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Pathways to circular construction: An integrated management of construction and demolition waste for resource recovery

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ABSTRACT

The challenges of sustainable construction, industrial growth and importance of resource efficiency are clearly recognised by the UK government and are now at the forefront of strategy and policy. A critical component of the government's sustainability strategies concerns way in which construction and demolition waste (C&DW) is managed. In this study a mixed method approach was adopted to investigate current practices of C&DW management and circular construction (re-use, recycle and recovery of materials) concept awareness in the UK. Relevant stakeholders from the construction industry (contracting, demolition and C&DW organisations) were selected and their views solicited on arguments about circular construction to help establish common visions and further encourage sustainable behaviour across the sector. The study revealed that legislation by the government on the re-use and recycling threshold for every new project can substantially improve circularity within the built environment. More specifically, focus should be on smart dismantling of buildings and ways of optimising cost effective processes. This will enable fair competition between stakeholders and eventually lead to investments in innovative approaches for resource recovery from C&DW. Further incentives and appreciations from government should also be given to stakeholders who are innovating and setting benchmarks in circular construction. This can lead to harmonised technological and non-technological solutions, closed-loop material processes and a circular economy.

1. Introduction

The construction industry generates about 35% of waste to landfill across the globe (Solís-Guzmán et al., 2009). In the UK, out of 100% of waste generated in 2013, 44% was due to construction and the rest was as a result of commercial, industrial, household, mining and agricultural activities (Ajayi and Oyedele, 2017). More than half of construction and demolition waste (C&DW) is disposed directly to landfills In the UK (Chinda, 2016). C&DW generation for the UK in 2014 was 58 million tons (Menegaki and Damigos, 2018). Integrated and optimised management of this waste is one of the pillars of strategy 2020, "A Roadmap to a Resource-Efficient Europe", whose goal is to reduce, re-use and recycle the waste (European Commission, 2011; Rodríguez et al., 2015). Policies worldwide recognise that the construction sector needs immediate mitigation actions for reducing greenhouse gas (GHG) emissions, climate change and resources depletion, with a focus on adopting circular economy approach to ensure sustainable use of construction materials (Hodge et al., 2010; Sieffert et al., 2014). Circular economy is an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes (Kirchherr et al., 2017). The circular economy model tries to keep the products and materials 'in flow' by means of effective and smart re-use strategies, therefore, reducing the use of virgin materials and negative environmental impacts (Mirata, 2004).

The circular construction will increase the UK's competitiveness by protecting businesses against shortage of resources and unstable prices, this will then create innovative business opportunities and efficient methods of producing and consuming (Kirchherr et al., 2017; Witjes and Lozano, 2016). The challenges lie within changing the mind-set of industry stakeholders towards cleaner production of raw materials following circular construction models and overcoming the technical issues, where there could be a low market readiness/acceptance (e.g. price, legal barriers and regulations) for circular construction solutions (Sieffert et al., 2014). The EU Waste Framework Directive (2008/98/EC), targeting 70% recycling of non-hazardous C&DW by 2020 has contributed to a shift among construction industry stakeholders to follow strategies for

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more sustainable processing and re-use of materials/products. This Directive, which favours preventive measures (i.e. reduce) as the best approach to tackling waste, has been implemented in the UK through Waste Regulations (England and Wales) 2011 (Ajayi and Oyedele, 2017). More specific to the construction industry, the Sustainable Construction Strategy (2008) sets overall targets for diverting C&DW from landfill. However, land-filling still remains a common way of handling this type of waste, which shows ineptitude in the way C&DW is presently managed.

The financial support from various funding agencies and the increased awareness, has led to an upsurge in quantity of publications related to solid waste re-use and recycling, from 58 in 1992 to 658 in 2016 (Li et al., 2018). Many research projects have been focusing on C&DW and innovative management strategies towards a circular economy, e.g. InnoWEE, RE4, VEEP, HISER, IRCOW, C2CA. For instance, the VEEP project (acronym for "Cost-effective recycling of C&DW in high added-value, energy-efficient prefabricated concrete components for the massive retrofitting of our built environment") is an European funded research and innovation programme (HORIZON 2020) which focuses on developing upcycling technologies for waste treatment to recover aggregates and ultrafine cementitious materials for precast concrete elements with a high percentage of C&DW content (>75% by weight). InnoWEE project (acronym for "Innovative pre-fabricated components including different waste construction materials reducing building energy and minimising environmental impacts") is another EU funded project under H2020. The project aims to embed the C&DW (e.g. fragmented bricks, fragmented plaster or concrete, fragmented glasses, machined wood from windows frame or from wood beams after demolition etc.) in a geopolymer matrix to produce prefabricated insulating and radiating panels for energy efficient buildings. RE4, an on-going EU project, (acronym for REuse and REcycling of C&DW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction), aims to develop a prefabricated energy-efficient building concept which is easily assembled and disassembled for future reuse, containing up to 65% in weight of recycled materials from C&DW. The HISER project (Holistic Innovative Solutions for an Efficient Recycling and Recovery of Valuable Raw Materials from Complex Construction and Demolition Waste), focuses on the recovery of concrete aggregates from complex C&DW, exploring even more cost-effective solutions for the 0–4 mm fraction of the waste concrete. Previous research projects funded by the European Commission such as IRCOW, C2CA and HISER focused on the recycling of C&DW that demonstrated the economic and environmental feasibility of the use of secondary raw materials recovered from C&DW. The IRCOW project (acronym for "Innovative Strategies for High-Grade Material Recovery from Construction and Demolition Waste"), completed in 2014, presented an insulating concrete from recycled cellular concrete which performed better in all environmental impact categories, at a reduced costs when compared to aerated concrete with similar properties. The C2CA project (acronym for "Advanced Technologies for the Production of Cement and Clean Aggregates from Construction and Demolition Waste"), completed in 2014 developed a mobile advance dry recovery (ADR) unit that processes the concrete demolition waste to coarse aggregates. Advanced C&DW sorting systems can contribute to the developments of pre-fabricated building blocks made from high percentages of C&DW recovered raw materials. Pre-fabricated components can improve the safety records, profitability, availability of skilled workforce, reduce delays and contribute to the economy of the sector (Molavi and Barral, 2016).

This study uses a mix-method approach to achieve the objectives of identifying key integrated solutions for circular construction. The strategy implemented is: 1) to scrutinise the state-of-the-art in the circular construction concept and its approaches in C&DW management; 2) a survey questionnaire and face-to-face interview were conducted to investigate the relevant UK construction industries regarding the current C&DW management strategies and to gain insights into their awareness and implementation of circular economy concepts.

1.1. Circular construction theories and strategies

Unprecedented quantities of materials from the earth's crust are currently being extracted and consumed (Stephan and Athanassiadis, 2018). The global extraction of non-metallic minerals (gravel, sand, clay, limestone and gypsum), reached approximately 35 billion tonnes in 2010. Sand and gravel constituted the main share of global extraction of non-metallic minerals in 2010 (40.8% gravel and 31.1% sand) (Miatto et al., 2017). Infrastructure developments and construction projects are the major end-users of this consumption. The transition towards a more circular economy where output flows could be reintegrated as secondary resources presents a promising solution for the construction industry (Stephan and Athanassiadis, 2018). Nevertheless, current figures estimate the global economy is only about 6% circular (Haas et al., 2015). Hence, a mismatch between policies, political aspirations and current practices exists.

Materials in buildings should sustain their value where buildings should function as banks of valuable materials and products. This can be done using smart design and circular value chains, which is crucial for a sector to reduce both its waste and the amount of virgin resources used. Therefore new business models which replace the 'end-of-life' perception with reducing, reusing, recycling and recovering materials in production/distribution and consumption processes (Kirchherr et al., 2017). Transition to a circular construction involves changes in value chains, from product design to new markets, from new models of consumer behaviour to new ways of turning waste into a resource. A sustainable waste management system requires vigorous feedback loops and is concentrated on processes to divert wastes from disposal and convert them to secondary raw materials (Seadon, 2010). The knowledge and experience on the re-use options of construction products are very limited. Re-use typically requires minimal processing before reapplication in a similar context, whereas recycling is breaking down waste into a homogeneous material for a lesser value application or introduction as replacement feedstock for remanufacturing of components (Blengini and Garbarino, 2010).

From an economic judgment, recycling of C&DW is only attractive when the yielded product is competitive in relation to cost, quantity and quality. The recycling can thus be encouraged by increasing the price of virgin raw materials through taxation. In addition, setting end-of-waste criteria for specific C&DW streams can contribute to increasing the market for secondary raw materials (Dahlbo et al., 2015). Recycled materials can be more competitive in regions where a shortage of both raw materials and landfilling sites exists (Tam and Tam, 2006). In the past decades, the C&DW was mostly used in road foundations and embankment, which was considered down-cycling (Vandecasteele et al., 2013). Whereas, recycling C&DW as aggregates in new concrete has drawn much attention in recent years, as well as recycled waste glass or asphalt shingle as a raw material in the manufacture of cement (Al-Bayati et al., 2018; Li et al., 2018; Shi and Zheng, 2007; Verian et al., 2018).

Material scientists are currently investigating and developing products formulated using processed C&DW. These efforts have mainly focused on aggregate inclusion in remanufacturing of building components with functional properties, see for example (Arenas et al., 2017; Cardoso et al., 2016; Gómez-Meijide et al.,

2016; Lotfi and Rem, 2016; Ossa et al., 2016; Özalp et al., 2016; Puthussery et al., 2017; Rao et al., 2007; Shahidan et al., 2017).

Fig. 1 illustrates the recycling of processed C&DW in a plant production of masonry bricks in China. The products arising from the re-use strategy approach have limited applications (such as non-load bearing partition walls).

When reusing recycled materials, technical problems should be solved through extensive material formulations and detailed property investigations. For instance, the high water absorption rate in recycled aggregates causes durability problems in wall components. Moreover, it is illegal by the EU Regulation No 305/2011 to use products without certified performance in construction. This presents one of the main obstacles to re-use, above all in a structural capacity. The information about the product/material origins and their length in service for a particular application are limited which is the worst case scenario for the potentials of re-using secondary raw materials. Testing of performance can be expensive which adds to the cost of the product/material and may overrule any savings from re-use. Many of the challenges to re-use are linked to the availability of data (Lu et al., 2016).

The cost of treating and recycling C&DW for recovering the imperative secondary manufacturing of value added products is very high, due to steps such as material screening and reprocessing which puts the C&DW treatment companies under pressure for generating profit. Lotfi and Rem (2016) introduced a concrete recycling process for recycling high volume end of life concrete streams into prime grade aggregates and cement. The technology developed is a low-cost classification advanced dry recovery (ADR) system. The rationale for this system is to reduce the transport required for moving the waste to external sorting/processing facilities, by establishing an on-site waste segregation/processing solution, although, limited site space could be a problem. The system is based on laser-induced breakdown spectroscopy (LIBS), to enable the ability to analyse and record information on the properties of secondary materials (e.g. classification of C&DW components and determination of composition) which will additionally allow the online quality control throughout the entire recycling process, i.e. from demolition to production such as fine-tuning of processing parameters in reaction to sensor data.

The development of technologies which enable the production of materials with increased purity from C&DW is the foundation stone of circular construction.

2. Research methodology

The research was based on the collection, analysis and interpretation of data gathered in a survey conducted (via questionnaires and interview) in the UK construction industry. The interview (semi-structured) was conducted face-to-face with a technical director of a demolition company to analyse the present barriers of C&DW management from the demolition sectors prospective as it is believed this sector can play a vital role in the achievement of circular construction. The choice of a survey method was informed by the nature of the research questions that ought to be investigated to achieve the key study objective of understanding the current C&DW management strategies employed in practice. In particular, questionnaire surveys are considered the most appropriate means of studying, with a known level of accuracy, the job and behaviour of a large population (Caldas, 2003; Rea Louis, 2015). A plain language statement was provided to participants, and ethics approved by the University.

2.1. Questionnaire and interview

UK stakeholder's interview and questionnaires were carried out in this largely qualitative research study. The questionnaire used, was designed with three sections. The rationale behind Section (A) was to get the general view of the respondents on C&DW management with particular reference to opinions about the existence of the government directives, programmes for research and innovation in C&DW, landfill tax, the biggest setbacks for re-use/recycling of C&DW, and the potential for a contract clause provisions which promotes and provides incentives for the use of recycling materials in new projects. In Section (B), the concepts such as circular loop construction and circular economy were scrutinised, along with dedicated questions on demolition and current C&DW management processes. Section (C), on the other hand, focused on processing and sorting of C&DW issues. The study population was based on organisations operating in the UK construction industry who are often involved with C&DW major activities.

A total of 100 such organisations were selected on the basis of their activities: construction, demolition, and C&DW processing companies. The number of participants (sample size) considered appropriate for a study is dependent on data saturation. Out of the 100 questionnaires sent out 30 responses were retuned (i.e. 30% response rate), which is quite suitable given that surveys within the construction industry typically achieve low response rates (Abdul-Rahman et al., 2006; Futrell, 1994; Polkinghorne, 1989). A total of 30 experts, who constitute information-rich participants (i.e. above 15 years of experience in the industry) are therefore appropriate for the research.

Details of the respondents who participated in this study and their respective organisations (Construction contractors, demolition companies, and C&DW processing companies) are presented in Table 1.

3. Results and discussions

The questionnaire was specifically designed to investigate perceptions of the UK construction sector's key stakeholders of C&DW on two main issues: i) the bottlenecks in C&DW management and,

Fig. 1. Workflow of masonry brick production from processed C&DW in China (Jin et al., 2017).

Table 1
Respondents' organisations, their designations and years of work experience.

Type of organisations	Position of participants	Years of experience	Percentage of total participants
Construction contractors	Design manager Sustainability manager Senior H&S manager	15–30	40%
Demolition companies	Technical director Demolition site manager Environmental manager	18–30	40%
C&DW processing companies	Engineering director Senior product development engineer	15–25	20%

ii) awareness of C&DW related directives and closed loop waste management (i.e. re-use and recycling). Logically, the current practices in the UK for C&DW management should be investigated to have a holistic overview which can lead to recommendations for future investments.

3.1. Evaluation of current practice on C&DW management in the UK

Table 2 represents data gathered from the questionnaire related to UK's C&DW management practices, from selected stakeholder's perspective.

The C&DW management practices in the UK have raised varied feedbacks according to participants in this survey. For instance, the quote from the engineering director of a C&DW processing company shows that they are positive about the current practices and that the UK could be on track to meet the waste targets: "*The UK is one of the leading regions for C&DW recycling, 2012 stats showed a recycling rate of close to 70%* (Defra, 2014)*. Technologies used in the UK are influencing the rest of the world*". However, negative viewpoints were also raised, such as the following "*The legislation in place has driven the industry towards better practice but the processes involved are sometimes overly bureaucratic to operate*" (design manager – construction contractors). Other issues raised were the lack of appreciation or rewarding for recycling and re-use of C&DW: "*There should be greater reward for recycling, in demolition it is key to a successful project and we typically recycle 90+% of all the waste we generate*" (technical director – demolition company).

The potential existence of a contract clause which requires the contractor to use recycled materials where possible, was also investigated. The clause should be package specific, linked to the project's overall recycled material target and to the relevant environmental assessment method (e.g. BREEAM, LEED). The rationale for this was to find out whether it is feasible to implement such strategies that contribute towards circular construction. The results revealed that only 15% of participants did not think there should be such contract clause. They were from demolition companies, who raised the point of being too expensive and the potential warranty issues on items such as cladding, windows and raised flooring. One selected statement was the following: "*items such as crushed concrete to be used as aggregates in concrete should be rewarded and encouraged through this strategy*". The rest of participants who believed there should be a contract clause regarding the recycling, had interesting comments which reflected their concern about the implementation and achievability of this clause. For instance, the sustainability manager of a construction contractor commented that, standards and engineering specifications for construction materials (e.g. concrete and steel) can rule this potential out. The reason for this is often sighted as being due to structural concerns. The material for re-use should demonstrate to be technically suitable as well as environmentally friendly. This means that the construction products prepared for re-use must meet the requirements of standards or guidelines given for specific end application and any additional requirements specified by the customer. Comments from the senior product development engineer at CD&W processing company included: "*this* (the contract clause) *would force companies to start innovating and investing time and money into new recycling techniques. Contracts could be used to re-enforce legislation and also set out own company targets. There should also be a requirement for contractors to provide evidence of compliance*".

From a planning point of view, the respondents were asked if they have dedicated site assessments and planning for C&DW valorisation. This question was answered with a "Yes" from 69% of the respondents. Interesting points such as the importance of early design stage was emphasised in its role on how it can reduce the costs for contaminated waste treatment or envisaged strategies of re-use. This is in line with the waste valorisation concept as it can lead to resource recovery. Additionally, the sustainability manager of a construction contractor emphasised their practice of having waste minimisation workshops which can be beneficial for increasing awareness about C&DW re-use and recycling. The environmental manager of the demolition company also commented about their site assessment which is to keep a record of all waste streams forecasted, and predictions at project commencement with baselines updated on a monthly basis. This is similar to the demolition company's practice, which mentioned that they carry out an on-site evaluation to value the waste and determine

Table 2
C&DW management related issues in the UK construction industry.

Item	Percentage selecting each option	
	Yes	No
Are you satisfied with the current government enforcements for C&DW (i.e. Landfill tax)?	85	15
Do you think that the waste management plan overall is helpful to reduce C&DW generation in the UK?	69	31
Do you think that there should be a contract clause that requires the contractor to use recycled material where possible?	85	15
Are you satisfied with current recycling processes in the industry?	22	78
Do you think you receive enough recognition/appreciation (e.g. BREEAM score) for recycling C&DW?	0	100
If no, would more recognition/appreciation motivate you to recycle C&DW?	100	0
Do you have dedicated site assessments and planning for C&DW valorisation?	69	31
Do you have pre-demolition audits and appraisals for categorisation of C&DW streams?	100	0

what can be resold.

The prevention of waste with the lowest environmental impact in the management hierarchy requires major changes to the socio-technical system of waste infrastructure with economic, social, legal, and even cultural elements (Hultman and Corvellec, 2012; Van Ewijk and Stegemann, 2016). On the other hand, the current recycling processes in the UK increase cost as skilled labours and energy intensive pre-treatments are required. High cost of specific sorting machines is also a concern for the companies to start recycling on-site. Although, due to financial implications, evidence suggests that imposition of landfill tax, i.e. £82.60 and £2.60 per tonnage of active and inert waste respectively, has improved construction waste management in the UK industry (Ajayi and Oyedele, 2017). The aggregate levy, introduced as an environmental tax in 2002, is also an additional fiscal provision aimed at reducing construction waste and encouraging materials re-use of aggregates (e.g. gravel, sand and rock). The levy is charged at a flat rate of £2 for every tonne of aggregate extracted (Gov.UK, n.d.).

BRE UK (Building Research Establishment) conducted a study which showed that up to £130M can be gained by the UK economy just by reducing 5% of its construction waste (Ajayi and Oyedele, 2017). These savings are in forms of the cost of acquiring the waste materials, cost of storage, cost of transportation and disposal as well as the landfill tax payable for waste disposal.

3.2. The bottlenecks in circular construction

Despite the secondary raw materials market potential, the reintroduction of C&DW into the built environment, as added value products, i.e. up-cycling, is still hindered by many barriers. Fig. 2 shows the data collected from the survey which assess the main bottlenecks in efficient recycling/re-use of C&DW and the options for improvements in the recycling process. Difficulties in C&DW recycling and re-use can be itemised according to the order of results (see Fig. 2a) with the highest setback being logistics (41%), followed by cost (29%), time/H&S regulations (12%) and other (6%). Other studies have identified, the lack of standards for C&DW recycling and re-use, certification, effective sorting, and the lack of balance between the demand and supply in the recycling and re-use market as other impeding factors to the circular construction concept (Chinda, 2016; Gangolells et al., 2014; Tam et al., 2007). Additionally, project stakeholder's attitude towards implementing on-site sorting and the associated management efforts influence the on-site sorting and processing of C&DW (Paranhos et al., 2016; Yuan et al., 2013).

The aforementioned bottlenecks cause the construction stakeholders to primarily choose C&DW landfilling (sometimes illegally) or those channels of low-value operations (e.g. backfilling). Essentially, by tackling the re-use of C&DW with an integrated approach, a much needed transformation in the construction industry will be implemented, providing traditional construction companies an opportunity to engage in the era of this new construction paradigm, one that will surely have a significant number of impacts including economic, social, environmental and architectural dimensions.

Fig. 2b shows that 44% of participants believe that on-site operations must be improved and implemented in order to increase recycling of C&DW. The UK construction industry stakeholders not only need to invest more in innovative technologies, they need to use more effective dissemination to share their practices and therefore help implement the best strategy for on-site operations of C&DW. It can be gathered from this study that the stakeholders in UK's construction industry have plans in place to valorise C&DW but they do not focus on technologies, such as for on-site sorting and processing. Yuan et al. (2013) presented that construction waste management regulations considerably improve on-site C&DW sorting in Hong Kong. Interestingly, they found that site space and project stakeholders' attitudes are the most critical factors, but labour and cost were no longer of major concerns in implementing on-site C&DW sorting. The improvements of on-site sorting was found to result in increased secondary raw materials re-use and recycling efficiency with reductions in C&DW landfilling (Yuan et al., 2013). The on-site sorting for processing of C&DW can be problematic due to space limitations, health and safety restrictions, added cost, equipment for sorting of C&DW and interfering with other important construction activities (Wang et al., 2010).

The landfill tax played a critical role in increasing the quantity of fixed and mobile crushing/recycling sites, however, these C&DW recycling sites experience shortages of materials or customers subject to their location (Lawson et al., 2001). Interestingly, the answers to the question: "*Are you satisfied with current recycling processes in the industry?*" echoes the importance of further developments in sorting and separation technologies, e.g. response from a sustainability manager – construction contractors: *"No- I believe these could be improved but it relies on better segregation on site and also increased investment and regulation of the waste industry"*.

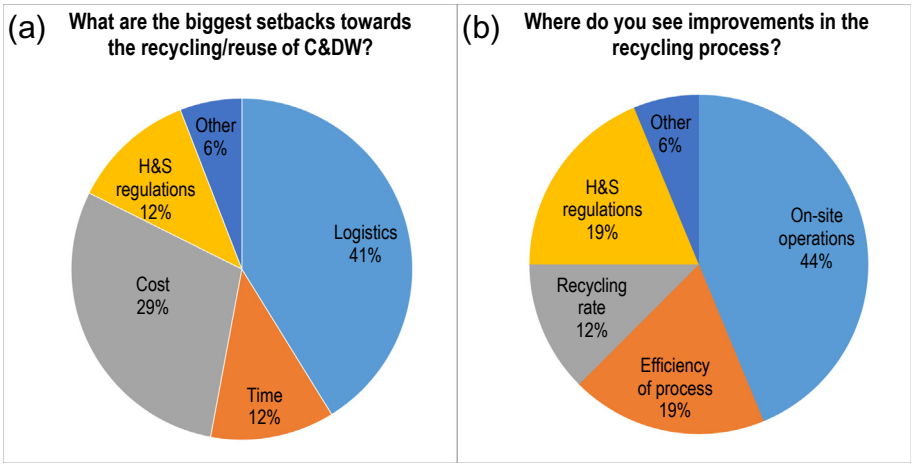

Fig. 2. Bottlenecks in efficient recycling and re-use in UK as revealed from questionnaire survey.

In the interview with the technical director of the demolition company we explored further the depth of circular construction with the following question: *What do you believe to be the issue for the industry as to not adapting the re-use of materials into project designs?*, the answer was that the clients will not buy re-used materials, so they are waste. *"As a demolition company we will not recover them if there is no place for them to go. Clients are not interested due to the reduction of the products warranty, meaning that they will require maintenance sooner than a new product. The saving made from reusing materials is insignificant for them, such as a £10,000 saving on a £250 million job.*" Moreover, using recycled products with a shorter lifetime is not necessarily better for the environment than using raw materials. Remanufacturing products still has an environmental cost (energy, material use and GHG emissions). Although, an LCA study could be beneficial for a specific case study to prove which options is best for a project (Di Maria et al., 2018).

3.3. Assessment of the circular construction awareness of UK's industry stakeholders

Table 3 summarises the results of the awareness of participants on areas related to the circular construction concept and its implementation in the UK construction industry. All of the participants in this survey were aware of the Waste Framework Directive that 70% of C&DW is to be recycled by 2020, which suggests that the target has been well publicised across the industry.

The awareness about the closed loop construction was investigated with the following questions to the participants: "*Do you believe that closed loop construction gets enough promotion?*" The entire participant answered with a resounding "*No*". The environmental manager of a demolition company and engineering director of a C&DW processing company, commented that the closed loop construction "*is just coming into the mainstream spotlight*" and that "*the promotions are not frequent*", respectively. Circular construction would turn building components that are at the end of their service life into resources for others, closing loop in industrial ecosystems and minimising waste. It can change economic logic as it substitutes production with sufficiency, i.e. re-use what you can, recycle what cannot be re-used, repair what is broken, and remanufacture what cannot be repaired. Circular construction approach will lead to a sustainable, low carbon, resource efficient and competitive construction economy for the UK and the rest of the world (Dahlbo et al., 2015; Kurdve et al., 2015). The promotion of such conceptual solution, i.e. the circular construction, is a good starting point, although, as long as the circular solutions are uneconomical compared to traditional ones, we will not witness success on large scale.

All the participants from companies dealing with C&DW sorting/processing answered "Yes" to both of the following questions: "*Would your company be interested in future investments/strategies associated with circular economy*?" and "*Do you believe that with the operations available from companies such as yourself, the target of 70% of C&DW to be recycled can be met?*". This is encouraging as it shows the UK's willingness to embrace the circular economy and overcome the challenges for an effective implementation in industry.

In the interview, the technical director of the demolition company was asked about their current performance regarding the recovery of materials to be re-used. Interesting points were revealed here, which emphasises the government's lack of effective enforcements to drive the circular construction principles. The harsh reality of the industry became clear and that is the fact that companies know they can improve their practices to reduce their negative impacts on the environment but choose not to, purely because they will not be able to compete in the market.

This is evidenced by the following quote from the interviewee: *"we change our methods for individual projects only when the client requests us to. For example, one client requested that we use bio-oil on all machinery for one job; because we were made to do it I was more than willing to swap the oils for all the machines. However, this oil performs poorly and costs more than conventional oil so without a client request and/or law forcing me to use it; I will always use the oil that saves me both money and time. Without a law or request from a client, I have no incentive to use it or else I risk losing the job to other companies.*" This is the sad truth which is valid about the implementation of circular construction strategies. It shows that the level of engagement of policymakers with the concept of circular construction is not satisfactory, as they are not able to understand the benefits it could have towards achieving some of sustainable development goals and combating global challenges such as global warming, climate change and resource scarcity.

3.4. C&DW management strategies towards circular construction

From the questionnaire results, we noticed that one of the sustainability managers from a construction contractor commented that the charges and enforcements on the producer e.g. main contractors can be a more effective method to reduce the production of C&DW. In the interview with the technical director of a demolition company it was revealed that there is a gap across the construction/demolition industries for a law to ensure that clients make the most of reusing/recycling materials where possible. The law would make their unwillingness to re-use products/materials less of an issue as they would have no choice but to use them.

Competition across the industry would increase the amount of recycled and re-used materials implementation and would also provide reason for companies to invest in research projects. These new concepts would contribute to clients meeting the waste targets set by law. The following quote is a suggestion from the technical director of a demolition company: "*A law such as 5% of a new buildings material must be re-used from a previous project should be produced. The government would be required to drive the change to the industry*". The re-use/recycling rates can confidently increase if a new law in UK's construction were to be introduced. This is also

Table 3
Data analysis of the awareness of the UK's industry on circular construction.

Item	Percentage of selecting each option	
	Yes	No
Are you aware of the 2008/98/EC directive that 70% of C&DW is to be recycled by 2020?	100	0
Are you aware of the current EU Framework Programme for Research and Innovation dealing with C&DW?	15	85
Are you aware of closed loop construction, i.e. circular economy concepts in the construction industry?	15	85
Do you believe that closed loop construction gets enough promotion?	0	100
Are you aware of the reversible building design concept?	100	0
If yes, are you implementing this concept in your current/Future projects?	15	85

confirmed from the interview with technical director of another demolition company: *"I am very confident that we would see a huge change across the industry. For example, the HSE* (Health and Safety Executive) *set a target for the number of accidents a site can have, companies strive to beat the target and promote their success. Again, the Euro 6 targets were set; the result from this is that we are currently changing all of our machinery (e.g. engines) to improve their emission performance to meet the targets set. The same would happen for the re-use/recycling targets"*.

The stakeholders in construction at the moment have no reason to innovate in terms of material recovery and processing technologies, as the market does not incentivise them to do so. The introduction of the law for companies to meet specific re-use/recycling targets would provide reasons for them to invest into waste management solutions. It is unfortunate that new legislations are required to provide such incentive needed to drive the change across the industry regarding the re-use/recycling of materials and not the appreciation for global challenges and environmental concerns.

In the long term, it is predicted that the new law on re-use/recycling of materials will have great potential, however not at this current time. The government would not produce such a law at the moment due to BREXIT. European companies are already debating whether to stay in the UK or not, and as this new law would make UK construction more expensive for clients, it would be less appealing for them to stay as they can save money for construction in countries where this law wouldn't apply.

Legislation and regulations in the UK are the main drivers for construction waste reductions. Governmental initiatives in reducing waste, use of pre-fabricated building components, and education/training are the most recommended management methods in the UK in terms of overall worthiness or spending to create savings or minimise waste.

In circular construction, buildings and infrastructure will be designed according to circular principles. Pomponi and Moncaster (2017) define "circular buildings" as buildings that are designed, planned, built, operated, maintained, and deconstructed in a manner consistent with circular economy principles. Circular design concepts for disassembly, re-use and flexibility form an essential part of circular construction, for instance facades, windows, doors, floors and structural elements, i.e. modular buildings with prefabricated components. Suppliers make these parts precisely to order specification, hence, the loss of materials and/or waste generated at the construction site is minimised.

For the construction, demolition and waste management industries to remain competitive in a global market place, they have to continue to develop and implement supply chain innovations for improved efficiency, resilience, reduced energy, waste and resource use. To achieve this, significant research in smart, mobile and integrated systems is necessary. Radically advanced robotic artificial intelligent systems of sorting and processing must be developed with the focus on the required re-use of materials and components. Many industries are facing an uncertain future in which today's technological limitations cannot be assumed to apply. The construction industry is likely to be significantly affected by the potentials of transformative technologies such as Artificial Intelligence, additive manufacturing, nanotechnology, virtual/augmented reality and robotics. The application of such technologies presents both significant opportunities and challenges. Construction industry has to transform current capital-intensive assembly lines into smart systems using on-site mobile platforms, construction automation and robotics that can facilitate the modular buildings (Farinelli et al., 2017; Ghaffar et al., 2018; Pan et al., 2018).

Fig. 3 illustrates our developed concept diagram for an integrated eco-innovative solution in circular construction based on the discussions made around circular construction. Through the combination of the advanced sensors and the robotic sorting, circular construction recycling systems can offer a unique upcycling approach that can be utilised for a selection of input materials whilst consistently keeping the ability to produce high quality outputs, i.e. circular products. The practitioners in industry must be inspired and encouraged to be passionate about changing the mind-sets of stakeholders and the general public, to showcase and prove the potentials of new paradigms. This can be driven by a combination of: (1) creative design, (2) focused academic research and applied technology, (3) external industry engagement, and (4) flexible, responsive regulation (see Fig. 3).

4. Conclusions

Effective and comprehensive collaborations between scientists, policymakers, government ministers, and companies must be established. The focus should be to expand the scale and the quality of C&DW recycling and it's potential to also be re-used to construct new buildings which are energy efficient. Although, circular construction is not only about resource recovery, re-use and recycling, is a much broader concept. C&DW management requires a tool and protocol which will compel the stakeholders to invest in closed loop construction. This would involve bringing together industrial, research, civil organisations, public authorities and policy makers' actors. It was revealed that the re-use of components can be improved if smart demolition and/or selective dismantling are implemented. If design codes emphasised the environmental aspects of the construction and gave designers more opportunities for material sourcing, the chances of re-use can be enhanced. It was revealed that 44% of respondents believe that on-site operations must be improved and put in practice in order to see improvements in overall recycling. All of the participants in this study believe that the closed loop construction does not get enough promotion. Therefore, more targeted dissemination is needed to increase public and industry awareness which should lead to effective impact. Logistics was chosen by 41% of participants as the biggest setback towards the recycling of C&DW. Mobile robotic sorting and reprocessing machines with innovative technologies, such as

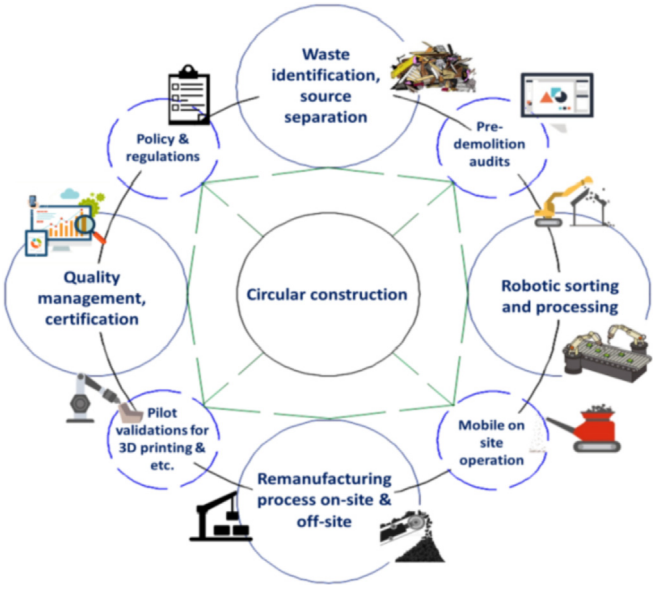

Fig. 3. Circular construction concept.

artificial intelligence and internet of things, can be a breakthrough for the realisation of circular construction concept.

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