environmental problems and socio-economic metabolism. To evaluate and measure circularity Braungart et al. (2007) promote a cradle to cradle (C2C) approach based on the idea that resources are ideally never turned into waste but are kept in the loop for as long as possible with minimal loss of quality. C2C design received criticism from Reijnders (2008) who sees closed loops as a source of increase in the emissions of biological nutrients which could surpass the limits that nature can absorb and therefore be potentially negative to the environment (e.g. eutrophication). Braungart et al. (2007) argue that LCA approaches are unsuitable for circularity measurement as, they claim, these are inherently linear. This is somewhat contrasted by Bakker et al. (2010 p.2) who, in conducting "a reality check" on C2C products, conclude that LCA and C2C can and should be used as complementary tools. For instance, the authors argue that C2C risks identifying all solar technologies as CO_2 neutral/positive whereas this might not always be the case, and find in LCA the appropriate tool to assess whether a specific solar technology yields a net carbon reduction over its life cycle (Bakker et al., 2010). Franklin-Johnson et al. (2016) acknowledge the importance of LCA assessment methods but also highlight some limitation and therefore develop a new metric that takes into account the longevity as a key element to measure circularity. The suitability of LCA for CE research, and specifically to assess circular systems, is also confirmed by Scheepens et al. (2016).

The use of Life cycle assessment (LCA) and material flow analysis (MFA) within disciplines such as industrial ecology have therefore represented the missing link in a harmonious orchestration of the technical, economic, and environmental dimensions of a system (Fischer-Kowalski and Hüttler, 1998; Frosch and Gallopoulos, 1989). After all, this was the very first intention of cross-sectorial disciplines, that is to represent the crucial "systems-oriented approach that integrates economic and environmental phenomena" (Lifset, 1997 p.1). Additionally, the breadth of study allowed by LCA and MFA—which can cover issues as diverse as a manufacturing plant, a whole country, and global flows of materials—is also particularly suited to an apparent contrast within CE research. This contrast sees on one hand economists identifying a problem of scaling up solutions to achieve monetary savings that would foster a wider implementation of techniques (e.g. Genovese et al., 2015; Lacy and Rutqvist, 2015) while, on the other, designers and naturalists plead for greater local foci and an even-greater respect of diversity (e.g. Braungart et al., 2007; McDonough and Braungart, 2002, 2013; Ulanowicz et al., 2009). The suitability of these techniques to consider and balance both scales is confirmed by many studies undertaken in the past few years.

4. Available framings of circular economy research

During the 70s and 80s—when most of the world was waking up to an awareness of the environmental limits of our planet (Brundtland et al., 1987)—few academics and thought-leaders were extending their thinking beyond what is still the current economic paradigm. The main innovation within the idea of a CE consists in decoupling resource depletion and growth, allowing that an ever-growing economic development and profitability can happen without an ever-growing pressure on the environment.

Nature and design

Back in the 1980s, Frosch and Gallopoulos (1989) called for a new industrial paradigm that would transform the then linear model into a more integrated industrial ecosystem. Their recommendation embedded inherent circularity, for they suggested effluents of industrial processes should serve as raw materials for other processes, so that "[t]he industrial ecosystem would function as an analogue of biological ecosystems" (Frosch and Gallopoulos, 1989 p.144). This principle resurfaced years later in more defined forms known as biomimicry (Benyus, 1997) and biomimetics (Bhushan, 2009) which, in their simplest meaning, refer to good design inspired by nature (Pawlyn, 2011). Biological analogies are also often found in the prolific work of William McDonough and Michael Braungart (Braungart et al., 2007; McDonough and Braungart, 1998, 2002, 2013; McDonough et al., 2003). Their work is perhaps the form of CE most familiar to the wide public. They identified the source of apparent incompatibility between industrial prosperity, environmental harmony, and economic viability in a human-specific activity: design. The key role of design towards increased durability of a product has also been investigated by Bakker et al. (2014). The importance of a different design paradigm can also be implicitly found in Fischer-Kowalski and Hüttler (1998). However, when they evaluated the possibility of closing open cycles they concluded that "[u]pon closer scrutiny it is obvious […] that this option applies only to a narrow range of materials and processes" (Fischer-Kowalski and Hüttler, 1998 p.120). McDonough and Braungart hold instead a much broader view on the topic and developed a design framework based on two circular loops, the technical and biological cycles, where resources are kept in for as long as possible, with minimal loss of quality and leakage. This 'C2C' design materialised as a certification program for businesses, and the underlying principle has since been adopted by the Ellen MacArthur Foundation (2013).

Resource efficiency and technological advancement

McDonough and Braungart (2013) suggest that design imbued with intelligence, which separates biological and technical nutrients, will not only solve the current scarcity of energy and materials, but could even result in an abundance. Their fundamental redesign of industrial flows switches from mainstream eco-efficiency (doing less bad) to eco-effectiveness (doing good). A similar scepticism over an ever greater efficiency as a pathway to sustainability is argued by Ulanowicz et al. (2009) who used information theory to quantitatively call for caution in maximizing efficiency in any field, whether it is physics, economics, or ecology. The reasoning underpinning their method of analysis may resemble the biomimicry philosophy at a first sight, but it bears a fundamental difference. While biomimicry suggests learning from nature to inspire design, Ulanowicz et al. (2009) encourage us to transfer our understanding and modelling of natural elements (such as ecology and ecosystems) to more human concepts such as economies. This is clarified in later work by the same authors (Goerner et al., 2009 p.76) where a measure called Quantitative Economic Development (QED) is developed to provide a mathematical basis to support "current theory [which] fails to differentiate healthy development from mere growth". Overall, they use System Science as the method of analysis for a sustainable economic development since "similar energy concepts and network analysis methods can be applied to all matter-energy-information flow systems because […] such systems exhibit strong parallels in behavioural patterns and developmental dynamics" (Goerner et al., 2009 p.76-77).

However Amelung and Martens (2008) see C2C as a technical fix which seeks solutions for the technological and material realms without taking into proper account societal and cultural dimensions. A critical investigation into the ideal of a CE and the "messy world" is given by Gregson et al. (2015 p.235) who conclude that, whilst the idea of decoupling economic growth from resource consumption is a laudable attempt, its current implementation, especially in EU policy, resembles a subjective approach which neglects the real challenges of waste recycling and the role of international waste markets and flows.

It seems therefore that current critiques of the CE hold it responsible for a sometimes simplistic approach which does not really address societal and political challenges or the complexity of human nature. This suggests that it is time to engage in a wider discourse with other scientific realms in order to contribute their own research perspective. Such a call is not new; fifteen years ago Boons and Roome (2001 p.51) made a plea for an integration of the research components of industrial ecology with those of good social science. Their view echoed a longstanding syllogism from Dolby (1971) who recognised a sociological and cultural relativity in all scientific knowledge claims. He believed that "it is only when different groups with different theoretical approaches to similar problems are exposed to one another in scientific debate […] that contrasting presuppositions become clear" (Dolby, 1971 p.10).

In a CE context, Dolby's view resonates with the words of Gregson et al. (2015 p.219) who argue that academics and practitioners tend to use the concept in an "approbatory, uncritical, descriptive and deeply normative" fashion. CE can therefore appear dogmatic (Bakker et al., 2010) in the belief that having devised a solution implicitly means having solved the problem. Such strong faith in the effectiveness of a technical fix (Amelung and Martens, 2008) resembles the truth claims of the positivistic philosophy of science which neglects the interdependence between knowledge production and social origins of belief (Dolby, 1971). More recent trends see scientific research as an inevitably value-laden activity (Gonzalez, 2013).

Recycling, reuse, green supply chains and waste reduction

Not all scholars see social or behavioural issues as something that has to do with circular economies. An example is the framing of Sauvé et al. (2015) who do not see CE as having any social objectives, but rather as a system which focuses on reuse and recycling as substitutes for raw virgin materials. Some degree of similarity can be found in the work of George et al. (2015) who place recycling at the core of a macroeconomic model for circular economies. However, George et al. (2015) do have a social objective function which aims to maximise social welfare by optimising resource consumption and pollution.

To enable these flows of materials and resources whilst guaranteeing economy growth, some scholars see a key role in the broad spectrum of sustainable supply chain management thus awarding a predominant role to the economic dimension (e.g. Genovese et al., 2015; Lacy and Rutqvist, 2015). However, whilst Genovese et al. (2015) seem inclined towards refining current practices within 'green' SCM, Lacy and Rutqvist (2015) foresee and actively work towards a whole rethinking of the SCM *status quo* to meet the new challenges posed by CEs. A strong economic dimension also emerges from the work of Abu-Ghunmi et al. (2016) who feel that an environmentally beneficial activity has to be firstly economically viable and profitable. Slightly different is the framing of Lieder and Rashid (2016), which has a strong focus on environmental issues (both at impact and resource scarcity levels) whilst however acknowledging an important role of the economic benefits.

The substantial contribution from Lacy and Rutqvist (2015) keeps a strong focus on the competitive advantage companies would achieve if they embraced a CE perspective, which the authors call the 'circular advantage'. Their work is deeply rooted in an analysis of waste in our society, which they identify in four different forms: wasted resources, wasted lifecycles, wasted capability and wasted embedded values. These are then tackled through five circular business and supply chain management models which require a radical "rethink of the relationships between markets, customers, and natural resources" (Lacy and Rutqvist, 2015 p.XV). Whilst their work is instrumental towards a practical implementation of successful CE models, it looks nonetheless incomplete to frame CE as a new paradigm that would benefit society at large. A practical example of such narrow focus is that of considering a remarkable success diverting 150 tons of daily food waste for a US company that was "a major cost in terms of lost revenue and disposal fees" into "inexpensive and clean energy that powers a 49-acre campus housing offices" (Lacy and Rutqvist, 2015 p.58).

Such view seems lacking the necessary holistic attitude for sustainability, which would perhaps avoid food waste and reduce the power needed in offices rather than diverting food waste from landfill to become an expensive form of biomass to power buildings.

Policy, people and society

Overall, most current CE research seems characterised by a partial approach which does not truly account for the complexity of all the dimensions involved. This seems confirmed by Sauvé et al. (2015 p.7) who see CE as a useful tool for sustainable development but argue that its “final objective remains unclear and certainly narrower than sustainable development”. Similarly, Andersen (2007) identifies the need for CE to extend its focus to embed broader issues of sustainable development in its trajectory. His view is society-centric: if the cost of one more circular loop for a material/waste flow exceeds the benefit to the society it should not be promoted (Andersen, 2007). The views of Huamao and Fengqi (2007) are also anthropocentric, considering as the ultimate goal the realisation of *human beings’* sustainable development.

The work of Naustdalslid (2014) pairs policy and technology and warns that an excessive focus on materials and their optimisation may underestimate the key role of stakeholder involvement and societal participation to implement CE successfully. The role of society emerges also in a broad discussion on the necessary system perspective for CE by Webster (2013) who emphasises the fundamental part played by education. To successfully transition to a CE, he pleads for more participatory, feedback-rich teaching and learning experiences or education will end up “ineffectively teaching the irrelevant to the uninterested.” (Webster, 2013 p.553).

The need for moral and psychological adjustments was already very clear half a century ago to Boulding (1966) who saw them as indispensable and instrumental in the transition to an embryonic version of CE, which he called closed sphere. As a precursor of the importance of flows and connections underscored by Webster (2013), Boulding (1966) already believed that knowledge (or information) was far more important than matter because, in his view, matter only acquires meaningfulness to humans when becomes the object of our knowledge.

A further element seldom considered in framing the CE is people’s behaviour. This has been flagged by Smith (2014) who recognises the crucial role of behavioural studies, “even before we arrive at design and repair because it may be the case that people do not want to repair that specific thing”. The influence of behavioural aspects on the diffusion of product services for a resource-efficient and CE have also been considered by Tukker (2015). A similar behavioural dimension for circularity, in a customer-centric perspective, emerged in the review of Ghisellini et al. (2016) who researched collaborative consumption models and in van Weelden et al. (2016) who explored consumers’ acceptance of refurbished products in the Netherlands.

A further important aspect is the role of policy towards successful circular economies, which Huamao and Fengqi (2007) see as a fundamental block. Policy is also discussed in Geng and Doberstein (2008) who identified barriers and challenges in terms of technology and public participation. Barriers are also one of the points considered by Genovese et al. (2015) who see government bodies as facilitators to overcome them in economic and industrial systems. The opportunities for policymakers to implement CE are also discussed in Esposito et al. (2015) who looked at the practical levers such as tax, laws and regulatory frameworks within specific industrial sectors or the society at large. Regarding the latter group, however, a very western-centric view emerges in Esposito et al. (2015 p.2) who maintain that the ultimate goal of a CE is "to preserve *our* current way of life by making it technically viable for the longer term by producing within a closed system". This statement neglects the fact that there is no such thing as a *global* current way of life but rather a very comfortable life in developed countries which we want to hold to as tightly as possible. A concept, which resonates with the views of Gregson et al. (2015 p.236) who see CE "as a form of geo-political insurance; in a world where rampant economic growth in the developing world threatens the stability of economies long accustomed to having resources their own way". A similar viewpoint comes from Kerschner (2010) who reflected on the popularity that de-growth (*decroissance*) concepts (see e.g. Georgescu-Roegen, 1977; Latouche, 2007) regained a few years ago and concluded that economic de-growth and growing economy are not mutually exclusive but, in fact, complements, where "de-growth is not a goal in itself, but the rich North's path towards a globally equitable South" (Kerschner, 2010 p.544).

Meta-analysis

Table 1 shows a meta-analysis of the literature reviewed. In rare cases, the focus on CE was mono-dimensional whereas we often found a link to the three pillars of sustainability: economy, environment, and society. However, it appears that at least three more defining elements are not explicit in the triple bottom line view, though they were all mentioned—in a more or less explicit way—in some of the current literature on the topic. They are: the role of governments (i.e. policy), the role of matter (e.g. design, technology, materials), and the role of individuals (i.e. behavioural). All of these are pivotal for the success of a global system such as CE and should be warranted equal attention and merit to the other three. In addition to the six dimensions discussed, Table 1 also includes both bottom-up and top-down approaches as they appeared in the literature. Whilst the majority of the studies reviewed suggested one approach over the other there have been a few which did not see them as mutually exclusive and, in fact, as both necessary to a successful implementation of a CE.

Table 1 – Meta-analysis of existing CE framing

REFERENCES	APPROACH (TD = Top-down; BU = Bottom-up; U = Undefined)	CIRCULAR ECONOMY DIMENSIONS: Economic	Environmental	Technological	Societal	Governmental	Behavioural	TOTALS
Boulding (1966)	TD, BU	x	x	x	x			4
Frosch and Gallopoulos (1989)	TD		x	x				2
Benyus (1997)	U		x	x				2
Fischer-Kowalski and Hüttler (1998)	TD			x	x			2
McDonough and Braungart (1998)	BU		x	x				2
McDonough and Braungart (2002)	BU		x	x				2
McDonough et al. (2003)	BU	x	x	x				3
Anderson (2007)	TD	x	x	x	x			4
Braungart et al. (2007)	BU	x	x	x	x			4
Huamao and Fengqi (2007)	TD, BU	x	x	x	x			4
Geng and Doberstein (2008)	TD	x	x	x		x		4
Bhushan (2009)	BU			x				1
Goerner et al. (2009)	TD, BU	x	x		x			3
Ulanowicz et al. (2009)	U	x	x		x			3
Ellen MacArthur Foundation (2013)	BU	x	x	x	x			4
McDonough and Braungart (2013)	BU	x	x	x	x			4
Webster (2013)	TD, BU	x	x	x	x			4
Naustdalslid (2014)	TD	x			x	x		3
Smith (2014)	BU				x		x	2
Esposito et al. (2015)	BU	x	x	x		x		4
Genovese et al. (2015)	TD, BU	x	x	x		x		4
George et al. (2015)	TD	x	x		x			3
Gregson et al. (2015)	TD, BU	x	x	x				3
Lacy and Rutqvist (2015)	U	x		x		x		3
Sauvé et al. (2015)	BU	x	x	x	x			4
Ghisellini et al. (2015)	TD, BU	x	x	x	x			4
Lieder and Rashid (2016)	TD, BU	x	x					2
TOTALS		20	22	21	15	5	1	

5. Circular economy and the built environment

The previous section has shown how authors from different disciplines view CE. In this section we propose a framework for CE research for the built environment which builds on the outcome of the critical literature review of the previous section. Additionally, we tie it up to the current discourse in construction sector practice to evaluate whether the framework can be a support for researching the benefits and challenges of a CE.

5.1 Defining dimensions of circular economies: a research framework

Figure 2 presents the proposed framework. The idea of a 'six pillars' framework is based on the fact that to successfully meet the goals of today's sustainability research it is necessary to combine the use of different disciplines, such in transdisciplinary research (Kajikawa et al., 2014).

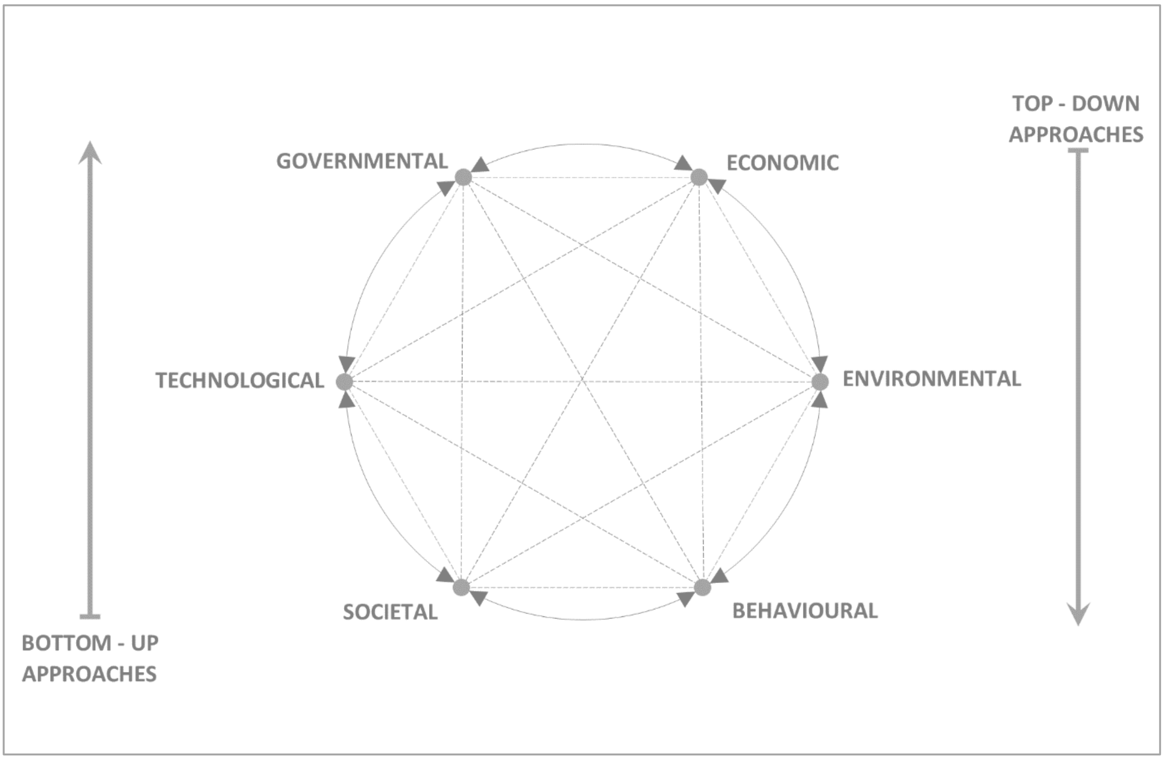

Figure 2 - Frame of reference: six dimensions for building research in a circular economy

Firstly, the peripheral arrowed arcs represent the need for a holistic approach and a harmonised collaboration of research initiatives in each of the six pillars. Secondly, the inner dashed lines stress the importance of practical links between each pillar and the others. In some cases, indeed, not all research dimensions may be needed in practice and the framework also allows for sub-groups of two, three, four, and five dimensions. Top-down and bottom-up approaches are considered equally as the impact of grassroots innovation could be equally important to that of forward-thinking governmental policies.

Those six dimensions also concur to frame the development of building research over time, as Figure 3 shows. It can be seen that initial research on green buildings merely focused on technology and environment has now evolved to that on sustainable buildings. The different height in the blocks of Figure 3 aims to represent the growth of building research - especially in its breadth and remit – rather than the relative importance of the research dimensions.

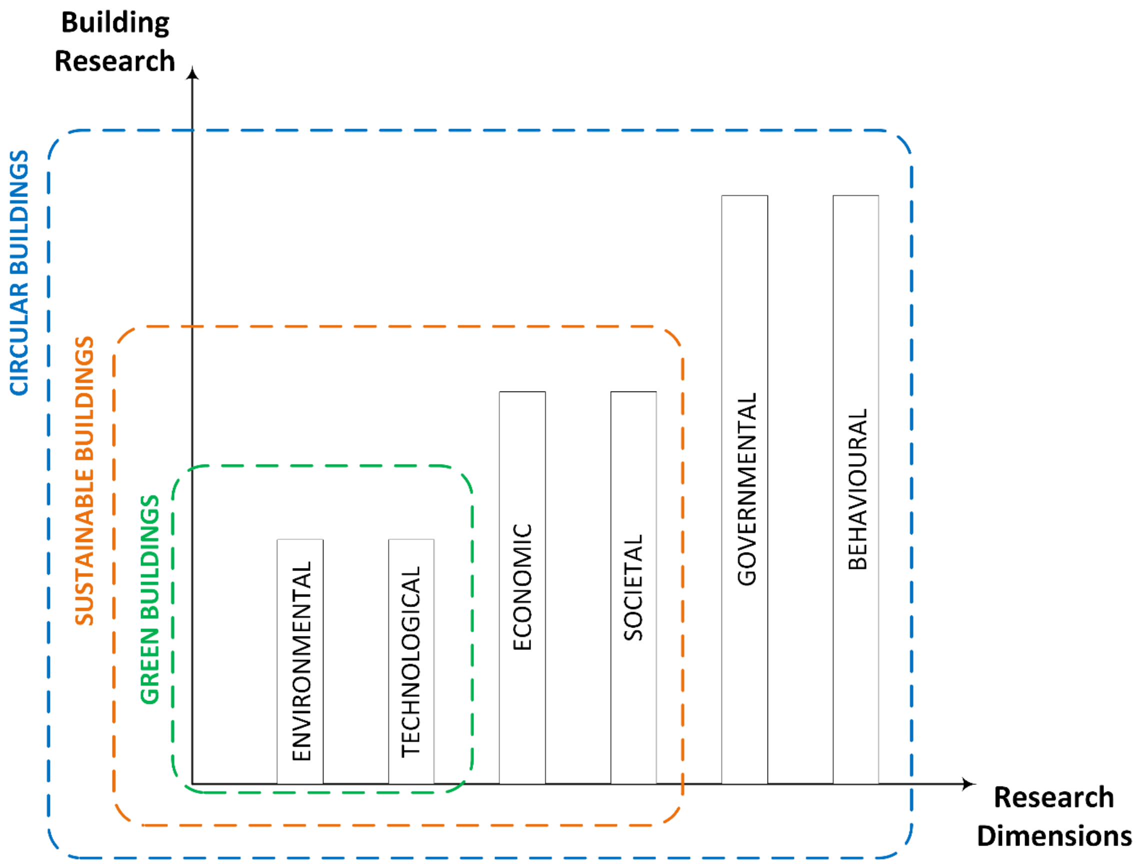

Figure 3 – Evolution and research dimensions of building research

5.2 Current discourse in the built environment

In order to verify the dimensions considered in the literature and test the relevance of the framework, we attended a number of events in London between late 2015 and early 2016 themed around the topic of CE and the construction sector. This helped us to identify the current issues of concern, and to assess whether they were adequately described by our framework in order to evaluate its use as a supporting tool for CE research in the built environment.

Governmental dimension

From the events attended it was clear that a strong voice has emerged pleading for government and policy support. In discussing the barriers to steel reuse in construction, for example, Roy Fishwick (Corbey et al., 2016) highlighted the role that policy can play, as current market prices for steel are so low that steel reuse is hardly economically viable. Additionally, he reported on a lack of will at EU regulatory level that he considered could kill steel reuse. At a lower geographical level, Cécile Faraud (2016) reported on initiatives of planning authorities to achieve CE, focusing on the aim of Peterborough in England to become a circular city. She stressed the difference between Peterborough and the initiatives of worldwide metropolis; whereas cities like Amsterdam, Glasgow and Copenhagen are applying CE principles to cities, Peterborough believes conversely that a circular city is the pathway to a CE (Faraud, 2016). Faraud also stressed the need for planning authorities to be aware of their local context, to make sure they understand the diversity and individual nature of the challenges ahead (Faraud, 2016). At a national policy scale, Katherine Adams (2016) discussed the importance of tax breaks to encourage more use of reclaimed material in buildings.

Economic dimension

The need to change current ownership models and develop a different paradigm for profitability has been a recurring topic over the last two years (e.g. Chamberlin, 2015; Cheshire, 2016; O'Connor, 2015). David Cheshire (2016) gave an example of lighting systems that are not owned by the building owner/occupier anymore, who just pays for the lighting service through an agreement that also includes performance. Other case studies of building projects used collaborative models between all contractors and sub-contractors involved from the outset, rather than basing the choice of such key actors on the cheapest tenderer at the end of the supply chain (Cheshire, 2016). Erica Purvis (2015) encouraged more collaborative business models and more openness about relevant data to promote quicker feedback/feed-forward loops.

Environmental dimension

Discussions about the environmental aspects stressed the lower environmental impacts that reuse has over new products, such as in the cases of steel (Corbey et al., 2016) and wood (Adams, 2016). While most of the current published research on built environment sustainability focuses on whole life energy and carbon as impact categories (Pomponi and Moncaster, 2016), such an approach can miss out on other, equally crucial, environmental indicators with the risk of shifting environmental burdens from one impact category to another (Pomponi et al., 2016). Therefore, whilst an exhaustive list of environmental indicators is neither desirable nor necessary, the majority of environmental impacts should nonetheless be considered (Steinmann et al., 2016).

Behavioural dimension

The behavioural dimension, seldom discussed in CE literature, emerged as a key element in current discussions as a route to a breakthrough in built environment sustainability. It was identified as instrumental for success in the uptake of recycling (Overbury, 2015), energy and carbon reduction (Daly, 2015), knowledge on low-carbon buildings and technologies (Fieldhouse, 2015), and people’s attitude towards reused material (Adams, 2016; Corbey et al., 2016; Khoo, 2015; Overbury, 2015; Owens, 2016). Similar issues are also encountered in furniture sharing and reuse (Beavis, 2015; O'Connor, 2015). Roy Fishwick (Corbey et al., 2016) sees behavioural issues as one of the two biggest threats to CE uptake and steel reuse in buildings, since “people do not want to buy steel for their brand new shiny building from the scrapman”. Quite to the contrary, Adams (2016) reported that attractiveness and aesthetic appeal scored as the top criteria for people choosing reclaimed wood, which suggests that behavioural patterns differ depending on the material under consideration. There is clearly a strong need to accelerate behavioural research in built environment sustainability; it is apparent that it is people, rather than technologies, who are the key to embracing circularity.

Societal dimension

The CE is sometimes referred to as the 'sharing economy', highlighting its strong social roots. This often involves partnerships and collaboration in building projects (new and existing) and a wider engagement with all involved stakeholders (Daly, 2015), networks for resource sharing and reuse (Beavis, 2015; Faraud, 2016), and a different approach to building's design (Cheshire, 2016; Greenfield, 2016). In the literature review we have seen that education also has a crucial role, and this seems particularly important for example in learning to design and build with reused and reclaimed materials.

Technological dimension

Technology repeatedly emerges as a key aspect to enable circular loops, to connect demand and supply, and to handle, store, and manage the huge amount of data that a CE requires. Examples of the latter are online platforms and web-based apps for resource sharing (Khoo, 2015; O'Connor, 2015; Owens, 2016). Technological innovations in manufacturing and operations can also have enormous impacts, such as mortar-less 3D printed bricks and cardboard ductworks (Cheshire, 2016), Design for Manufacture and Assembly (DfMA) (e.g. Laing O'Rourke, 2016), or Design for Deconstruction or Disassembly (DfD) (e.g. Adams, 2016; Densley Tingley and Davison, 2011).

Boundary conditions

In addition to the six dimensions discussed our framework also includes both bottom-up and top-down approaches as boundary conditions. Examples of top-down approaches are CE programs at EU level (EC, 2015; WRAP, 2013) or those developed at national (UKGBC, 2016) or regional scale (Faraud, 2016). Bottom-up initiatives have equally proven their effectiveness such as the case of grassroots innovations for circular economies (Charter and Keiller, 2014; Smith, 2014).

5.3 Synopsis

Concrete proposals for a different approach are widely available for the technological dimension and, to a lesser extent, for governmental and policy frameworks and environmental assessment metrics. The greatest challenges that lie ahead will deal with the role of people, both as individuals and as society as a whole, and that of new economic models to promote and implement circularity. Interdisciplinary research is essential to solve these challenges, for its ability to switch from a narrow technical focus to a wider research basis, without sacrificing depth for breadth.

One final example is the consideration of the durability of houses and buildings. Here the problem is not merely technical know-how; in fact, it turns out to be scarcely technical at all. The Pantheon was built in 117AD, and it is still usable and indeed used today. Yet, despite a steady technical development, housing and building construction has severely declined in durability (Boulding, 1966). As Boulding (1966 p.12) worded it, "I suspect that we have underestimated, even in our spendthrift society, the gains from increased durability".

Current technology would certainly allow us to build more durable buildings, and the benefits for the environment in terms of resource conservation and waste reduction are undeniable. And yet, there are numerous cases of buildings of 30/40 years that are being demolished (e.g. Cheshire, 2016). Building research will have to engage with all relevant stakeholders to understand why this is so, and the reasons behind believing that demolition is an appropriate choice. It is likely that the answers will be multiple and complex, and therefore the contributions that different disciplines can offer will be pivotal to achieving a real understanding.

6. Conclusions

The built environment is the sector which puts the most pressure on the natural environment and its role in transitioning to a CE is pivotal. In framing building research from a CE perspective there is a lack of focus on buildings, with most research designed either around cities and neighbourhoods or construction materials. There is also a reduction in interdisciplinary research related to the scale of analysis. We have therefore framed the problem on a three-tier level: macro (cities and neighbourhoods), meso (buildings) and micro (assemblies and components). To understand in which ways building research could be shaped by the CE, we first reviewed the seminal literature in CE to identify different dimensions emerging from different disciplinary backgrounds. The outcome is a frame of reference in which we propose six fundamental dimensions for CE research in the built environment. The framework has then been applied within CE-themed events in the construction sector in order to evaluate its capability to capture current challenges in embedding CE principles in the built environment. The framework demonstrated that it included the key elements of current initiatives, ideas, and approaches to achieve more 'circular buildings'. It is therefore proposed as a useful starting point for researchers and practitioners alike with an interest in CE and the built environment.

The initiatives themed around CE in the built environment however demonstrated little interdisciplinarity underpinning the complexity of such transition. We would therefore encourage a significant increase in interdisciplinary research on the role of buildings in a CE and vice versa. Evidence from practical examples have indeed shown that the greatest challenges ahead lie not in further technological innovation but rather in the role of people, both as individuals and as a society. Future research should explore in greater detail the links between technological and societal challenges to come up with solutions that are well received and correctly utilised by the intended users. Research into the role of policy measures to promote circularity should also be furthered as well as that looking into environmental and economic viability of solutions for a successful and sustainable transition to a circular built environment.

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