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BEYOND SUSTAINABLE BUILDINGS: ECO-EFFICIENCY TO ECO-EFFECTIVENESS THROUGH CRADLE-TO-CRADLE DESIGN

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Abstract. *Sustainable building development focuses on achieving buildings that meet performance and functionality requirements with minimum adverse impact on the environment. Such eco-efficiency strategies are however not feasible for achieving long-term economic and environmental objectives as they only result in damage reduction without addressing design flaws of contemporary industry. The cradle-to-cradle (C2C) design philosophy which has been described as a paradigm changing innovative platform for achieving ecologically intelligent and environmentally restorative buildings appears to offer an alternative vision which, if embraced, could lead to eco-effectiveness and the achievement of long-term environmental objectives. Adoption of C2C principles in the built environment has however been hindered by several factors especially in a sector where change has always been a very slow process. From a review of extant literature, it is argued that the promotion of current sustainable and/or green building strategies - which in themselves are not coherent enough due to their pluralistic meanings and sometimes differing solutions - are a major barrier to the promotion of C2C principles in the built environment. To overcome this barrier to C2C implementation, it is recommended that research should focus on developing clearly defined and measurable C2C targets that can be incorporated into project briefs from the inception of development projects. These targets could enable control, monitoring and comparison of C2C design outcomes with eco-efficient measures as well as serve as a guide for project stakeholders to achieve eco-effective “nutrient” management from the project conceptualization phase to the end of life of the building.*

Keywords: *barriers, cradle-to-cradle, eco-efficiency, eco-effectiveness, sustainable buildings*

1 INTRODUCTION

The achievement of sustainable development in the built environment has been receiving growing attention in the last decade (Williams and Dair, 2007). This has led to widespread research on how to achieve “zero carbon”, “zero waste” or “zero emissions” targets in buildings (Xing et al., 2011). Most of these strategies are however embedded in an eco-efficient paradigm where there seems to be a priori stance that development projects are bound to impact negatively on the environment. This stance has given rise to a proliferation of reductionist strategies that seek to minimize any such negative environmental impacts of buildings. McDonough et al. (2003) have argued that applying sustainability principles to systems that are fundamentally flawed from a design perspective can only be successful in reducing resource consumption and pollution in the short term. It just amounts to limiting the negative impacts of poor designs by having to send less material to landfill or use less energy to heat "energy-efficient" buildings (McDonough and Braungart, 2003). It is considered that such marginal reductions in carbon emissions accruing from the implementation of conventional sustainability principles are likely to be undone by the burgeoning global population and ever increasing resource demands. Thus in the long term, achieving eco-efficiency would have little value unless the underlying flaws associated with the design of human systems are addressed (McDonough and Braungart, 2003).

Unlike conventional sustainability philosophy, the cradle-to-cradle (C2C) philosophy articulates a conceptual shift beyond the achievement of eco-efficiency towards eco-effectiveness - which has emerged as a metaphor that represents a vision of designing to create a positive footprint on the environment (McDonough and Braungart, 1998; McDonough et al., 2003). Rather than design systems that seek to minimize any negative environmental impacts, the C2C philosophy seeks to promote intelligent designs that have a positive synergetic relationship with the environment (Braungart et al., 2007). C2C has therefore been described as a paradigm changing innovative platform (Mulhall and Braungart, 2010) that requires new thinking if it is not just going to end as a fad in the built environment context.

The aim of this paper is to interrogate the C2C design philosophy as a strategy for achieving eco-effectiveness in the built environment and to argue a case for its wider adoption as the principal philosophy to drive planning, design and implementation of development projects. To achieve this, the concepts of eco-efficiency and eco-effectiveness are contrasted based on a review of extant literature to establish the gaps in environmental and economic performance that must be bridged. The case for C2C as the missing link is then presented. Subsequently, the C2C implementation processes as well as potential barriers to the achievement of eco-effectiveness in the built environment through C2C designs are discussed. The potential implications of these barriers to C2C implementation are further discussed before conclusions are drawn.

2 ECO-EFFICIENCY VERSUS ECO-EFFECTIVENESS

Sustainable development strategies over the years have focused on reducing the negative impact of human activities whilst ensuring that economic and social benefits are not compromised (Williams and Dair, 2007). Such strategies therefore strive for eco-efficiency – doing more with less – by targeting a reduction in resource and energy consumption. The Oxford English Dictionary defines being efficient as the quest to achieve maximum productivity with minimum wasted effort or expense, and more specifically preventing the wasteful use of a particular resource (Dictionary, 2006). Eco-efficient strategies are therefore underpinned by concepts of dematerialization, reduced toxicity, increased recycling (Braungart et al., 2007) and extended product lifespan (Stahel, 1982). Setting a zero target and working towards this target presents a scenario whereby waste reduction from the construction process by 90% for instance or reduction in negative emissions from a production process by 80% is considered a considerable achievement. McDonough and Braungart (1998) argued that such reductions usually appear outwardly admirable because of the double barrelled economic and environmental benefits that accrue from cutting down waste as well as natural reduction in resource consumption, energy use and emissions. It also eases the feeling of guilt since corporations and individual households are being "less bad" (McDonough and Braungart, 1998).

The UK Government for instance, has set an ambitious target to achieve zero carbon homes in the UK by 2016 (Osmani and O'Reilly, 2009b). Different legislation and EU directives are also being promoted to reduce waste to landfill in UK and across the EU. Releasing fewer toxic emissions, generating lesser amounts of waste and using lesser energy are however short term measures that only "slow down" the negative consequences of human activities on the environment. Harm is still being caused, only at a much slower pace. Even the much popular 3R's strategy of reduce, reuse and recycle (Kibert, 2001) which has often being promoted as a strategy for achieving sustainability in the built environment has not resulted in the creation of a true circular/spiral loop of material flows. Although well intended, Braungart et al. (2007) have described this form of recycling being practiced as "downcycling" as products are not designed from the very onset to facilitate true material recycling. Recycled building materials are often downgraded in quality that they have to be used for lesser quality purposes until they ultimately end up in landfills. Design considerations are not made to support accumulation of intelligence that can contribute to preserving or enhancing the integrity and value of materials over time – upcycling. Arguably, these zero carbon and zero waste efforts which have become necessary as "stop gap" measures to address global climate change challenges and which have been promoted in study streams such as circular economy (Zhijun and Nailing, 2007), industrial ecology (Erkman, 1997) and sustainable building (Williams and Dair, 2007; Häkkinen and Belloni, 2011) have not been entirely successful in altering the linear end-of-pipe (cradle-to-grave) material flow systems where materials eventually end up in landfill sites.

The generation of waste is a human phenomenon (Anastas and Zimmerman, 2003) as natural eco-systems do not generate any waste. The persistent problems of waste and toxicity therefore raise questions regarding the embeddedness of the eco-efficiency paradigm in the reduction of resource consumption, carbon emissions and waste as shown in Table 1. Braungart et al. (2007) for instance have described the quest to achieve eco-efficiency as a reactionary approach that: (1) does not address the need for a fundamental redesign of industrial material flows, (2) does not support long-term economic growth and innovation, and (3) does not effectively address the issue of toxicity. Perhaps eco-efficiency strategies concentrate much more on reducing the negative impacts of flawed designs thus strangling opportunities for promoting a rethink on how to design systems that actually have a positive rather than zero or fewer negative impacts on the environment.

The eco-effectiveness vision in contrast to the eco-efficiency vision aims to inspire designs underpinned with the intention to create a positive rather than reduced negative or zero effects on the environment. Effectiveness is defined in the Oxford dictionary as successfully producing intended results (Dictionary, 2006). McDonough and Braungart (2002) therefore proposed the concept of eco-effectiveness where unlike reduction and dematerialization, a truly supportive relationship between ecological, social and environmental systems is created through the establishment of cradle-to-cradle (cyclical) material flow metabolisms. Thus, eco-effectiveness focuses on promoting a positive ecological footprint and positive emissions by designing with the intention of creating gains. It is a proactive rather than reactive approach where toxic materials are replaced with air cleansing and self-purifying material alternatives (Mulhall and Braungart, 2010), and designs are conceived with the intention of facilitating true recycling or even upcycling and where a truly regenerative, closed and continuous loop system is realised. As McDonough and Braungart (2003) put it, "imagine buildings that make oxygen, sequester carbon, fix nitrogen, distil water, provide habitat for thousands of species, accrue solar energy as fuel, build soil, create a micro climate, change with the season and are beautiful". This would then mean that the higher the number of such buildings, the better it would be for the environment and for human health due to the positive effects.

The above arguments for the adoption of an eco-effectiveness vision in the built environment do not however render eco-efficient strategies useless. The combined implementation of eco-effective and eco-efficient strategies as complimentary approaches has been acknowledged in literature (see Braungart et. al., 2007). Such a two-pronged strategy promises enormous benefits for the environment in the long-term.

	Eco-efficiency paradigm	Eco-effectiveness paradigm
Vision	• To achieve "zero waste" and "zero carbon" emissions	• To achieve positive ecological footprints/emissions
Focus	• Reactionary approach that focuses on damage management and waste management	• Proactive approach that focuses on damage avoidance and the creation of gains
Strategies	• Energy efficiency, reduced consumption, extended product lifespan and design for durability	• Cradle-to-cradle designs, intelligent material pooling
Approach to material usage	• Minimization in the use of materials • Design for durability • Recycling which gradually ends up as downcycling	• Celebrates creative and extravagant use of materials • Allows for shorter life span of products • True recycling by designing to facilitate maintenance of material flows in a closed system
Approach to toxicity	• Reduction in use of toxic substances	• Replacement of known toxic substances or maintaining these in a closed continuous loop if replacements are unavailable
Study streams	• Circular economy, industrial ecology, sustainable building	• Cradle-to-Cradle

Table 1: Eco-efficiency versus the eco-effectiveness design paradigms

3 ECO-EFFECTIVENESS THROUGH CRADLE-TO-CRADLE DESIGN IN THE BUILT ENVIRONMENT

As argued above, a long term strategy for the built environment would be to create a truly positive synergy between ecological, social and economic targets – eco-effectiveness. This concept of eco-effectiveness has been described as the major strength of the C2C body of thought (Debacker et al., 2011). With inspiration from natural flow systems where the sun is the primary source of energy and where so called wastes from biogeochemical processes undergo metabolism to generate food for other biological processes, McDonough and Braungart (2002) proposed three C2C principles for achieving eco-effectiveness as:

- Waste is equal to food: waste either serves as a technical or biological nutrient
- Use of current solar income: dependence on solar sources of energy
- Celebrate diversity: promoting biodiversity, cultural and conceptual diversity.

Achieving these three principles in the built environment begins with a C2C design where buildings and other infrastructure are designed such that anything that would otherwise have resulted in waste is conceived as a nutrient for other technical or biological processes. Thus, buildings should be designed to facilitate disassembly and true recycling or upcycling of technical and biological nutrients (Mulhall and Braungart, 2010). Such design considerations could be for example preserving the value of steel by separating the different grades and specifying where they have been used in the design so as to avoid the loss of value that could accrue from mixing different grades of steel in the recycling process. Design considerations should also be made to facilitate the deployment of an intelligent material pooling (IMP) process throughout the service life of the building and after decommissioning. This can be in the form of specifying use periods for different components of the building, providing dis-assembly instructions and specifying details of where the different components can be sent back to at the end of their service life. The IMP process can also be facilitated by the establishment of IMP communities that are supported by common material banks (Braungart et al., 2007). These common material banks would operate as support hubs for upcycling and recirculation of technical nutrients across the IMP community. A building materials database that features the eco-toxicological profile of different materials can also be established to guide materials specifications at the design stage. Thus toxic materials should be avoided entirely and where non-toxic replacements for materials are unavailable, design considerations can be made to ensure that toxic materials fit into a closed continuous technical material loops (Braungart et al., 2007). Features such as bio-digesters and wastewater treatment ponds (Mulhall and Braungart, 2010) could also be integrated into the development to treat and recycle the biological nutrients in wastewater. Self-cleansing and self-purification façades (Hüsken et al., 2009) can also be incorporated into the designs to clean and purify the surrounding air.

With energy, the aim is a total dependence on solar income or other renewable forms of energy that are still primarily driven by the sun’s radiation – wind, geothermal and hydro and biogas. However, it is acknowledged that renewable energy technologies such as solar photo voltaic (PV) and solar thermal can at present only be relied upon for the provision of intermediate-load electricity whereas base-load electricity is still provided by conventional energy sources: coal, nuclear and fossil fuels (Goffman, 2008). Irrespective of these technical difficulties, McDonough and Braungart (2002) still emphasise the dependence on solar income as a long-term aspiration of the C2C vision where renewable energy can gradually substitute for the use of conventional energy sources in the future as well as even feed off excess solar energy to the national grid. This way, buildings and other infrastructure could serve as energy production hubs rather energy consuming facilities (Mulhall and Braungart, 2010). Features are also integrated into designs to support biodiversity as well as cultural and conceptual diversity i.e. providing habitat for other flora and fauna, designing to fit the local area and designing flexible structures that can support mixed uses respectively. Biodiversity for instance could be promoted in the designs by integrating features such as aquaponics, roof gardens or even fish ponds.

By establishing closed and continuous energy, water and material loops, a positive synergy between buildings, infrastructure and the environment can be realised. Waste would no longer be an issue as materials would be truly recycled through the IMP process. Implementing C2C in the built environment context is however a slow process that can be hindered by various industry specific barriers which are briefly explored in the next section.

4 BARRIERS TO C2C ADOPTION IN THE BUILT ENVIRONMENT

The construction sector has been described as very conservative sector that is dominated by a high number of small to medium sized firms, making innovation and the change adoption a very slow process (Debacker et al., 2011). Though the implementation of C2C principles in the built environment promises to be an innovative strategy towards the positive re-coupling of the relationship between buildings, infrastructure and the environment, there are several implementation barriers. Braungart et al. (2007) have acknowledged that establishing eco-effective material flow systems rests on establishing a coherent network of information flows. Diffusion of appropriate knowledge across the construction supply chain is therefore undisputedly fundamental to the implementation of C2C in the built environment and any barrier(s) to the accumulation, management, diffusion and sharing of such knowledge is likely to be the ‘Achilles heel’ to C2C implementation in the built environment. However, a major barrier to the diffusion of C2C knowledge in the built environment could arguably stem from the already pluralistic meanings of “sustainable buildings” and its related terminologies. Stenberg and Raisanen (2006) revealed that the plurality of meanings of “green buildings” as a terminology promotes competing ideas. Similarly, Guy and Moore (2007) have echoed that the remarkably diverse proliferation of ideas about the term “sustainable architecture” inhibits a coherent classification of what it stands for. These pluralistic meanings of different sustainability strategies which are arguably more embedded in the eco-efficiency paradigm are likely to inhibit the promotion of a complimentary strategy such as the achievement of eco-effectiveness through C2C designs.

Apart from these knowledge sharing and transfer barriers, the inability to achieve a high level of collaboration amongst development stakeholders that is required for implementing C2C principles on projects is likely to constitute a barrier to C2C implementation in the built environment. There is also the tendency for a short-term rather than a long-term focus amongst development stakeholders where even in the case of green buildings, Chalifoux (2006) revealed that construction professionals tend to eliminate green building features without taking life cycle cost assessments into consideration even though this raises the operational cost of buildings. The reluctance of developers and other built environment professionals to buy into new and emerging technologies that are unproven is also likely to pose a barrier to C2C adoption. The mere fact that the C2C concept is being propagated as a platform that can facilitate innovation towards the achievement of a closed loop material metabolism cycle suggests that project development stakeholders should be prepared to adopt new and innovative technologies that may not have been tried and tested. In a study undertaken by Osmani and O'Reilly (2009a), it was also revealed that there was a general lack of confidence in emerging green technologies amongst housing developers in England and Wales. Developers for instance are therefore less likely to implement new technologies due to the unknown inherent risks. All these factors could constitute socio-cultural barriers to C2C implementation in the built environment.

There are also technological barriers to C2C implementation as the level of technology available in the built environment can still not meet C2C objectives in its entirety. Debacker et al. (2011) found from their case studies of C2C inspired developments that the lack of comprehensive material selection options were a major barrier for adopting the C2C principles in building projects. There is therefore the need for development of new C2C oriented products for use in the construction sector given that the most easily accessible products on the market do not meet C2C criteria and even when they do, are not available in volumes and varieties that can meet project requirements.

There could also be some economic barriers to the implementation of C2C in the built environment as even in the sustainable building literature, existing economic models have been criticised for being unable to concretely demonstrate to client stakeholders that operational costs would offset any initial investment costs (Häkkinen and Belloni, 2011). For example, there is even a lack of agreement on the estimated energy performance of PV panels and the length of time that it would take for such installations to payoff installation costs in the long term (Cousins, 2011). Indeed, this lack of comprehensive economic models could be as a result of the lack of adequate knowledge on the long-term costs and risks associated with new technologies. There is therefore the need for comprehensive economic models that can demonstrate economic benefits of C2C adoption. Again, rather than assuming the commercial attractiveness of C2C developments which could lead to economic benefits of such developments, it is imperative that such commercial benefits are demonstrated in reality to inspire C2C adoption in the built environment.

C2C barriers	Examples of barriers
1. Socio-cultural barriers	• Knowledge sharing/transfer barriers arising from plurality of meanings of existing eco-efficient strategies • Lack of collaboration amongst development stakeholders • Preferability of conventional technologies and products that have been tried and tested as against new products and technologies • Affinity for short-term rather than longer-term operational benefits amongst development stakeholders
2. Technological barriers	• Lack of comprehensive building material database that meet C2C criteria • Lack of renewable energy technologies that can provide the bulk of energy demands • Lack of extensive knowledge and expertise for adoption and proper installation of C2C oriented technologies amongst professionals • Extensive proliferation of eco-efficiency as the target of technological innovations
3. Economic barriers	• Lack of extensive demand for C2C products and designs • Lack of a proven economic model to demonstrate to client stakeholders that C2C implementation provides long-term economic value • Lack of proven examples to demonstrate commercial attractiveness of C2C developments
4. Legal and regulatory barriers	• Lack of flexibility in existing building regulations • Legal difficulties in establishing take-back lease agreements • Embeddedness of existing legislation in the eco-efficiency vision

Table 2: Potential barriers to the implementation of C2C in the built environment

There are also legal and regulatory barriers to C2C implementation in the built environment. Debacker et al. (2011) revealed that inflexible laws and regulations were a major barrier to C2C implementation as this was usually cited by stakeholders as a major hindrance. Hoffman and Henn (2008) have also revealed that many regional building codes do not permit the integration of certain features such as composting toilet or greywater systems into building designs. Current legislation on waste and energy are arguably more likely to favour the achievement of eco-efficient rather than eco-effective targets given the continued focus of EU directives and legislation on “waste reduction” and cutting down of carbon emissions. In addition to these regulatory barriers, the “product of service” concept which has being advocated by Braungart et al. (2007) as an ideal strategy for the transition from eco-efficiency to eco-effectiveness is likely to require a corresponding legal framework in the built environment context. This concept is premised on the arrangement that various components of a building for example, are leased to the property owners for a defined period and are taken back after their service life. Although this concept releases the property owner from the task of disposing of these components or products at the end of their service life and facilitates the IMP process, such an arrangement would have to be supported by an appropriate legal framework which at the moment is non-existent. These legal barriers have to be overcome to facilitate C2C implementation in the built environment. The potential barriers to C2C adoption in the built environment context are summarized in Table 2.

5 POTENTIAL IMPLICATIONS AND DIRECTIONS FOR FUTURE RESEARCH

The implementation of C2C principles in the built environment could serve as a platform to promote developments that truly create a positive synergetic relationship with the environment. This can only be possible if potential barriers to C2C implementation in the built environment context are overcome. The various barriers discussed in the previous section could also serve as C2C drivers in the built environment if steps are taken in the right direction. Government initiatives are required to drive C2C implementation in the built environment either through the provision of fiscal incentives such as tax rebates for incorporating C2C features in developments. Again, the introduction of C2C oriented legislation or policies as well as flexibility of existing regulations to accommodate C2C innovations is likely to drive the adoption of C2C as a design and development model for the built environment. Such legislation for instance could advocate for provisions to be made in development proposals to ensure that any form of by-products generated as a result of the development fits into a pre-specified technical or biological material metabolism pathway. There is also the need for more research on solar and other renewable energy technologies as well as research that can result in a wide variety of materials and products that meet C2C criteria. If C2C is to be promoted successfully in the built environment, there is also the need for a more coherent C2C framework that is supported by practitioner manuals to guide built environment professionals on how C2C principles can be tangibly realised in building and infrastructural designs and how these can be properly articulated in design briefs. Clearly defined and measurable C2C targets that can be incorporated into project briefs from project inception could enable control, monitoring and comparison of C2C design outcomes with other eco-efficient measures as well as serve as a guide for project stakeholders to achieve eco-effective “nutrient” management from the project conceptualization phase to the end of life of the building.

The arguments presented in this paper are only based on a synthesis of extant literature and there is the need for further empirical research to evaluate the efficacy of achieving eco-effectiveness in the built environment through C2C designs as well as barriers to C2C implementation amongst development stakeholders.

6 CONCLUSIONS

The conceptual and operational differences between the eco-efficiency and the eco-effectiveness paradigms have been discussed. It has been argued that eco-efficient strategies are likely to be of no value in the long-term due the burgeoning global population and the associated increase in demand for material, energy and water resources. Based on these discussions, it has emerged that there is the need for a vision that goes beyond the achievement of eco-efficiency in the built environment. The eco-effectiveness vision has been heralded as a complimentary strategy for creating a positive footprint on the environment in the long-term. Strategies for the achievement of eco-effectiveness in the built environment through C2C design have also been discussed. However, there are several barriers to the implementation of C2C principles in the built environment. These barriers have being categorised as socio-cultural, technological, economic as well as legal and regulatory barriers. Central to most of these barriers is the current proliferation of eco-efficiency measures as a development model in the built environment as well as the pluralistic meanings of terminologies such as “green building”, “sustainable buildings” and “sustainable architecture”. These pluralistic meanings of the presently dominant eco-efficiency strategies are therefore likely to present knowledge diffusion and transfer barriers in the usually conservative built environment sector.

These barriers could however become drivers to C2C implementation in the built environment if necessary steps are taken to promote C2C oriented technological innovation, promote the necessary legal and regulatory support framework as well as a coherent C2C framework accompanied by guides and manuals that support the tangible realisation of C2C in designs. Given that the arguments presented in this paper are only based on a synthesis of extant literature, it has also been suggested that further empirical research be conducted to evaluate the efficacy of achieving eco-effectiveness in the built environment through C2C designs as well as the barriers to C2C implementation amongst development stakeholders.

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