HISER International Conference

Advances in recycling and management of construction and demolition waste

21, 22 & 23 June 2017
Delft, The Netherlands

Editors:
Francesco Di Maio
Somayeh Lotfi
Maarten Bakker
Mingming Hu
Ali Vahidi
Advances in Recycling and Management of Construction and Demolition Waste

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Preface

Dear Colleagues,

We are pleased to organize the first International conference on Advances in Recycling and Management of Construction and Demolition Waste, from June 21-23, 2017, in Delft, The Netherlands. This conference intends to provide researchers, practitioners and industry experts with the opportunity to exchange the latest knowledge and tools in advanced/innovative technologies and methodologies to process and valorize C&DW in the context of circular economy.

Production of waste materials, via industrial and human activities, creates big environmental and economic problems but also opportunities to recover valuable resources. EU28 currently generates 461 million tons per year of ever more complex Construction and Demolition Waste (CDW) with average recycling rates of around 46%. There is still a significant loss of potential valuable minerals, metals and organic materials all over Europe.

Considering the fact that public and private sectors have become aware of the urgency and importance of CDW recycling, the European Commission has taken initiatives towards sustainable treatment and recycling of CDW. In 2014, the European Commission announced a call for proposals with the subject of “Recycling of raw materials from products and buildings”. The aim was to develop solutions for a better recovery of CDW, particularly in the most promising targets, such as deconstruction of non-residential buildings, showing the feasibility of increasing the recovery rate of CDW (e.g. metals, aggregates, concrete, bricks, plasterboard, glass and wood), and the economic and environmental advantages associated with CDW treatment, thereby closing the current gap between reality and the overall 70% recycling target for CDW as set in the Waste Framework Directive. This call resulted in a successful project with the full title of “Holistic innovative solutions for an efficient recycling and recovery of valuable raw materials from complex construction and demolition waste” with acronym of HISER. The main goal of HISER project is to develop and demonstrate novel cost-effective technological and non-technological holistic solutions for a higher recovery of raw materials from ever more complex CDW, by considering circular economy approaches throughout the building value chain (from the End-of-Life Buildings to new Buildings).

Following the success achieved in the HISER and its earlier EU projects such as C2CA and IRCOW, Technical University of Delft, took an initiative to organize an
international conference on construction and demolition waste management and recycling together with the project coordinator Tecnalia.

The response on the call for papers was encouraging and convincingly illustrated the importance of the subject. Finally around 80 papers were submitted, coming from more than 20 countries. The contributions cover the wide, coherent field of construction and demolition waste recycling and management and make this conference a meeting point to exchange technology and engineering best practices.

We hope you will find the conference and your stay in Delft both valuable and enjoyable.

Dr. Ir. Francesco Di Maio,
Dr. Ir. Somayeh Lotfi,

Organizing Committee
Keynote Lectures
The future of concrete

Peter Rem¹, Francesco Di Maio¹, Somayeh Lotfi¹, Abraham Teklay¹, Ali Vahidi¹

¹Department of Civil Engineering and Geosciences, Delft University of Technology, the Netherlands

Abstract

After a decade of intensive research into the recycling of End-of-Life (EOL) concrete into high-grade new concrete, largely supported by funding from the European Commission, it appears that a circular economy for concrete is technoeconomically feasible. A collection of advanced technologies, in particular smart demolition for clean mono-flows of EOL concrete, new attrition and classification processes for removing the fine, moist-, lights- and cement-rich fraction from coarser aggregates, sensor sorters for removing larger pieces of wood, plastics and metals from recycle aggregate, green thermal treatment for concentrating and purifying the EOL cement paste and Laser-Induced Breakdown Spectroscopy tools for verifying the quality of input materials for the mortar facilities, have been put into place to make recycled concrete in some technical aspects even superior to concrete made from river gravel. And at competitive costs. Is this enough to make the transition to circular concrete into a success? Not necessarily. The integration of circular concrete into the routine of construction requires new procedures and agreements between stakeholders to avoid risks in producing an extremely cheap but at the same time strongly quality-guaranteed concrete commodity from a new and variable feedstock. It is argued that extremely tight quality checks should be installed in combination with a commitment of the entire chain to gently increase the fraction of recycled materials into new concrete as the EOL concrete flow grows as a consequence of phasing out buildings from the post-war boom.
**Use of accelerated carbonation technique to enhance the properties of recycled aggregate concrete**

Chi Sun Poon

Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

**Abstract**

In Hong Kong, huge quantities of construction and demolition (C&D) wastes (57,000 ton-per-day) are produced representing the largest fraction of the total solid waste stream. The disposal of the wastes has become a severe social and environmental problem in the territory. Government sources have indicated that there are acute shortages of both public filling areas (reclamation sites) and landfill space in Hong Kong. Hong Kong’s three mega landfills are expected to be full within 5-6 years’ time. The possibility of reducing and recycling these wastes is thus of prime importance.

The Hong Kong Polytechnic University has been conducting research on methods to recycle construction waste. The potential applications of the recycled materials are in road pavements, concrete, concrete blocks and mortars. Some of the developed techniques have been commercially utilized in industry. This presentation summarizes the major findings of the research conducted, and introduces some case studies on utilizing accelerated carbonation technique to enhance the properties of recycled aggregate concrete.

In recent years, adopting the accelerated carbonation technique to improve the quality of recycled concrete wastes as well as to capture and store CO$_2$ has been investigated by a number of researchers including our group at PolyU. The potential CO$_2$ capture ability of recycled concrete aggregates (RCAs) was related to the carbonation conditions and the characteristics of RCAs. It was found that a moderate relative humidity, a CO$_2$ concentration higher than 10%, a slight positive pressure or a gas flow rate of > 5 L/min were optimal to accelerate the RCAs carbonation. The properties of RCAs were improved after the carbonation treatment. The reduction of water absorption was up to 16.7%. There was about 4.0% increase of 10% fine value and a 26% reduction of crushing value.

This resulted in performance enhancement of the new concrete prepared with the carbonated RCAs, especially an obvious increase of the mechanical strengths and an even more significant improvement of durability properties. In addition, the replacement percentage of natural aggregates by the carbonated RCAs can be increased to 60% with an insignificant reduction in the mechanical properties of the new concrete.

Additionally, the potential utilization of fresh concrete slurry waste (CSW), which is sourced from dewatered solid cement residues after washing out over-ordered/rejected fresh concrete and concrete trucks in concrete batching plants, has been investigated. Due to its rich calcium-silicate content and cementitious feature, it was considered as a cementitious paste as well as a CO$_2$ capture medium to produce new products. Subjecting to accelerated carbonation, rapid initial strength development and lower drying shrinkage for the prepared concrete mixture were achieved. Moreover, the production of the concrete mixtures for partition wall blocks using the developed technique can be considered as carbon neutral.
Advances in studying of recycled aggregate concrete in China

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Abstract

This report firstly presents the current state of construction and demolition (C&D) waste generation in PR China. It is found that the composition of C&D waste in mainland China is much different from other countries, leading to some difficult on the aspect of waste concrete recycling. As a result, in China, some reclamation chains have been well-established, which are suitable for local conditions. Secondly, the research work on recycled aggregate concrete (RAC) in mainland China is introduced, including mechanical property of RAC material, structural behavior of RAC load-bearing elements, and seismic performance of RAC frame structures. The experimental study results prove that it is feasible to apply RAC as a structure material in building structures. Lastly, this report presents an outline of Chinese technical codes for RAC organized and edited by the speaker. It also puts forward some successful applications of RAC in building structures in the mainland of China which will be helpful to promote and popularize RAC as one kind of ecological structural materials.

Keywords: Recycled aggregate concrete (RAC), Reclamation, Material property, Structural behaviour, Technical code, Application.
Accelerating circular city development

Bob Geldermans¹

¹Program Manager Circular City Research, Amsterdam Institute for Advanced Metropolitan Solutions

Abstract

In Circular Cities, resources that drive human activities are by definition regenerative rather than linear or degenerative: be it energy, water, materials, nutrients or air. Meaning the focus shifts from gradual destruction of resource-value – “take, make, waste” – to value-creation through models based on cascades and cycles. In order to establish such regenerative resource flows that retain or increase value in cities’ subsystems there is dire need for new concepts as well as rigorous and critical testing of existing ones: both at an academic and practical level. This relates for example to aligning & connecting flows, exploring shared value models, implementing smart sensing technologies, identifying negative external effects etc. The impact on how cities are conceived, materialized and operationalized in a circular framework can hardly be overstated. Some impacts can be imagined, based on current knowledge, but others can at best be anticipated. This is due to cities being complex, adaptive systems in which “an increasing number of independent variables begin interacting in interdependent and unpredictable ways” [Sanders 2008]. The implications of a circular agenda are thus significant, and we only just begin to fathom the magnitude. Moreover, there is a proliferation of different interpretations concerning the meaning of ‘circular’. Some interpretations are essentially linear processes made more efficient, whereas other interpretations may seem ‘too holistic to succeed’. Accommodating circular processes in all their diversity means that potential contradictions in the actions we take need careful consideration. The abovementioned notions resonate in the Circular City research program through three, strongly interrelated subthemes: 1) materials & buildings, 2) nutrients recovery, and 3) urban energy systems. Each subtheme has its own research priorities, informed by the interplay between society, science and business, rooted in the definition that circular cities understand, establish, monitor and control circular economy principles in an urban context, whilst realizing the vision of a resilient, future-proof city.

An important focus within the 1st theme is on materials that are temporarily stored in built constructions for diverging periods of time. Including the question how to streamline supply, demand and conversion processes of those materials, components and buildings on different time- and scale levels. The 2nd theme concerns nutrient recovery from (waste) water streams. At stake are methods and systems to better reutilize nutrients, materials and energy in water flows, as well as the integration of wastewater treatment systems on various scales in urban regions. The 3rd theme centres on the transition to renewable energy sources and its spatial and infrastructural implications, dealing with increased variability in consumption, storage and production, and concerning multiple energy products and services. This theme accentuates innovation in systems engineering & integration, energy storage, and ICT, adopting a citizen perspective.
Acknowledgements

This project is being funded as part of the “r³” program (Innovative Technologies for Resource Efficiency – Strategic Metals and Minerals) adopted by the German Federal Ministry of Education and Research (BMBF).
The use of renewable materials in reversible building design: a literature study

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Abstract

Today we are getting more and more confronted with the finiteness of mineral and fossil deposits of organic material. Extraction costs are rising and the availability of resources is decreasing. Together with an increased demand -as world population expands and developing nations are becoming wealthier- the situation will become unbearable, even if resources are recycled in perpetuity. Instead of using finite resources, such as concrete and steel, renewable materials, such as flax and hemp, can be used in the building sector. Renewable materials are sourced from living plants and animals and do not disadvantage future generations. They do not only take pressure off finite resources, they can be composted at the end of their useful life if no undegradable materials are added, beside other advantages.

Furthermore, the use of reversible building design is recommended to reduce the extraction of resources. For example, a building can be more easily maintained and can anticipate changing needs during its useful life, such as a changing family composition, without generating additional waste by using reversible building components.

By combining both strategies, the use of renewable building materials and the use of reversible building design, the advantages of both strategies can be combined too. The use of renewable materials in reversible building components enables the closure of the loop at both scale levels: material and component level. In this way, a building component can be reused, but can be composted when a component is damaged.

Therefore, in this paper additional advantages, opportunities, barriers and threats are identified of using renewable resources in reversible building design. In addition, current application is examined.

Keywords: circular product design, reuse, renewable materials.
Characterizing the generation and flows of construction and demolition waste in China

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Abstract

Associated with the continuing increase of construction activities such as infrastructure projects, commercial buildings, and housing programs, China has been experiencing a rapid increase of construction and demolition (C&D) waste. Till now, the generation and flows of China’s C&D waste has not been well understood. This paper aims to provide an explicit analysis of this based on a weight-per-construction-area method. Our results show that approximately 2.36 billion tonnes of C&D waste were generated in China annually during the period of 2003–2013, of which demolition waste and construction waste contributed to 97% and 3%, respectively, in 2013. East China contributed over half of the total C&D waste in China due to their rapid economic development and expansion of cities, followed by Middle China (21%) and South China (11%). Potential economic values from the recycling of C&D waste were found to vary from 201 billion (the worst scenario, i.e., the current practice of C&D waste management) to 401 billion US dollars in 2013 (the most optimistic scenario, i.e., C&D waste is assumed to be well recycled); and the landfill space demands were estimated to range from 7504 million m³ (the worst scenario) to 706 million m³ (the most optimistic scenario) accordingly. Consequently, increasing the recycling rate and reducing landfill rate of C&D waste could not only improve the potential recycling economic values, but also dramatically reduce land use and potential environmental impacts.

Keywords: C&D waste, Waste characterization, Economic values, Land space, China.
A survey on the construction and demolition waste in Mongolia

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Abstract

In many developing countries, the rapid growth of town and cities has generated a rising levels of waste and illegal dumps have become a serious issue. The booming construction industry in Mongolia has resulted in the production of massive amounts of CDW which is one of the largest waste streams. In Ulaanbaatar (UB) and other cities in Mongolia, the construction waste is dumped illegally. In order to promote the sustainability of the building industry, plenty of regulations focusing on reducing or recycling the CDW have been carried out worldwide. This paper investigates the current CDW management in Mongolia and proposes a quantification of the amount of CDW in UB by using a Material Flow Analysis (MFA). Questionnaire surveys and interviews were conducted with main stakeholders in construction and recycling sector. From the questionnaire results, it is clear that the awareness about the CDW issues in Mongolia is low among the principal stakeholders in the sector, such as Government agencies and construction companies. On the other hand, recycling in Mongolia belongs to an informal sector and the lack of investment constitutes a major problem. In this regards, the technical and non-technical solutions to improve CDW management system are proposed. A stricter control of landfilling for CDW and a creation of a dedicated regulatory framework specific to CDW are needed. To increase the recovery and recycling rates of materials an optimum demolition strategy (for example process, costs, logistics, procedures, timing) is recommended.

Keywords: CDW recycling, Construction and Demolition waste management, Material Flow Analysis, Landfilling, Mongolia.

Introduction

The construction industry generates about 35% of industrial waste in the world (Construction Materials Recycling Association, 2005; Hendriks and Pietersen, 2000). In many developing countries, the rapid growth of town and cities has generated a rising levels of waste and illegal dumps have become serious issues. In order to preserve the environment and guarantee growth, a number of studies have been conducted and several solutions have been proposed. Most of these solutions seek to minimize and regulate Construction and Demolition Waste (CDW).

In order to promote the sustainability of the building industry, plenty of regulations focusing on reducing or recycling the CDW have been carried out in many countries and regions such as the EU countries (Symonds Group Ltd., 1999), the US (USEPA, 2009) and Hong Kong (Hong Kong government, 2005). In Hong Kong, the Government has implemented an administrative rule that specifies that CDW containing more than 20% inert material by volume (or 30% by weight) cannot be disposed at landfills (Hong Kong Government – Environmental Protection Department, 1998). In addition, since 2003, a Waste-Management-Plan (WMP) method for all construction projects is required (Tam, 2008). However, the lack
of financial incentives together with the increase in overhead costs is considered as the major obstacles for its implementation.

The problem of quantification of CDW is central to establish reasonable policies as well to propose alternative solutions. The first method to quantify the amount of CDW was proposed in the Netherlands by Bossink and Brouwers (1996) who quantified the waste generation during several residential construction projects. Researchers in countries such as Greece (Fatta et al., 2003), Portugal (Coelho and de Brito, 2011), Hong Kong (Poon et al., 2001, 2004) proposed different methods to estimate CDW. In EU, Llatas (2011) and Mália et al. (2013) carried out studies to propose indicators to estimate the amount of CDW.

The booming construction industry in Mongolia has resulted in the production of massive amounts of CDW. It is estimated that this waste accounts for the large majority of all overall solid waste produced in Mongolia. CDW is thus one of the largest waste streams in Mongolia. In Ulaanbaatar (UB) and other cities in Mongolia, the construction waste is dumped illegally. A huge part of the construction and demolition work is done by small and medium-sized contractors and subcontractors. Thus, small medium enterprises (SMEs) are producing most of the CDW, and their current unsustainable approaches have negative impacts on human health and the environment in Mongolia.

The Mongolian Ministry of Environment reported on average 80,000 tonnes of CDW per year in UB. However, it is only an approximation and it is not clear if this figure is referring to the total amount of CDW or only that registered at landfills. In any case, the uncertainty on total amount of CDW reflects the difficulty of knowing how much CDW is being illegally disposed.

The proposed research will allow to quantify and trace the CDW materials and distinguish the material categories that are more relevant to the developed EU technologies and regulations.

Material and methods

1. Surveys and interviews

Conditions in the Mongolian CDW sector have been qualitatively investigated using two questionnaire surveys and semi-structured interviews with main stakeholders in construction and recycling sector. The surveys were based on similar questionnaires found in journal articles (Tam, 2008; P. Villoria Saez et al., 2013) but tailored to the Mongolian needs. The semi-structured interviews followed a general outline but allowed for areas of interest to be explored in further detail (Punch, 2005). The interviews were intended for gathering further comments; elaboration and interpretation in the results obtained from the questionnaire. The questionnaires were distributed to each target group and a response rate of 75% was considered satisfactory.

A first survey was carried out to clarify the common practices among construction companies and their level of interaction with other stakeholder within the industry. To obtain a representative sample of the companies to be interviewed, TUD selected 70 active construction companies which are divided in:

- 45 active construction companies in UB area.
- 35 active construction companies outside UB. The 35 construction companies covered almost every Aimag (province) in Mongolia, included the Omnogovi province.

The number of construction companies constitutes the 10% of the total members of Builder Association. In total, 700 construction companies are active in Mongolia from which 450 companies are active inside and 350 companies operate outside of UB.
A second survey was directed to the main stakeholders in the recycling sector in Mongolia, such as scavengers/collectors, collection points and recycling industries. Recycling industries are most commonly concentrated in capital city along with Mongolia’s population and industry. For reasons of efficiency, factories tend to locate themselves near the source of materials or end markets, or both. A total of 21 recycling industries are currently operating in Mongolia and 20 industries are located in the seven districts of capital city UB. Namely the following entities are operating in cooperation and non-cooperation with the Mongolian National Recycling Association (MNRA). The two questionnaires are shown in Table 1.

Table 1. Questionnaires sent to construction companies and to recycling companies in Mongolia.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Section</th>
<th>Required information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey to construction companies to</td>
<td>General Information</td>
<td>- The number of construction projects for each company</td>
</tr>
<tr>
<td>investigate CDW sector in Mongolia</td>
<td>- Location of different</td>
<td>- Location of different construction projects.</td>
</tr>
<tr>
<td></td>
<td>construction projects</td>
<td>- Different types of constructions (Residential / Non-Residential).</td>
</tr>
<tr>
<td></td>
<td>- The number of employees for</td>
<td>- The number of employees for each company and years of experience in the construction</td>
</tr>
<tr>
<td></td>
<td>each company</td>
<td>sector.</td>
</tr>
<tr>
<td></td>
<td>- List of the information</td>
<td>- List of the information needed to be provided at the beginning of a construction</td>
</tr>
<tr>
<td></td>
<td>needed to be provided at</td>
<td>project.</td>
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<tr>
<td></td>
<td>the beginning of a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>construction project.</td>
<td></td>
</tr>
<tr>
<td>Construction information</td>
<td>- Relation between company</td>
<td>- Relation between construction company and hired contractor.</td>
</tr>
<tr>
<td></td>
<td>and hired contractor.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Material Wasted: average</td>
<td>- Material Wasted: average different materials</td>
</tr>
<tr>
<td></td>
<td>different materials</td>
<td>quantities (Bricks, Concrete, Plastic, Glass, Wood) wasted in a construction project.</td>
</tr>
<tr>
<td></td>
<td>quantites (Bricks, Concrete,</td>
<td></td>
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<tr>
<td></td>
<td>Plastic, Glass, Wood)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Type of inspections received</td>
<td>- Type of inspections received during a construction process.</td>
</tr>
<tr>
<td></td>
<td>during a construction project.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- The exact sequence of</td>
<td>- The exact sequence of operations for the construction process.</td>
</tr>
<tr>
<td></td>
<td>operations for the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>construction process.</td>
<td></td>
</tr>
<tr>
<td>Construction material procurement</td>
<td>- The suppliers’ information</td>
<td>- The suppliers’ information for each material.</td>
</tr>
<tr>
<td></td>
<td>for each material.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Average prices for</td>
<td>- Average prices for construction materials.</td>
</tr>
<tr>
<td>Demolition information</td>
<td>- Collaboration with</td>
<td>- Collaboration with contractors.</td>
</tr>
<tr>
<td></td>
<td>contractors.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Type of permit needed to</td>
<td>- Type of permit needed to perform the demolition.</td>
</tr>
<tr>
<td></td>
<td>perform the demolition.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- An average number of</td>
<td>- An average number of workers necessary to perform demolition and the average number</td>
</tr>
<tr>
<td></td>
<td>workers necessary to</td>
<td>of days to complete it.</td>
</tr>
<tr>
<td></td>
<td>perform demolition and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the average number of</td>
<td></td>
</tr>
<tr>
<td></td>
<td>days to complete it.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- CDW produced during a</td>
<td>- CDW produced during a demolition.</td>
</tr>
<tr>
<td></td>
<td>demolition.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Level of knowledge of</td>
<td>- Level of knowledge of asbestos risks and procedures followed to treat hazardous</td>
</tr>
<tr>
<td></td>
<td>asbestos risks and</td>
<td>waste.</td>
</tr>
<tr>
<td></td>
<td>procedures followed to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>treat hazardous waste.</td>
<td></td>
</tr>
<tr>
<td>Survey to recycling industries operating in Ulaanbaatar</td>
<td>General information</td>
<td>- Current waste flow and different stakeholders in the waste supply chain</td>
</tr>
<tr>
<td></td>
<td>- Location of the production</td>
<td>- Location of the production site and proximity to end-market</td>
</tr>
<tr>
<td></td>
<td>site and proximity to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>end-market</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Human resources operating on</td>
<td></td>
</tr>
<tr>
<td></td>
<td>site</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technological information</td>
<td>- Production capacity</td>
</tr>
<tr>
<td></td>
<td>- Type of secondary materials</td>
<td>- Type of secondary materials recycled and attitude toward CDW</td>
</tr>
<tr>
<td></td>
<td>recycled and attitude</td>
<td></td>
</tr>
<tr>
<td></td>
<td>toward CDW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Standards followed to</td>
<td>- Standards followed to produce recycle products</td>
</tr>
<tr>
<td></td>
<td>produce recycle products</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Technology used in the</td>
<td>- Technology used in the recycling process</td>
</tr>
<tr>
<td></td>
<td>recycling process</td>
<td></td>
</tr>
</tbody>
</table>
2. Methods to quantify the amount of CDW

In order to quantify the amount of CDW in UB, the methods proposed by Fatta (Estimation methods for the generation of construction and demolition waste in Greece, Fatta et al., 2003) and Llatas (Methods for estimating construction and demolition (C&D) waste, C. Llatas, 2013) were applied. In this study, the proposed MFA calculates the total amount of each material-i \( TW_i \) in tonne/year by the following expression:

\[
TW_i = QP + CW_i
\]  

(1)

Where \( TW_i \) is composed of the amount of material-i coming from demolition activity \( DW_i \) and construction activity \( SP_i \), both expressed in tonne/year.

To quantify the amount of DW, the proposed methodology starts from an analysis of the municipal context, in particular of the buildings in the capital Ulaanbaatar and of the main types of structures-j with the highest probability of being demolished, Bricks and Concrete structure. Furthermore, it is necessary to quantify total demolition waste for the different types of structure-j, \( DW_j \) in ton/year.

By using the formula proposed by Fatta (Estimation methods for the generation of construction and demolition waste in Greece, Fatta et al., 2003), the applied models for DW is as following:

\[
DW = ND \times NF \times SD \times WD \times D
\]  

(2)

- \( DW \) = demolition waste in tonne
- \( ND \) = number of demolitions
- \( NF \) = mean value of no. of floors
- \( SD \) = surface of each building being demolished
- \( WD \) = generation rate of each demolition
- \( D \) = density of waste

Different percentages, \( x_{ij} \), of each material in each building category were adapted from Llatas (Methods for estimating construction and demolition (C&D) waste, C. Llatas, 2013) as shown in Table 2.

### Table 2. Percentages of material-i in each of the building structures in UB

<table>
<thead>
<tr>
<th>Materials/ Buildings</th>
<th>Brick structure</th>
<th>Concrete structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Stony materials</td>
<td>91%</td>
<td>90%</td>
</tr>
<tr>
<td>Concrete</td>
<td>7%</td>
<td>50%</td>
</tr>
<tr>
<td>Ceramics/ blocks mixture</td>
<td>74%</td>
<td>25%</td>
</tr>
<tr>
<td>Concrete/ ceramics</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>% Metal</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>% Plastic</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>% Glass</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>% Wood</td>
<td>3%</td>
<td>3%</td>
</tr>
</tbody>
</table>

The final step it is represented by the quantification of the amount of each material-i studied \( DW_i \) by the following formula:

\[
DW_i = \sum_j DW_j \times x_{ij} \ \forall \ \text{material-i}
\]  

(3)
The amount of CW is directly related to the classification characteristics and construction techniques employed in each building; CW will therefore vary between projects. Given the plurality of projects actually running in UB, CW coming from each material-i is studied by using quantification in (Table 3 and Table 4) as proposed by Llatas in Methods for estimating construction and demolition (C&D) waste, C. Llatas, 2013 as shown in Figure 1. To calculate the total amount of construction waste in tonne/year, the total surface $S_C$ in $m^2$ is then multiplied by weighted averages CDW generation, $W_G$. Hence, the formula to obtain construction waste is given by:

$$CW_j = S_C * W_G \quad \forall \text{ category of building-}j$$  \hspace{1cm} (4)

Finally, the amount of each material wasted in construction $CW_i$ is obtained by splitting the total amount in tonne/year by the rounded average percentage of waste composition $x_{ij}$ calculated by:

$$CW_i = \sum_j CW_j * x_{ij} \quad \forall \text{ material-}i$$  \hspace{1cm} (5)

<table>
<thead>
<tr>
<th>Step 1: Quantification tables classified by project type are obtained (construction); uses (residential, non-residential: industrial, commercial, etc.); and similar technologies relevant to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 2: The features of the project are identified: type of project (construction); use (residential, non-residential: industrial, commercial, etc.); and the main technologies</td>
</tr>
<tr>
<td>Step 3: The surface area of the project is calculated (in $m^2$).</td>
</tr>
<tr>
<td>Step 4: The total waste amount (volume and/or weight) is obtained from the floor area of the project.</td>
</tr>
<tr>
<td>Step 5: The waste composition is obtained (amounts by type of waste).</td>
</tr>
</tbody>
</table>

**Figure 1.** CW quantification methodology [Methods for estimating construction and demolition (C&D) waste, C. Llatas, 2013]

**Table 3.** Average Demolition waste generation rates (kg/m$^3$) [Methods for estimating construction and demolition (C&D) waste, C. Llatas, 2013]

<table>
<thead>
<tr>
<th>Type of construction</th>
<th>Heavyweight</th>
<th>Lightweight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Residential</td>
<td>Non-residential</td>
</tr>
<tr>
<td>New building construction</td>
<td>120-140</td>
<td>100-120</td>
</tr>
</tbody>
</table>
Table 4. Rounded average percentage of waste composition by volume in construction (%) [Methods for estimating construction and demolition (C&D) waste, C. Llatas, 2013]

<table>
<thead>
<tr>
<th>Rounded average percentage of waste composition by volume in constructions (%)*</th>
<th>Heavyweight construction: masonry, concrete, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 Packaging Waste</td>
<td>0.6 – 0.7</td>
</tr>
<tr>
<td>15 01 01 Paper cardboard pack</td>
<td>0.02 – 0.04</td>
</tr>
<tr>
<td>15 01 02 Plastic packaging</td>
<td>0.05 – 0.07</td>
</tr>
<tr>
<td>15 01 03 Wooden packaging</td>
<td>0.5 – 0.55</td>
</tr>
<tr>
<td>15 01 04 Metallic packaging</td>
<td>0.02 – 0.03</td>
</tr>
<tr>
<td>15 01 06 Mixed packaging</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>17 C&amp;D Waste</td>
<td>0.3 – 0.4</td>
</tr>
<tr>
<td>17 01 01 Concrete</td>
<td>0.15 – 0.2</td>
</tr>
<tr>
<td>17 01 03 Ceramics-bricks</td>
<td>0.1 – 0.13</td>
</tr>
<tr>
<td>17 01 07 Mixed concrete ceramics</td>
<td>0.02 – 0.03</td>
</tr>
<tr>
<td>17 08 02 Drywalls</td>
<td></td>
</tr>
<tr>
<td>17 09 04 Mixed C&amp;D waste</td>
<td>0.03 – 0.04</td>
</tr>
</tbody>
</table>

Discussion

1. CDW management based on the interviews and surveys results.

Waste management in general in the UB city is facilitated by the city municipality. Collection services are operated through a mixture of direct services and sub-contracts with service providers. UB Municipality has recorded statistics on the amount of CDW entering into each of the three landfill sites via data obtained from its weighbridges. These statistics offer insight into the current patterns of waste generation from the construction industry. The distribution of CDW between the three landfill/dumpsites in UB is shown in Figure 2. The majority of the generated CDW is dumped in Narangiin Enger and Morin Davaa sites while only a small amount is being disposed at Tsagaan Davaa site. In the mentioned Figure the data for year 2015 stands for the duration from January to August resulting smaller numbers compared to the complete year of 2014.

Illegal dumping represents a serious problem in UB, about 20% of all waste generated in the city is illegally disposed. The numbers from all three official landfills in 2015 reports 65,859 tonnes of construction waste registered. It is reported that the city municipality spent 200 million Tugrugs to clean up illegal CDW in 2011. Backfilling off vehicles delivering materials to site is a common approach to waste collection in the construction industry in UB.
This approach utilises the empty vehicle whilst offering additional revenue for the driver. It is understood that much of this work is done on an informal “cash-in-hand” basis and may be executed without the knowledge of management from either party (e.g. construction company or transport company).

Illegal disposal of construction waste can occur at construction sites or anywhere else. A number of construction sites have reported that construction waste from the construction activity is buried under the site itself. Demolished building materials also are often disposed following the same mechanism. Otherwise illegally disposed construction waste ends in areas along the construction truck route. This route is often route between construction sites, and construction material producers, including gravel quarries.

![CDW disposal in UB 2013-2015 by Landfill](image)

**Figure 2.** CDW disposal in UB during the period 2013 – 2015 divided by the three principal landfills

It is important to highlight the poor monitoring and evaluation system in Mongolia. The processes described in official regulations and documents concerning handling, transporting, and disposal of CDW, respective roles and responsibilities are not reflected properly. Conceptually there are a number of entities assigned to monitor and evaluate proper management of CDW, however their absence is felt as illustrated by the presence of illegal disposal practice and sites. The lack of attention to monitoring transportation and disposal of CDW, is especially evident compared to other monitoring activities regarding construction industry in general, such as land rights.

After presenting information from the questionnaire survey about practices adopted by construction companies in Mongolia, the following conclusions can be drawn:

- Lack of awareness and culture regarding waste management by Government agencies.
- Lack of support and human resources from key stakeholders such as Inspection Agency.
- Lack of incentives from construction regulatory authorities and low costs of sending materials to landfill.
- Lack of community attention on CDW management.
- In the building materials industry in Mongolia processing technology and equipment are often obsolete.
- Demolition activity is not followed by the separation of CDW because companies have no incentives to perform this task.
- Construction companies do not collaborate with recycling companies, most of the time they are not aware of the existence of recycling sector in Mongolia.
- Lack of a database for the buildings of UB create a big obstacle to a clear understanding of the quantities of CDW produced after a demolition.

2. Recycling sector in Mongolia

Recycling is a new concept in Mongolia. The Mongolian recycling sector plays an important aspect of Mongolia’s environment and society. A strong and sustainable recycling sector is essential for Mongolia to utilise resources more efficiently and maximise the full value of materials. At present there is limited information on the recycling sector and the potential for this sector to contribute to environmental, economic and social outcomes. The key reasons underlying this lack of information are the following:
- The recycling sector is often considered along with the waste sector and it is not always possible to isolate the data and information that relates to the recycling sector alone.
- The recycling sector is often highly integrated with other sectors, particularly transport, waste and manufacturing, and it is not always possible to, or there has been no attempt to, isolate the data and information that relates to recycling activity.
- Recycling sector is not clear belong to which government department collect data information, and strategy. There is no fixed law and regulation for recycling sector.

One of the purposes of the in-depth interviews conducted for the research was to arrive at an understanding of the effectiveness of current waste management policies and regulations. Waste management reform is in its early stage of development since Mongolia’s transition to market economy. The relevant legislative acts for this sector were started to be developed from 2000.

Comparing to other countries, recycling sector in Mongolia is an informal sector and a limited amount of data, and information are registered. The industry should be regulated by the government both at municipality and districts levels. Furthermore, the lack of investment constitutes a major problem, most of actual recycling plant’s equipment is obsolete and a strong renovation is needed.

The Municipal Governor’s Office is in charge of waste treatment along with its executive agencies including environmental protection authority and district maintenance companies. Furthermore, there is a lack of potential policies, techniques, financial resources and human resources.

3. MFA results

3.1. Demolition waste quantification

Future DW is calculated from the number of End-of-Life (EOL) buildings which are going to be demolished according to UB Municipality in the period 2015-2018. By following the aforementioned procedures, from a total of 32 concrete buildings and 275 brick buildings, the following numbers are estimated:

- DW Brick = 1,359,072.00 tonne
  - $NF$ = mean value of no. of floors that building has = 3.96
  - $SD$ = surface of each building being demolished = 975 $m^2$
  - $WD$ = generation rate of each demolition = 0.8 $m^3 / m^2$
  - $D$ = density of waste = 1.6 tonne / $m^3$

- DW Pre-cast = 97,335.71 tonne
  - $NF$ = mean value of no. of floors that building has = 3.69
The specific amount of each material-i is presented in Table 5 and Figure 3.

<table>
<thead>
<tr>
<th>Material</th>
<th>DW [t]</th>
<th>% DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>130,373.95</td>
<td>9%</td>
</tr>
<tr>
<td>Bricks</td>
<td>937,099.62</td>
<td>64%</td>
</tr>
<tr>
<td>Mixed concrete</td>
<td>136,815.87</td>
<td>9%</td>
</tr>
<tr>
<td>Metal</td>
<td>30,101.51</td>
<td>2%</td>
</tr>
<tr>
<td>Plastic</td>
<td>14,564.08</td>
<td>1%</td>
</tr>
<tr>
<td>Glass</td>
<td>43,692.23</td>
<td>3%</td>
</tr>
<tr>
<td>Wood</td>
<td>43,692.23</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,456,407.71</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

3.2. Construction waste quantification

UB is facing an important transformation in the last years and number of construction sites has started to increase again after a small interruption during 2013-2015. Figure 4 shows the number of active construction sites for each district.

Actually, 60 construction sites are open in UB with an average surface of 700 m².
Multiplying the total surface for $W_G = 130 \, \text{kg/m}^2$, construction waste $CW$ is obtained and amount of each material $CW_i$ is calculated using the method explained in section 2.2 Methods to quantify the amount of CDW. The final result is shown in Table 6 and figure 5. All the waste produced is going to disposal sites and it can be noticed that wooden materials represents the biggest amount mostly because of wooden packing used in the construction site.

### Table 6. Specific amount of each material-i from construction activity

<table>
<thead>
<tr>
<th>Material</th>
<th>CW [t]</th>
<th>% CW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>1,092</td>
<td>20%</td>
</tr>
<tr>
<td>Bricks</td>
<td>709.8</td>
<td>13%</td>
</tr>
<tr>
<td>Mixed concrete</td>
<td>436.8</td>
<td>8%</td>
</tr>
<tr>
<td>Metal</td>
<td>109.2</td>
<td>2%</td>
</tr>
<tr>
<td>Plastic</td>
<td>273</td>
<td>5%</td>
</tr>
<tr>
<td>Glass</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Wood</td>
<td>2,839.2</td>
<td>52%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5,460</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

### 3.3. Total CDW in Mongolia

To summarize the results obtained from quantification of CDW, UB is expecting a total of 1,461,867.71 tonne CDW over the next years (2015-2018). It is important to notice that Concrete and Bricks account for the large majority of the total amount and as expected, construction waste is marginal compared to demolition activity. Statistics show that the amount of CDW is booming every year in months March, September and October. Thus, it is obvious that the weather is a determinative factor in Mongolia to run the construction or demolition projects.

### Conclusions

In Mongolia, CDW management represents a significant challenge because the performance of SMEs in construction and demolition debris management is still poor. There are difficulties which keep SMEs away from good CDW management practices. In addition, CDW recycling SMEs in Mongolia face a lack of knowledge and the technical capability to deal with negative environmental impacts. Furthermore, there are no specific regulations or certifications for a proper demolition of an End-of-Life (EoL) building, recycling and reuse of CDW in Mongolia.

The purpose of this study has been to identify and document the current CDW management situation in Mongolia and quantify the amount of CDW in UB by using a Material Flow Analysis (MFA). The results indicate the lack of awareness regarding CDW among
stakeholders, especially Government agencies and construction Companies. The Government agencies lack of the support and human resources to effectively monitor illegal disposals and enforce CDW regulations. Construction companies do not collaborate with recycling companies and do not have any incentive from regulatory authorities to use recycled building materials in new constructions. On the other hand, recycling sector in Mongolia is an informal sector and a limited amount of data is registered. Furthermore, the lack of investment constitutes a major problem, most of actual recycling plant’s equipment is obsolete and a strong renovation is needed.
Following the EU practices a stricter control of landfilling for CDW is needed. Setting proper landfilling regulations will be a major driver towards better CDW management. In addition, the landfill disposal fees and taxes, governmental encouragement for environmental friendly practices and granting the related activities and management of demolition waste are key factors.

The CDW producer should develop a system which minimizes the adverse environmental impacts and maximizes the recovery of resources (recycling, reuse). For that reason, the implementation of a waste management policy with not only economic instruments (taxes on landfill), but legal measures such as: selective demolition obligation, voluntary agreements and responsibilities is needed. In this way, even during the production phase, the foundations are laid for the effective and environmentally compatible avoidance and recovery of waste. Once, legal framework is set up, it is necessary to create standards for recycled products to ensure quality and ease market tendency to buy those products. The implementation of secondary raw material regulation and standards is needed. Looking at concrete as the main waste flow estimated in Ulaanbaatar, EU standards can be applied and adapted. In EU, recycled concrete aggregates can be used as the substituent of the natural coarse aggregates for new concrete production. Use of up to 30% concrete aggregates as substitute of natural coarse aggregate is a common practice in the mortar and concrete production facilities.

To increase the recovery and recycling rates of materials an optimum demolition strategy (for example process, costs, logistics, procedures, timing) is recommended. In the Netherlands, selective demolition of EOL buildings is one of the common practices in CDW management projects. The difference between conventional and complete selective demolition is that in selective demolition the workers use light mechanical tools in order to recover the highest percentage of materials that can be reused, whereas in conventional demolition the workers use heavy equipment (explosives, wrecking balls, bulldozers) and, as a result, the generated waste is mixed and the recovery of materials is difficult.

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