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Exploring material circularity opportunities for a construction-SME on small-scale projects in Ireland

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Abstract. In Ireland, there has been a clear connection between construction output and construction and demolition waste production, with estimates of 17.8 million tonnes (Mt) in 2007 dropping to just over 3 Mt in 2014, which has mirrored the dramatic economic growth and subsequent sharp decline over that period. During this time of economy recovery and improving construction output, there is a unique opportunity to decouple this connection and rethink the traditional linear supply chain model to transition the sector towards nurturing resource efficiency and material circularity. This study explored opportunities to embed these principles within a construction-SME business model using an applied action research framework on selected case studies. A series of interventions (procurement protocols, sub-contractor engagement, auditing and benchmarking, source segregation and waste tracking) were piloted on two new-build construction projects ranging in a value from €1.5 to €2.8 million over a two-year period (2016-2018). The research is ongoing but initial results indicate that opportunities do exist in procurement/tendering, pre-construction planning and construction phases to improve resource efficiency practice and introduce material circularity principles into traditional construction-SME supply chain processes.

Keywords: construction, resource efficiency, circular economy, waste

1. Introduction

Globally, the construction sector is responsible for significant carbon emissions with the construction, operation and maintenance of buildings estimated to account for 40-50% of all energy use and anthropogenic greenhouse gas (GHG) emissions [1]. This is projected to grow by an additional 838 million tonnes of oil equivalent (Mtoe) by 2035 [2]. Annually in the EU, the construction and use of our buildings account for 40 per cent of final energy consumption, approximately 35 per cent of greenhouse

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gas (GHG) emissions, more than 50 per cent of all extracted materials (approx. 3 billion tonnes in the EU), 30 per cent of all our water consumption and 35 per cent of total generated waste [3]. In Ireland, there has been a clear correlation between construction output and construction and demolition waste (C&DW) production, with estimates of 17.8 million tonnes (Mt) in 2007 [4] dropping to just over 3 Mt in 2014 [5], mirroring the dramatic economic growth and subsequent sharp decline over that period. Preliminary EPA data [6] suggests that this trend is repeating itself with C&DW production on the rise again in Ireland as construction output improves leading to an increasing risk of returning to the pre-recession (2007) waste generation levels and associated poor environment practices i.e. fly-tipping.

One solution proposed to address these issues has been the concept of the circular economy (CE) and its potential applications to the built environment, which has garnered considerable industry and policy support internationally and at EU-level over the past four years. A key driver has been the 'EU Action Plan for the Circular Economy' [7], which proposes a restoratively-designed economy to keep products, components and materials at their highest value always [8]. The CE vision is underpinned by a dissatisfaction with the prevailing and traditional linear extract-produce-consume-dispose resource flow model of the modern economic system [9], which has traditionally been dominant in the construction sector. It advocates a reconceptualization of waste as a resource where products and components are intentionally designed to fit within biological or technical material cycles. This requires a paradigm shift towards a more circular system of reuse, recycling and disassembly focusing particularly on prevention and lifecycle assessment. The most popular definition to date has been provided by the Ellen MacArthur Foundation (EMF) [10] either in its original or abridged form:

'CE is an industrial system that is restorative and or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic materials, which impair reuse and aim for the elimination of waste through a superior design of materials, products, systems, and within this, business models.'

This will require a re-interpretation of traditional business models that will embed: eco-design; performance-based systems; collaborative consumption; upcycling; waste-as-a-resource; technological, social and organisational innovation principles within circular everyday working practice. This focus on value and utility does present several challenges that will require a multi-faceted approach and pragmatic stewardship to incorporate different business, financial and fiscal models together with technological and social innovation and the acquisition of new skills and knowledge through education [11]. Ritzén and Sandström [12] have highlighted the lack of organisational perspective and real-world evidence of implementation [13] while Korhonen et al. [14] suggests that the scientific and research content of the CE concept is 'superficial and unorganised' and highlighted the severe limitations associated with practical implementation of the concept, considering material cycles, renewable and cascading type energy flows in production-consumption systems. Allwood [15] also questioned the technical feasibility of a closed circle in combination with growing demand or problems related to the energy required to recycle materials, which may be higher for many materials than the overall environmental effect of acquiring the material from conventional sources such as mining.

This paper evaluates CE applications at a meso-level focusing on two quick-win CE 'interventions' on two new-build construction projects ranging from €1.5 to €2.8m in value over a two-year period (2016-2018). The next section will present an overview of the CE concept applications to the built environment. An academic-industry collaboration methodological framework will be presented, which facilitated the implementation of the pilot CE interventions on the selected case studies. The results section will highlight the main challenges and opportunities identified from benchmarking the impact of implemented interventions. A final discussion piece will summarise the main conclusions and provide a series of industry-specific recommendations.

2. A Review of Circular Economy Applications in the Built Environment

The EC Communication on ‘Resource Efficiency Opportunities in the Building Sector’ [16] clearly highlighting the importance of the design phase and the influence of material choice decisions, by calling for reliable indicators for: C&DW performance; recycling content in construction materials; recyclability and reusability of construction materials and products; and design for deconstruction. Recent EU publications [17, 18] have identified the need for generating increased confidence and trust across the whole supply chain in the C&DW management process through improved: waste identification; source segregation and collection; waste logistics; waste processing; and quality management. Suggested construction-related circular economy applications include: the development of easily repairable and resource efficient products that can be disassembled, reused or recycled; responsible sourcing of raw materials; designing out waste; designing for flexibility and deconstruction; using more renewable energy; reducing whole lifecycle embodied carbon; using collaborative supply chain logistics; and moving towards more service-based business models [19].

However, it is recognised that research into the practical application of these principles within the construction sector is still at a very early stage with Pomponi and Moncaster [20] stating that it has been primarily restricted to energy consumption and associated carbon emissions. At a more macro-scale, there has been some exploration of applying circular economy principles across the whole construction sector in Denmark, Finland, the Netherlands, Norway, Scotland and Sweden [21-23]. These studies have highlighted opportunities: to embed material loops within the supply chain to maximise value and utility of materials; integrate lifecycle thinking and performance models into procurement strategies; and rethink building material design and manufacturing processes to incorporate design for disassembly, modularisation and 3D-printing. Supporting these identified opportunities are general recommendations set out by the UK-GBC [19] and the Irish Green Building Council (IGBC) [24], which focus on resource efficiency, waste prevention, responsible sourcing, renewable energy, embodied energy, use of environmental product declarations and reducing lifecycle impacts. At a project-level scale, Cheshire [25] and the Ellen MacArthur Foundation [26] have provided a series of case studies that demonstrate how resource efficiency and circularity strategies can be embedded into the construction process by: using low embodied, low toxicity, recycled and resource efficient materials and components; improving energy performance; designing for deconstruction; designing out waste; and using performance-related services i.e. fixtures and fittings.

Recent European funding has also demonstrated support for the construction sector’s exploration of circular economy applications, most notably through: the Gypsum to Gypsum (G2G) project (€3.6m), which focused on aligning deconstruction and gypsum waste segregation practices to demonstrate the feasibility of transforming the recovered gypsum into a valued resource by incorporating it into the manufacturing process; the Holistic Innovative Solutions for an Efficient Recycling and Recovery of Valuable Raw Materials from Complex Construction and Demolition Waste (HISER) project, which examined the development of novel cost-effective holistic solutions (technological and non-technological) for a higher recovery of raw materials from ever more complex construction and demolition waste (C&DW) by considering circular economy approaches throughout the building value chain (from end-of-life buildings to new buildings); and the EU Horizon 2020 funded Buildings as Material Banks (BAMB) project, which aims to inform designers about how to use employ reversible design strategies to enable buildings to be more easily adapted, transformed and disassembled at building, system and product levels.

Despite this good work, a clear gap does exist in the holistic application of CE principles within the built environment [27], mainly due to the challenges associated with the inherent complexity of buildings and materials and the traditionally fragmented supply chain processes. Further to this, Pomponi and Moncaster [20] suggest that a lack of inter- and transdisciplinary research needs to be addressed to foster understanding and application. This is supported by Adams et al. [27] who found that clients, designers and sub-contractors were generally perceived to have a lower awareness of CE principles than other industry stakeholders. Limited awareness, knowledge and a lack of clarity across the whole supply chain were identified as significant challenges with a clear business case recognised

as the most important enabler. This clearly identifies the key role that knowledge, attitudes, competences and behaviours have in framing the circular economy within any sector [28]. Adams et al. [27] also highlighted that little or no research has explored the development of new business models focusing on value and utility within the construction supply chain with the focus to date being largely limited to construction waste minimisation and recycling.

3. Methodology

This study employed a case study methodological approach in collaboration with a SME main contractor based in the West of Ireland. The contractor provided a suitable sample because of its fundamental role during the construction phase [29] and its willingness to examine current procurement, pre-construction planning and on-site practices to facilitate pragmatic action research. This involved active participation by the researcher during these phases to explore the setting with a view to advancing understanding of the material circularity opportunities during the construction process [30-32]. A sequential series of activities (site visits, onsite observations and benchmarking, informal dialogue with site personnel, development of circularity protocols, site meetings with management, implementation and tracking of protocol impact) were undertaken across the two case studies to identify 'actionable' interventions to produce information and knowledge that would be useful to participants [33] allowing them to make sense of their own situation and inform the subsequent evaluation of implemented actions [34-37]. This was framed by the cyclical model proposed by Susman and Evered [38], who outlined the importance of: diagnosing the issue or problem; developing an action plan to address the problem or improve the situation; implementation of the plan; evaluating the impact; and specifying learning from this process. This required a close collaborative working environment, which encouraged deep participant involvement.

The participating contractor was a small-to-medium sized building contracting company who is in operation for over 20 years. The company specialises in non-residential projects including healthcare, industrial, commercial, retail, institutional and educational developments. An academic-industry research collaboration was established between the company and the Department of Building and Civil Engineering in the Galway-Mayo Institute of Technology (GMIT) in 2013 as part of an EPA project to explore the feasibility of implementing resource efficiency strategies during the construction phase on a series of selected case studies over a three-year period (2013-2015), which resulted in total cost savings of €14,568.41 (39). This represented 0.48 per cent of the total project value (€3,050,032) and 15.9 per cent of a theoretical profit margin of 3% (€91,500.96). This work had informed the organisational structure and culture prior to the move to explore material circularity opportunities outlined in this paper. For this reason, the first case study evaluated the simple material circularity quick-win of waste segregation on site to inform the design and development of circularity protocols, which were piloted on case study 2.

4. Exploring material circularity opportunities on two selected case studies

The two case studies included: the construction of a new 1,640m² school with a value of €2.8m; and the construction of a new 557m² fire station with a value of €1.5m, all located in the West of Ireland. Two measures were explored: the segregation of waste materials on site including associated costs and the impact on the final end-use of each material type; the piloting of a circularity protocol with supply chain stakeholders (sub-contractors and suppliers) to determine compliance and impact.

On case study 1, the waste segregation policy ensured that all timber, metals, mixed recyclables (cardboard/packaging), general waste and food waste were segregated. This resulted in a saving of €1,506.86 in waste skips costs. The total waste generation factor was 0.026 tonnes/m² or 2.6 tonnes/100m², which would have achieved three BREEAM credits in the waste category². The waste cost factor was €6.86/m³, which represented 27% of an assumed profit margin of 1.5% (€42,000). The

² Neither case study was a BREEAM certified project but waste production on site was measured against the BREEAM guidelines to establish tangible targets.

waste segregation policy also ensured that all the timber, metals, mixed recyclables and food waste was diverted from landfill (18.22 tonnes in total) with an average 70% recovery rate for the mixed C&DW and general waste tonnages (19.56 tonnes in total), which gives a total landfill diversion rate of 88%.

On case study 2, the waste segregation policy ensured that all timber, plasterboard, mixed recyclables, general waste and food waste were segregated. This resulted in a saving of €1,878.41 in waste skip costs due to the employment of waste segregation techniques on site. The total waste generation factor was 0.048 tonnes/m² or 4.8 tonnes/100m², which would achieve two BREEAM credits in the waste category. The waste cost factor was €6.56/m², which represents 16% of an assumed profit margin of 1.5% (€22,500). The waste segregation policy also ensured that all the timber, metals, mixed recyclables and food waste was diverted from landfill (18.22 tonnes in total) with an average 70% recovery rate for the mixed C&DW and general waste tonnages (4.55 tonnes in total), which gives a total landfill diversion rate of 86%. If all the waste was placed in mixed skips, the diversion from landfill rate would be approximately 70%, not accounting for contamination factors. Case study 2 also implemented the following take-back initiatives with materials suppliers and sub-contractors: electrical contractor stored packaging on site and transported in bulk (0.10 tonnes) themselves to the recycling facility; roofing contractor supplied their own metal waste skips (3 no. 8 yard³ skips); building materials supplier took back 15 no. pallets resulting in a saving of €225.

An analysis of the end-uses of each waste type highlighted some of the challenges of not employing waste segregation on site i.e. the mixed C&DW and general waste goes through a recovery process at the waste transfer facility resulting in an average 70% recovery rate for each mixed skip or container resulting in a significant amount of material been sent to landfill. Segregated timber has a shorter material loop with markets more locally for woodchip or use as feed material (along with processed food waste) in the composting facility at the waste transfer station. Segregated metals go directly to a local metals recycling firm while plasterboard is sent to a specialist gypsum processor who utilises it in their compost blends and other applications. The mixed recyclables loop is a lot longer as it is usually baled (in its different fractions) for export as an incineration feedstock due to the lack of local or national markets. It is clear from this cursory analysis that segregation on site does not necessarily lead to shorter closed loops as there is a lack of market infrastructure and demand for secondary materials in Ireland at this current time. A far more effective approach is demonstrated by initiating take-back arrangements with supply chain stakeholders to ensure that unused materials go directly back in the closed construction sector loop, thereby retaining their value and utility.

Case study 2 also offered the opportunity to test the use of a material circularity protocol (MCP) as part of the main contractor's procurement, tendering and pre-construction planning stages. The main contractor's procurement team included the protocol in all tender packages sent out to the bidding sub-contractors and suppliers. Only nine out of 21 sub-contractors listed returned the MCPs even though it was a mandatory requirement of the tendering process. Another six sub-contractors (electrical services, mechanical services, metal deck systems, painting, radon membrane and structural steel) are listed as having replied but the main contractor had no record of their completed protocol. For those who did reply, the main actions included: optimisation of orders, deliveries and material sizing; specifying and using materials with recycled content and minimal packaging; employing take-back schemes with themselves or their suppliers; appropriate materials management on site; compliance with waste segregation policies on site including compaction to limit void spaces and the reuse of offcuts on site. All the 15 suppliers listed returned the material circularity protocol with another five suppliers listed as having replied but the main contractor has no record of their completed protocol. For those who did reply, the main actions included: optimisation of orders and deliveries; supplying materials with recycled content and minimal packaging where applicable; employing take-back schemes; appropriate materials management on site.

5. Conclusions and Recommendations

Traditionally, construction-SME contractors in Ireland operate within a competitive tendering model consisting of a fragmented supply chain process where distinct phases of design, tendering and

procurement, pre-construction planning, construction and operation exist. This study set out to explore the use of two quick-win material circularity interventions during the tendering/procurement and construction phases. The first intervention of implementing waste segregation practices on-site built on a previous collaboration between the construction-SME and the academic institution, which examined the impact of embedding resource efficiency good practices on site (39-41). The generation of waste production benchmarks, associated costs and hypothetical mixed skip scenarios were used as communication tools to clearly demonstrate the value proposition using a recognised end-of-pipe strategy. It was clear from the analysis of waste production on Case Study 1 that opportunities did exist to move the focus higher up the waste hierarchy towards reuse and prevention. To address this, a MCP was designed and piloted on Case Study 2 to evaluate the construction-SME and supply chain community response to implementing the following waste prevention and reduction practices: materials optimisation; use of materials with recycled content; waste segregation and benchmarking; appropriate materials management and logistics; use of minimal packaging; facilitating material take-back schemes and reuse of materials on site. Results suggest that building suppliers were open to most of these initiatives thereby highlighting the importance of clear material specification, supplier selection and early engagement as part of the procurement process. Sub-contractors clearly demonstrated more reluctance to complete the protocols, mainly due to the novelty of the request and a lack of self-awareness of how the initiatives applied to their specific work package. Anecdotally, it would seem that the main contractor did not employ a rigid interpretation of the mandatory requirement to return the protocols as part of the sub-contractor and supplier tender submissions i.e. the non-return did not preclude the appointment.

The cursory analysis of material end-uses provided by the appointed waste management contractor does highlight the lack of closed loop opportunities within the construction sector that exist when materials become a 'waste'. Most of the materials listed were down-cycled in some way, thereby failing to maximise value and utility, which is a core tenet of the CE concept. The greatest opportunities to move towards waste prevention and reduction from a main contractor perspective lie in early supply chain engagement where issues of material optimisation, use of materials with recycled content, materials management and logistics, waste segregation and benchmarking and reuse of materials on site can be discussed and agreed upon. The use of take-back schemes and the allocation of waste management responsibilities to the appointed sub-contractors do encourage more proactive collaborative across the supply chain.

The main limitations of this study are related to the initial analysis of just two implemented material circularity strategies on two selected case studies. The focus on cost, end-uses and compliance does provide a series of signposts at this time but does not provide an in-depth examination. It is proposed that further analysis will: develop more detailed benchmarks incorporating carbon emission reductions; track sub-contractor and supplier protocol commitments against actual implementation on site; and examine both closed and open loop end-use markets to determine associated outputs. The research is ongoing with further material circularity initiatives been tested on several other case study projects.

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