Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 00 (2018) 000–000

www.elsevier.com/locate/procedia

26th CIRP Life Cycle Engineering (LCE) Conference

Barriers and drivers in a circular economy: the case of the built environment

Jim Hart[a], Katherine Adams[b], Jannik Giesekam[c], Danielle Densley Tingley[d], Francesco Pomponi[a,*]

[a] *Edinburgh Napier University, Resource Efficient Built Environment Lab (REBEL), 10 Colinton Road, Edinburgh EH10 5BT, UK*
[b] *Loughborough University, School of Architecture, Building & Civil Engineering, Ashby Road, Lougborough, LE11 3TU, UK*
[c] *University of Leeds, School of Earth and Environment, Leeds LS2 9JT,UK*
[d] *University of Sheffield, Department of Civil & Structural Engineering, Mappin Street, Sheffield, S1 3JD, UK*

* Corresponding author. Tel.: +44 131 455 3590. *E-mail address:* f.pomponi@napier.ac.uk

Abstract

The circular economy has moved quickly from niche conversations to mainstream attention. Reports, white papers, academic articles, and guidance are produced in rapid succession, and the world's first standard on circular economy for organisations has been realised. Most of this body of knowledge has a broad focus, but sectors and products differ, and if circularity is to materialise, a more tailored understanding and approach is necessary. This paper focuses on the built environment, where its constituting elements (buildings and infrastructure) are characterised by long lifespans, numerous stakeholders, and hundreds of components and ancillary materials that interact dynamically in space and time. To facilitate the pathway towards circularity, we have attempted to identify the barriers to and enablers for the circular economy within the built environment. This will form the basis of future work to build consensus on the future development of the circular economy. Technological and regulatory developments alone will not suffice, and a shift is required in business models and stakeholders' behaviours and attitudes.

Peer-review under responsibility of the scientific committee of the 26th CIRP Life Cycle Engineering (LCE) Conference.

Keywords: circular economy; built environment, building materials, sustainable construction; materials reuse.

1. Introduction

1.1. The Circular Economy

A Circular Economy (CE) can be said to be one *'that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times'* and aims to decouple economic growth from resource consumption [1]. By maintaining the value of materials and keeping them in circulation, CE is seen as a way to reduce our reliance on material extraction and as a condition for the continuation of our current way of life. As such there is an impetus to address CE principles across business disciplines.

1.2. The Circular Economy – impediments to progress

After decades of discussion and research around CE and related concepts (e.g. Industrial Ecology, Industrial Symbiosis, Industrial Ecology, Cradle to Cradle), the make-use-dispose model of resource consumption (frequently with a brief – or even absent – use phase) is still deeply entrenched, at the expense of the circular model of resource stewardship. It is clear there must be barriers to a more circular economy, and there is a small but growing body of literature devoted to this. The assumption is that the more of these barriers that can be dismantled or bypassed, the better the progress will be towards

Peer-review under responsibility of the scientific committee of the 26th CIRP Life Cycle Engineering (LCE) Conference.
doi:10.1016/j.procir.2017.04.009

CE. Therefore certain enabling actions ('enablers') must be implemented, both to promote better conditions for CE generally and to deal with individual challenges.

How do we know what the barriers are and how important they are? Academic literature tends towards an objective approach to identifying barriers and enablers and establishing their importance, through consultation [2,3] or through systematic review of published case studies [4]. Papers from the industry, on the other hand, tend either to focus on the lessons from specific cases [5,6] or to read more as manifestos for CE, with many barriers and enablers name-checked [7]. But however systematic and objective the approach, an element of subjectivity remains. The frequency with which a barrier is identified does not necessarily correlate with its importance. Whether or not a barrier is recognised as such depends on who one asks: a barrier identified by a policy maker might not be recognised by a business representative [2]. Similarly, enablers and barriers can be viewed differently by representatives of different business functions; by different parts of the value chain within the built environment; or by 'engaged' businesses as opposed to typical businesses [4].

Many barriers and enablers referred to in the literature are not only applicable to CE, they apply equally to success in the linear economy. For instance, if one asks almost any SME whether access to finance (investment, bank loans, etc.) is a barrier to something – as identified in [4] – the answer will be along the lines of 'do one-legged ducks swim in a circle?'

2. Categorisation of barriers and enablers – as reviewed

For this paper, relevant academic and industry literature concerning challenges in developing CE has been reviewed, mostly concerning the built environment. References to barriers, challenges, enablers or drivers, whether explicitly stated or implied were noted and categorised. Any broad discussion on barriers and enablers is likely to face the question of how to categorise them, and there are many dimensions to explore, as discussed below. Some observed aspects of barriers and enablers:

2.1.1. Focus

Some factors are relatively specific to the built environment (e.g. very long product life); others focus on a relatively narrow point (e.g. VAT); and others relate to CE more generally (e.g. lack of understanding across the whole value chain).

2.1.2. Connections

Barrier-enabler pairings are evident in several forms. In some cases, barriers and enablers are mirror images (e.g. the barrier is the absence of the enabler): inevitably this leads to overlap in discussions about barriers and enablers. Some enablers are designed to target specific barriers, whilst others are discussed as ways to improve conditions for CE generally, potentially resolving multiple barriers. Additionally, chains or networks of enablers and barriers might be envisaged, with enablers facing their own barriers: for example, materials passports are an enabler to address barriers concerned with recovering value from resources at the end of life, but there will be further barriers to the adoption of such tools.

2.1.3. Incomplete enablers

Many identified enablers need some form of – usually unspecified – enabling support themselves. Such enablers tend to be stated vaguely, and/or focus on what must happen (e.g. more transparency in the value chain) rather than the action that needs to be taken to get that result. The shorthand we use here is GOWI (get on with it).

2.1.4. Uncertainty about the status of an aspect

Some factors might either help or hinder progress towards CE depending on the context, so we cannot know whether to class them as barriers or enablers. 3D Printing is an example, as acknowledged by Despeisse et al [8], on account of the diverse attributes that the technology possesses and the many kinds of activity, both beneficial and harmful in terms of resource consumption, that the technology can enable. Circular Business Models (CBMs) are routinely represented both as enablers and as facets of CE, but arguably they also fall into this uncertain category. Taking the car industry as an example, we can assume that Personal Contract Plans (a way of selling X miles of driving in Y years at an agreed price) have *not* been put in place by the industry to reduce vehicle production or to reduce gross vehicle-miles on the road. And in the built environment, stated enablers such as 'alternative ownership models including leasing and performance models' [7] are not always backed up with evidence of benefit. The 'pay-per-lux' model for lighting is often cited in this respect, but *Circular Models for the Built Environment* [9] caveats its endorsement of such business models with an observation that the performance contract alone is not enough – all aspects of the light fittings must be designed to take account of future demounting, disassembly and upgrade. Or, as Pauliuk puts it [10]: *'...there are business models which have the potential to 'fit' within a CE system. Unless the wider systemic context is considered... they are simply new or reimagined BMs operating within the prevailing linear economy.'*

2.2. Categorisation in the literature

As indicated in section 2.1, there are many ways to think about barriers and enablers to a more circular economy, and examples can be observed in the literature. A system suggested by de Jesus and Mendonça [11] divides barriers and enablers into soft (institutional and social) and hard (technical and economic) categories. Kirchherr et al [2] opt for cultural, market, regulatory, and technological categories, with the 'cultural' category taking care of most of the 'soft' factors. The categorisation is helpful in identifying four fronts on which progress must be made in order to progress towards a CE, but allocation is not always clear cut. For instance, the article identifies 'too few large-scale demonstration projects' as a technological barrier (defined as *'lacking proven technologies to implement CE'*); other articles identify a lack of convincing case studies, but this might equally be seen as a market barrier (the case for such projects cannot be made in a convincing way because of market factors), a cultural barrier (unwillingness to share the most useful details in a case study) or a combination of categories including an absence of a universally adopted on-line forum. The broad categorisation in this case – with no

reference to any particular sector – may not be so helpful in drawing attention to the necessary enablers.

In their construction industry survey Adams et al [3] map identified circular economy aspects onto building lifecycle stages, and barriers and enablers are discussed under the following seven headings: legislation and policy; awareness and understanding; manufacture of construction products (design for end of life); designing and operating buildings (design for disassembly, adaptability etc.); recovery of materials and products (market mechanisms); business (Circular Business Models - CBMs, contracts, metrics); economic (the financial case for CE).

In a pair of industry papers authored at least in part by Arup, whilst formal categorisation is not attempted, it is implied. In *From Principles to Practices* [12], the following five 'key themes' were identified: collaboration; knowledge; policy; leadership; and finance. These are all seen as groups of potential enablers to help overcome common barriers in the sector. In *The Circular Economy in the Built Environment* [7], enablers are put into a different set of four groups: Education, awareness & communication; policy & regulation; technology & innovation; and collaboration. Recommendations for future action by the industry are grouped slightly differently again.

3. Categorisation of Barriers and Enablers – as Proposed

Here we identify four categories of barrier and enabler into which all of those identified in the literature can be allocated: these are cultural, regulatory, financial, and sectoral, and are detailed in table 1. In some cases an enabler maps to a corresponding barrier in the same category, whilst in others the enabler maps to two or more barriers which might be in different categories. Enablers tend to be less clearly defined: authors can frequently see and evidence a barrier, but be unable to articulate what is needed to address it and unable to provide evidence that such action will promote circularity.

3.1. Cultural Barriers

Cultural barriers concern aspects of the social, behavioural and managerial contexts in which the CE is required to develop, such as the entrenched nature of the linear economy; perspectives on ownership and status; and silo mentality. These are applicable throughout the economy, but the issues around collaboration are particularly pertinent to the construction sector. The following barriers have been identified.

Lack of interest, knowledge/skills and engagement throughout the value chain (suppliers, customers, and internal). This is a broad description, but can be viewed as the crux of the problem and an overarching barrier: without progress on this – especially the lack of interest in circularity – progress will be slow. Many authors refer to some or all aspects of this barrier. Some frame it in terms of the challenge of **delivering CE projects in a linear economy** [2,8], which we identify as a separate barrier as this highlights the practical challenges of 'going it alone,' for instance developing a circular products business case in the absence of a supporting reverse logistics infrastructure [9]

Lack of collaboration between businesses is frequently cited as a barrier (or as a GOWI enabler). Competitive instincts play a role here, but authors also note the need to avoid anti-competitive practices (see regulatory barriers). Collaboration is usually mentioned in terms of vertical collaboration along the supply chain, but a lack of consideration of horizontal collaboration in the supply chain is also referred to [13].

Lack of collaboration between business functions [8] is commonly known as a silo mentality, and concerns the inability of functions within a business – such as finance; marketing; corporate responsibility – to work together and transparently around a common goal.

3.2. Regulatory Barriers

Regulatory barriers concern the policy and regulatory environment in general, and also specific areas of problematic legislation and regulation. Fiscal incentives are also included.

The **lack of a consistent regulatory framework** is frequently mentioned. This includes an absence of global consensus around policy support for CE, and a lack of targets beyond the basics of landfill diversion. As an example, Hill [14] states that UK policy has 'largely ignored the upstream consequences of resource extraction… particularly if those are outside UK borders'.

Obstructing laws and regulations are cited by many authors, usually in relation to the handling and categorisation of waste. Another example [13] concerns anti-trust legislation impeding socially useful forms of collaboration.

There is also understood to be a **lack of incentives for CE**. Authors do not always specify the type of incentive they have in mind, but fiscal and regulatory sticks and carrots are evident. Those mentioned most frequently are public procurement and tax incentives (carrots), and producer responsibility (stick).

3.3. Financial Barriers

Barriers focused on financial issues and concerned with the market rather than the fiscal environment are allocated to this category. Aspects of the construction market including raw materials, property ownership, and investment are included.

The business and investment community is frequently accused of operating with **short-term blinkers** – capital expenditure is prioritised over operational expenditure [9], and rapid returns on investment are expected. This tends to favour transactional relationships over long-term collaborations, and works against projects with wider social and environmental objectives but longer financial paybacks.

High upfront investment costs are mentioned in the contexts of a supporting infrastructure for CE (e.g. reverse logistics), R&D, and the certification and compliance processes needed for new CE models (e.g. reused structures [15]).

Low virgin material prices and even lower end of life (EOL) values is a high barrier to CE in many sectors but particularly in the built environment because of uncertainties about value in the distant future [2,3,15].

Poor business case and unconvincing case studies are frequently referred to. The business and environmental case is said to be poor or poorly articulated, and case studies

insufficient, incomplete, or poorly communicated. It is not always clear whether authors are referring to the projects themselves or to their dissemination: we assume both.

Limited funding. Many general complaints about access to funding and finance are included in this barrier. Additionally, there is a point about the longer-term finance needed for leasing models etc. [2].

3.4. Sectoral Barriers

Sectoral barriers are those that apply strongly (although not necessarily uniquely) to the built environment – i.e. the design, construction, ownership, maintenance, modification, dismantling, reuse and disposal of buildings and infrastructure.

Lack of bandwidth compounded by an absence of coherent vision for the industry. A potential barrier not explicitly addressed in the literature is a lack of bandwidth: the case for CE needs to be made in the context of competing and overlapping priorities. Participants in the construction industry might ask whether or not CE is an overarching framework to guide decision-making and, if so, how it relates to other frameworks, such as sustainable development, and their supporting tools. This barrier is closely related to the overarching cultural barrier: are the concept and tools good enough to excite interest and work alongside existing methods of addressing issues of resource productivity and environment?

Complexity / confused incentives. The various complexities of buildings and the industry are frequently discussed. Areas of interest include lack of accountability and split incentives [12], with a sequence of decision-makers being divorced from the consequences of their choices; fragmented supply chains [16]; a multiplicity of actors with perverse or conflicting incentives. In Adams et al [3] this is about complexity of buildings, and also for Arup [7] where *'complexity is one of the defining features of the built environment. Built environment assets tend to have long lifecycles in which multiple actors with diverging priorities and incentives interact... Multiple stakeholders and long lead times also mean there is rarely continuity of ownership and control.'* In Rizos et al [4], complexity is identified in contexts such as the supply chain, administrative burdens associated with certification, and the make-up of products.

The **Long product lifecycles** of buildings and most of their components is a special case of the complexity referred to above, which makes it difficult to build a strong financial case for CE in the sector. It also links to the uncertainties around future ownership, adaptability and EOL.

Technical challenges regarding material recovery is a topic covered in detail by Hopkinson et al [15]. Examples given include the challenges associated with separating bricks – especially when bonded with OPC; or the reuse of reinforced concrete elements; and of composite products in general. In the case of timber products, Campbell [17] highlights the industrialisation of natural products as being a barrier to productive reuse and recycling at EOL – moving products from the biological cycle towards the technical cycle: the classic representation of CE is based on separate biological and technical loops [1], and composites that cross the boundary can create problems. Two articles [3,15] refer to downcycling as a barrier, with Hopkinson et al [15] also highlighting the business imperative for quick site clearance during demolition impeding recovery of materials fit for reuse.

Lacking standardization is referred to in the context of specifications for recycled materials, and for re-used structures [15,17,18]. It is notable, though, that this gets a very low ranking in the Kirchherr et al's general survey [2].

Insufficient use or development of CE-focused design and collaboration tools, information and metrics. This barrier is broadly stated, and is widely alluded to by many of the papers already referenced. It includes design tools and guides covering design for CE, design for disassembly (DFD), design for adaptability, a range of collaboration tools, building and material information tools, and circularity metrics.

Finally, a sector-specific cultural barrier is **the sector itself – conservative, uncollaborative, adversarial.** It is suggested in at least two articles [4,12] that the sector is its own enemy in terms of CE. By nature it is wary of innovation, and takes an adversarial, risk-averse approach to contractual terms on liability that can restrain innovation further.

3.5. Cultural Enablers

Leadership is seen as key to delivery of CE, and this is particularly apparent in the case study articles. In the HS2 (UK high speed rail) case study [5], buy-in from the top is seen as critical to the establishment of principles of CE into the procurement process through inclusion in technical standards and supply chain briefings. There is some confusion about who should lead (e.g. contractors, investors, construction clients) [12], leaving the impression that GOWI is the answer. In the Rizos et al study of CE projects [4], company environmental culture (and, by extension, leadership) is the number one CE project enabler.

Sustainability/environmental drivers are related to environmental leadership, and engaging in processes like LEED can help to turn the spotlight onto CE (previous comments re bandwidth notwithstanding) [6,16]. Geissdoerfer et al [19] propose a framework underpinned by economic, environmental and social goals, together with stakeholder management, and a long-term perspective.

In order to **stimulate demand** for CE, consultation with clients is required from the start of a project, and beforehand when possible through industry-client workshops [7]. Collaboration with businesses and agencies to promote the CE agenda more generally is also required.

Value chain engagement activities are identified as a GOWI way of addressing the overarching cultural barriers [12]. An example of prioritising CE in procurement and using innovation challenges is in the HS2 infrastructure paper [5].

Forming **longer term relationships and partnerships** is another way of developing value chain engagement, and also of resisting short-term blinkers. In *Circular Business Models for the Built Environment* [9], the case is made that long-term partnerships result in more effective collaboration to common goals and a less adversarial approach to construction.

Systems thinking is identified as an enabler in BS8001[10], [13], but is not generally highlighted as such in the papers

reviewed here, except those focusing on it specifically [19], although it is needed to avoid a piecemeal approach to CE.

3.6. Regulatory Enablers

Policy support is recommended for skills and innovation, and metrics for CE and embodied carbon. Policy support can also extend to public procurement, a subject aired in the industry manifestos [7,12] and also mentioned in the Adams survey [3], although it is outside their list of top ten enablers.

Regulatory reform is an enabler implied by the various references to obstructive regulations. Additionally Hill [14] suggests revision of anti-trust laws to facilitate collaboration.

Incentives for CE. 'Carrots' can include fiscal incentives such as a reduction in VAT on refurbishment projects [9,12]. As for 'sticks,' producer responsibility is mentioned [3] as a possibility, favoured by contractors but not by manufacturers.

Table 1. Barriers and enablers, showing some of the most links between them. Each barrier is given a code, and suggested links to those barriers are indicated from enablers in the RH column. Although important, connections within the cultural section are not suggested, as they are numerous and diffuse.

	Code	Barrier	Enabler	Link
Cultural	C1	Lack of interest, knowledge/skills and engagement throughout the value chain	Leadership	S1, S7
	C2	Operating in linear economy	Sustainability/environmental drivers	S1
	C3	Lack of vertical and horizontal collaboration	Stimulate demand	F4
	C4	Lack of collaboration between business functions – silo mentality	Value chain engagement	F1
			Longer term relationships and partnerships	F1
			Systems thinking	S2
Regulat.	R1	Lack of consistent regulatory framework	Policy support & public procurement	R1
	R2	Obstructing laws and regulations	Regulatory reform	R2
	R3	Lack of incentives for CE	Fiscal support	R3
			Producer responsibility	R3
Financial	F1	Short-term blinkers – CAPEX prioritised over OPEX	Whole life costing	F1, S3
	F2	High upfront investment costs.	Easy wins	F4, F2
	F3	Low virgin material prices	CBMs	F5
	F4	Poor business case / unconvincing case studies	Scale	F4
	F5	Limited funding		
Sectoral	S1	Lack of bandwidth compounded by no coherent vision	Clearer vision for CE in the built environment	S1
	S2	Complexity / confused incentives	Better evidence base	R1, F5
	S3	Long product lifecycles (buildings and materials)	Collaboration and design tools and strategies	S6, C3
	S4	Technical challenges re material recovery	R&D, innovation	S4, C1
	S5	Lacking standardization	Develop standards and assurance schemes	S5
	S6	Insufficient use or development of CE-focused design and collaboration tools, information and metrics	Develop reverse logistics infrastructure	F2, S4
	S7	The industry itself – conservative, uncollaborative, risk-averse		

3.7. Financial Enablers

Whole Life Costing (WLC) [16] and new valuation techniques incorporating environmental, social and governance dimensions [12] are highlighted as approaches to shifting more emphasis onto the value of material assets. WLC has long been advocated as a potential enabler for energy efficiency – drawing more attention to OPEX – and the CE agenda adds further weight to the argument for such techniques.

Take the easy wins. This is an implied enabler rather than explicitly stated. If it is difficult to win support for a CE business case (as suggested by the barriers), then look first at the cost-saving inputs, for instance where using reclaimed materials can save money, or where designing for disassembly also means designing for quick assembly. Experiment with temporary building, as with the 2012 Olympic Games [16]. Develop CBMs that optimise what is already there (e.g. under-utilised floor space), and frame inevitable actions in terms of CE: many case studies include successes that – arguably – would have happened regardless of any CE agenda. In one sense, looking for 'easy wins' subverts the systems view required for developing a CE, but if there is a choice between no action and taking a fragmented approach, then the latter is probably preferable.

CBMs are generally understood as either enablers or embodiments of CE. These can include flexible living and working [7], Design Build Operate Maintain contracts, performance contracts [3,16], and product as service contracts [4,12,17].

Scale is another implied enabler. Aggregation of projects through collaboration might turn barriers into opportunities. The enormous scale of the materials available from Crossrail and demanded by the Wallasea Island project [6] made it cost-effective to overcome the many practical and regulatory barriers: the need to find a home for 3Mt of materials absolutely demanded the engagement of the Environment Agency in navigating the complexities of the Waste Framework Directive.

3.8. Sectoral Enablers

The sector should provide a **better evidence-base** for policy-makers and the wider industry alike. Build and communicate better case studies – through a combination of fully commercial projects (e.g. Public-Private Partnerships)

and pilots [7]. Evaluation of business case from all angles (finance, CE, social, etc.) and transparent dissemination.

Arup [7] argues that a **clearer vision for CE within the built environment** needs to be accepted and translated from principles into practice. *'Effective circular economy design frameworks and principles for the industry, together with a vision and roadmap to get there'* are needed.

Collaboration and design tools and strategies. Examples include BIM, BAMB, materials databases, building passports, knowledge gateways, information and metrics, DFD, assessment methods for building structure reuse [16], integration of design with resource cycles of other industries and locally [15]. *'Measuring the value of a product/material across its lifecycle'* is a 'top ten' enabler in [3]. New metrics such as the circularity indicator based on market value proposed by Di Maio et al [20] may be a piece in the jigsaw, although Lonca et al [21] highlight pitfalls associated with a focus on material circularity at the expense of wider environmental impacts.

R&D and innovation. Whilst technological barriers are not seen as overwhelmingly important [2,3] it is clear that innovation can unlock new opportunities. New technologies such as 3D Printing, sensors and controls, and Internet of Things can be explored for their utility to CE; sharing platforms for underused assets can be further developed; and resource recovery technologies can be further developed [15].

Development of standards / assurance schemes to enable re-use of structural materials and use of recyclate [3,15].

Development of a reverse logistics infrastructure: materials marketplaces, materials storage facilities, upcycling facilities etc. can help with practical issues around reusing materials released by refurbishment or demolition [15].

4. Concluding remarks

A review of the literature concerning challenges in developing a more circular economy has identified and classified more than 200 separate references to barriers and enablers. A consensus appears to be emerging that while many technical and regulatory challenges remain, the real obstacles to a more circular built environment are the cultural and financial / market issues, such as the approach businesses take to collaboration with the supply chain (or not), and the difficulties of demonstrating a strong business case for circular models. Future work will test this analysis and define what is required to put the enablers into practice and accelerate uptake of CE in the built environment.

References

[1] The Ellen MacArthur Foundation, "Towards a Circular Economy - Economic and Business Rationale for an Accelerated Transition," 2015.

[2] J. Kirchherr *et al.*, "Barriers to the Circular Economy: Evidence From the European Union (EU)," *Ecol. Econ.*, vol. 150, pp. 264–272, 2018.

[3] K. T. Adams, M. Osmani, T. Thorpe, and J. Thornback, "Circular economy in construction: current awareness, challenges and enablers," *Proc. Inst. Civ. Eng. - Waste Resour. Manag.*, 2017.

[4] V. Rizos *et al.*, "Implementation of circular economy business models by small and medium-sized enterprises (SMEs): Barriers and enablers," *Sustain.*, 2016.

[5] A. Charlson and A. Dunwoody, "Embedding circular thinking in a major UK infrastructure project," *Proc. Inst. Civ. Eng. - Eng. Sustain.*, pp. 1–4, 2018.

[6] M. Cross, "Wallasea Island Wild Coast Project, UK: circular economy in the built environment," *Proc. Inst. Civ. Eng. - Waste Resour. Manag.*, 2017.

[7] R. Zimmann, H. O'Brien, J. Hargrave, and M. Morrell, "The Circular Economy in the Built Environment," 2016.

[8] M. Despeisse *et al.*, "Unlocking value for a circular economy through 3D printing: A research agenda," *Technol. Forecast. Soc. Chang.*, vol. 115, pp. 75–84, 2017.

[9] G. Carra and N. Magdani, "Circular Business Models for the Built Environment," *Arup, BAM CE100*, pp. 1–25, 2017.

[10] S. Pauliuk, "Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations," *Resour. Conserv. Recycl.*, 2018.

[11] A. de Jesus and S. Mendonça, "Lost in Transition? Drivers and Barriers in the Eco-innovation Road to the Circular Economy," *Ecol. Econ.*, vol. 145, no. September 2017, pp. 75–89, 2018.

[12] D. Acharya, R. Boyd, and O. Finch, "From Principles to Practices: First steps towards a circular built environment," 2018.

[13] F. Pomponi, A. Moncaster, and M. (Cantab, "Briefing: BS 8001 and the built environment: a review and critique," *Proc. Inst. Civ. Eng. - Eng. Sustain.*, 2018.

[14] J. E. Hill, "The circular economy: from waste to resource stewardship, part I," *Proc. Inst. Civ. Eng. - Waste Resour. Manag.*, vol. 168, no. 1, pp. 3–13, 2015.

[15] P. Hopkinson, H.-M. Chen, K. Zhou, Y. Wong, and D. Lam, "Recovery and Re-Use of Structural Products from End of Life Buildings," *Proc. Inst. Civ. Eng. - Eng. Sustain.*, 2018.

[16] D. Densley-Tingley, J. Giesekam, and S. Cooper-Searle, "Applying Circular Economy Principles to Reduce Embodied Carbon," in *Embodied Carbon in Buildings: Measurement, Management, and Mitigation2*, F. Pomponi, C. De Wolf, and A. Moncaster, Eds. 2018, pp. 265–285.

[17] A. Campbell, "Mass Timber in the Circular Economy: Paradigm in Practice?," *Proc. Inst. Civ. Eng. Eng. Sustain.*, 2018.

[18] L. M. Luscuere, "Materials Passports: Optimising value recovery from materials," *Proc. Inst. Civ. Eng. - Waste Resour. Manag.*, 2017.

[19] M. Geissdoerfer, S. N. Morioka, M. M. de Carvalho, and S. Evans, "Business models and supply chains for the circular economy," *J. Clean. Prod.*, vol. 190, pp. 712–721, 2018.

[20] F. Di Maio, P. C. Rem, K. Baldé, and M. Polder, "Measuring resource efficiency and circular economy: A market value approach," *Resour. Conserv. Recycl.*, 2017.

[21] G. Lonca, R. Mugg eo, H. Imbeault-T etreault, S. Bernard, and M. Margni, "Does material circularity rhyme with environmental efficiency? Case studies on used tires," 2018.