FRAMEWORK FOR ANALYSIS OF DEMOLITION SUPPLY CHAIN TO OPTIMISE USE OF RECYCLED CONCRETE AGGREGATE (RCA) AND RECYCLED AGGREGATE (RA)

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Abstract

The paper discusses the factors that affect the recycling rate of recycled aggregates (RA) and recycled concrete aggregates (RCA) derived from demolition waste of reinforced concrete buildings. The recycling rate for construction and demolition waste presently stand at 57% in Australia, where countries such as Japan has achieved 98% recycling rates for demolition waste. A framework is proposed to investigate demolition waste management supply chain as a whole and to critically analyse and investigate the factors affecting the recycling rate of concrete and fines to produce RA and RCA from demolition waste. The factors affecting the recycling rate of concrete and fines across the waste supply chain are categorised into technical, economic and regulatory and policy related factors. The framework proposed is to analyse the inter-relationships between these factors.

Keywords: Sustainability, Waste Management**,** Demolition Waste, Recycling, Recycled Concrete Aggregate

1. Introduction

Construction & Demolition (C&D) waste account for 30-40% of waste generated on a worldwide average. It is considered as a large volume single waste stream.

The extent of the C&D waste stream differs from country to country and differs considerably between countries worldwide. The differences are significant even among developed countries such as Japan (16%), United States (29%), Australia (42%) and UK (>50%). Per capita waste generations also show large variations such as Norway with 0.2 tons/ capita, Australia with 0.88 tons per capita and UK with 2 tons/ per capita approximately. The variations could be explained by the economic activity, differences in building tradition and materials, the maturity and the current phase of the construction industry and differences in data collection with inclusion and exclusion of specific streams such as earth excavations.(Hiete et al., 2011)

Typically demolition activity accounts for less than 10% of total C&D activity, yet demolition waste accounts for about 50% of total C&D waste stream(Tam et al.,2012). This could vary significantly from country to country and the stage of development of the area under concern.

The total construction and demolition waste generated in Australia was 19 million metric tonnes in 2008-2009 and of this 55% was recovered and recycled.(Hyder Consulting, 2011)

Fairly high C&D recycling has been achieved by countries such as Denmark and Germany (Above 90% in late 1990s) and Ireland also achieved rates above 80% by 2005/2006. Japan had a goal of 95% of recycling of C&D in 2010. The present rate for Australia remains at 57%(Hiete et al., 2011).

Table 1 : C&D resource recovery rates in Australia

	NSW	VIC	QLD	SA	ACT	WA	NT	TAS
2008-09 Recovery rate of C&D waste	73%	53%	37%	77%	81%	29%	<1%	15%
2008-09 Recovery rates of Asphalt, Bricks, Concrete and Other masonry	80%	64%	47%	81%	88%	32%	Unknown	21%

There are various options for the management of demolition waste. Reuse and recycling are at the top of the sustainable options, while land filling is considered the least desirable option considering the environmental effect by consumption of landfill space and the associated environmental liabilities. There are various factors affecting the quality and quantity of demolition waste, which can be reused and recycled. The paper analyses such factors and attempts to propose a framework for further investigation on how to achieve higher rates recycling rates of demolition waste in Australia, specifically focusing on concrete and fines.

1.1.1 Recycling of demolition waste

The constituents of waste resulted in demolition largely depends in the demolition method/ technique adopted, type and architecture of building, structural material used and also the quality and standards of segregation adopted on site.

The demolition waste typically consist of concrete and bricks, asphalt, metal, timber, plastics, plaster board, rock and excavation stone, soil and sand, roof tiles, asbestos and cardboard. Typically concrete waste accounts for 50% of the demolition waste stream (Tam, 2012).

When concrete and fines are recycled to produce recycled aggregates (RA) and recycled concrete aggregates (RCA), it goes through a series of processes. At the demolition site the waste needs to be segregated and transported to a recycling facility. At a recycling facility, typically it undergoes manual and mechanical sorting (manual separation of large items and magnetic separation of metals etc.), screening, washing and crushing. The recycled aggregate is then sold as a substitute for natural aggregates for various applications.

The paper identifies the reasons for high recycling rates and analyses the effects and relationships through a proposed framework for further analysis of the total demolition waste supply chain to focus towards maximising recycling.

2. Methodology

2.1 Framework for optimising the use of RCA in high value applications

The framework is summarised in Figure 1.

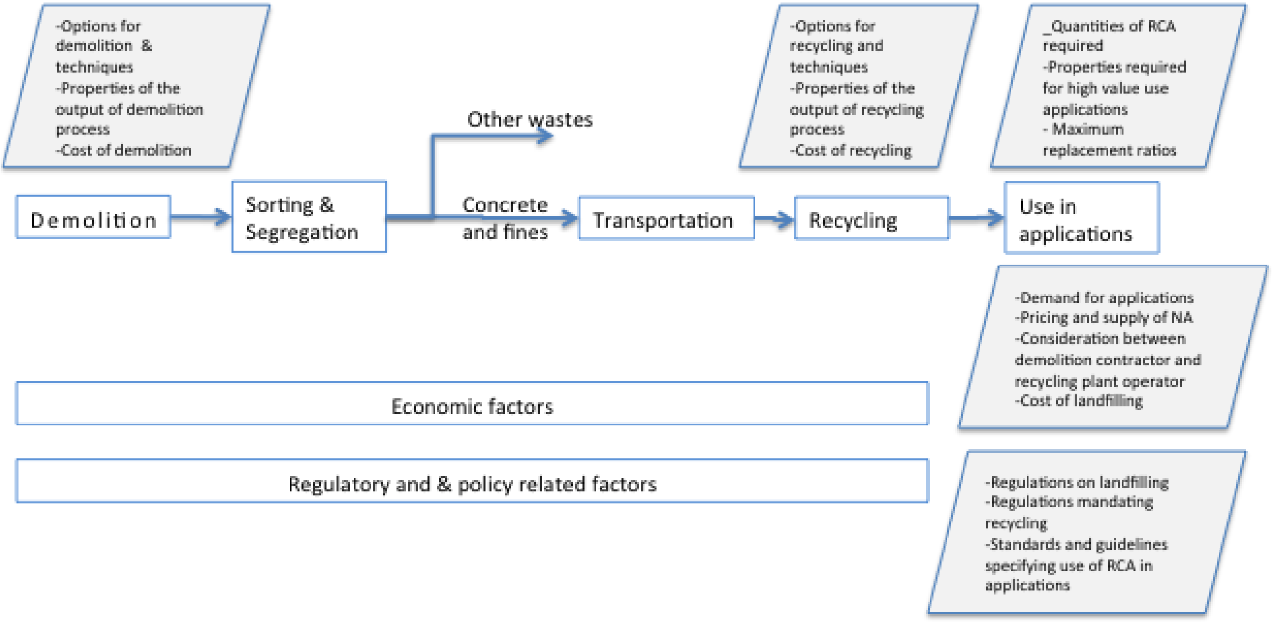

Figure 1: Framework for analysis of demolition supply chain to optimise use of RCA in concreting

2.1.1 Methodology

Demolition chain supply chain consists of a series of key processes. Particularly the supply chain for processing RCA includes demolition, segregation and sorting, transportation, recycling and final residue treatment from the recycling process.

Demolition is the first key process in the supply chain and the method used for demolition is critical as that is the process, which generates demolition waste. The demolition outcome and the output of the demolition process need to be predicted for a given building data.

The process following demolition would be sorting and segregation prior to assigning them for different treatment or disposal methods. Presence of a site waste management plan, prior planning adopted on managing the demolition activity are pre-requisites to conduct sorting and segregation operations effectively.

The concrete and fines are segregated and handed over to a transporter to take to a recycling facility following segregation, and may be stored at site. It is assumed that different recycling practices, methods and the intensity of quality control of process will produce different output of recycling product, and recycling process needs to be driven based on the market demand and price for RCA to produce certain properties.

RA and RCA needs to be produced to match the demand in the market for recycled aggregates, which will depend on the specific applications used and the demand of RCA and RA for those particular applications.

The model predicts that by analysing the demolition supply chain as a whole the amount of RA and RCA diverted to high value applications can be optimised, taking in to consideration the variety of options available at demolition, recycling and the particular applications. The objective is to optimise the demolition supply chain to be application driven to produce the required properties and the required quantities.

2.1.1.1 Applications of RCA and properties required of RCA to promote for high value use

Use of RCA typically accounts for low value and high value uses. High value use of RCA include use for concrete, pre-cast concrete blocks and in clinker manufacturing.

The low value uses include use of RA and RCA as a road filling material in use in pavement sub-bases. One significant advantage of using crushed concrete as a road sub-base is that the same weight of recycled material may offer 10-15% higher product volume. This means the user will get more volume for less value if recycled material is purchased (Hyder Consulting, 2011).

RCA is different in physical properties to the commonly used crushed natural aggregates (Lori G. et al.) mainly due to the presence of very fine particles. Presence of fines affect the hydration and water absorption properties generally (Krezel et al.,2007). Sulphate content is another limiting factor in determining replacement ratios of recycled product.

RCA can be used in concrete for structural and non structural applications. A criterion of acceptance for RCA to be used in concrete has been established which recommends use of RCA for specific structural and non structural applications. For aggregate characterisation composition tests of aggregate, absorption, density, sulphur content and soluable sulphates in acid have been carried out. Depending on the concrete and ceramic particles, the RCA is recommended to be classified into 3 categories by (Agrela et al., 2011).

1.Concrete Recycled aggregate (CRA) - Concrete content >=90%,

2.Mixed Recycled Aggregate (Mix RA) -Ceramic content >10% and <=30%, 3.Ceramic recycled aggregates (CerRA) -Ceramic content >30%

In the above CRA is suggested for concrete applications whereas MixRA is recommended for non-structural applications.

One limiting factors identified in using MixRA for applications of non structural use are high water absorption which result in a need for regulation of the total amount of water in the mix. The sulphate content in the MixRA limits the maximum replacement in the mix, which typically amount to about 40%. Literature suggests further investigations on compressive and tensile strengths with additions of MixRA in concrete for non structural use(Mas et al., 2012).

While use of RA and RCA in concrete in a closed loop is the most desirable in terms of conservation of material and hence sustainability, there are a few key challenges identified and measures suggested in current literature(Soutsos et al., 2011). They are developing technology and conduct research and development on improving the quality of RA with better recycling methods, specification of RA in concrete in standards and expand specifications for the use of RCA in concrete for specific applications, conducting confidence building among users, influencers and other stakeholders by demonstrations and sharing of results in use and facilitate flow of information on the use of RA in concrete.

The model above also takes in to account two other main factors, which have an impact on the amount of RA and RCA diverted to high value applications.

The factors are discussed under two broad headings, namely economic and demand driven factors and regulatory and policy related factors.

2.1.2 Economic and demand driven factors

The economic factors include the economic incentives and consideration applied in the demolition supply chain. If the economic incentives are the main driving force for decisions specifically for the demolition contractor, recycling plant operator and RCA buyer, the dynamics of the supply chain will be influenced greatly by economic incentives.

Duran et al. (2005) established that out of the two policy instruments, namely the command and control measures and market based instruments, the market based instruments are the best method for policy makers to increase economic viability of recycling. Market based instruments could work in two main ways applicable to RCA.

By imposing a tax on landfilling the incentive to recycle increases for the generators of waste. The tax on landfilling here is a reflection of environmental damage and hence the social cost associated with landfilling (Duran et al., 2005).

The second is to impose a tax on NA which makes NA costly for purchasing and makes RCA price competitive with NA for the user of aggregate product. This works ideally when there are underlying assumptions that the user does not perceive a difference between NA and RCA for concreting and all other factors are indifferent towards the use of RCA. (Duran et al., 2005)

When RA is used for low value uses such as a road sub base aggregate, usually the cost of supplying the recycled material to the market including the cost of crushing, exceed the price of material for the particular use (Soutsos et al., 2011). In that context, the demolition contractor needs to pay the recycling plant operator a fee for the recycling of concrete and fines. This acts as disincentive for concrete and fines to be diverted to recycling, when land filling is also an expensive option and when little or no regulations exist mandating diverting of recycleable waste in the C&D stream to recycling.

Specifically concerning the recycling party, Zhao (2011) established that three key factors affecting the feasibility of a recycling plant are the profit, the unit recycling cost and the extra revenue from location advantage.

Tam (2012) established that there is an economic advantage in recycling over natural aggregate use, by conducting a cost-benefit analysis, also taking in to account the environmental cost associated with land filling.

The demand and supply of natural aggregates, differential pricing taking in to account perceptions, the maximum demand for RCA with the identified replacement levels for the relevant applications and the effect of seasonality and variation in supply are other important factors to look at in identifying supply, demand and market based dynamics of movement of RCA volumes.

In summary, landfill tipping fee, market price of natural crushed aggregates are important external determinants driving the demand of RCA while from the operational side, the price paid by the demolition contractor in obtaining material to the recycling plant and the gate fee of RCA at the recycling plant are determinants indicating the economic incentives to parties involved in the process.

2.1.3 Regulations and policy related factors

The regulations governing C&D waste management including reuse, recycling and disposal is important to look at in seeking possible avenues to improve the recycling rates. The policy on C&D waste management and waste management in general also has an impact in this context. The basic principle policy and regulations establishes is the “the polluter pays” principle, where pollution and improper waste management is enforced and incentive mechanisms are implemented to discourage polluters by higher taxation or price mechanisms.

Srour et al. (2012) established that, the enforcement framework, marketability of by products and incentives are important factors in improving recycling rates of C&D waste in countries which suffer from lack of national C&D waste management procedures and facilitiesSpecific regulations governing demolition and C&D waste management, mandatory recycling implemented for identifiable waste types, enforcement of regulations by establishing monitoring mechanisms on waste management and movement are a few best practices adopted by countries having higher recycling rates.

While it is important to regulate waste management and recycling, it is also important to specify use of recyclable products. It is observed that the specification on recycleable products are present more in guidelines and standards than in regulations. It allows flexibility for application improvement. Specifying use of recyclable products is identified as a means of standardising practises of use and communicating to many stakeholders involved on the appropriate use. Construction and Demolition Waste Status Report, Australia by Hyder Consulting (2011) recommends that development of standards and specifications of recycled product as an important means for this purpose.

A brief comparison has been made below on specific measures taken by Germany, UK, Japan and US.

Table 2 : Policy & instruments promoting C&D waste recycling

Country	Present recycling rate	Important measures taken in the regulations and policy
Japan	Concrete recycling 99% in 2006	- General waste management approach towards integrated waste and material management approach - Introduced Concrete Waste Recycling Law, which require demolition contractors to separate and recycle specific construction wastes such as concrete, asphalt and timber. The law applies to large scale demolition projects that exceed a certain threshold
UK	C&D – 70%	- Established Site Waste Management Plans (SWMP) and enforced through UK Environmental Agency. SWMP needs to include declaration of type of waste removed from site, site the waste was taken to, required environmental permit to dispose waste. Implementation of this was combined with increase of landfill tax
Germany	C&D – 86%	- Commercial Wastes Ordinance was enacted in 2003, which regulates the separation of certain types of recyclable waste in the construction and demolition industry. - Waste Wood Ordinance was enacted in 2003, which bans wood waste from landfill and requires diversion to recycling or waste-to-energy options

		- Regional governments are responsible for enforcing regulation regarding C&D waste recycling, which includes issuance of C&D permits which incorporate detailed deconstruction plans and detailed recycling specifications of building materials.

Table 3 : Policy & instruments promoting use of recycled product

Country	**Policy & instruments promoting use of C&D waste material**
UK	- Specifications and design guidelines exist for the use of recycled C&D materials in C&D applications such as Specification or Highway Works, Design Manual for Roads and Bridges etc. The manual covers reclaimed asphalt, RCA and RA - Aggregates Levy is in place which addresses the environmental impacts of the extraction and transportation of NA. The levy seeks the market price of NA reflect the intrinsic environmental cost due to natural resource consumption and make the prices of aggregate alternatives more competitive.
USA	- US Department of Transportation, Federal Highway Administration provides a set of “User Guidelines for Waste and By product Materials in Pavement Construction” for the use in asphalt concrete, Portland cement concrete, granular phase, embankment or fill, stabilised base and flowable fill. The recycled material specified are reclaimed asphalt pavement, roofing shingle scrap and reclaimed concrete - Has a general procedure for enabling use of waste derived by products after carrying out demonstrable applications. The Department of New York State will issue a Beneficial Use Determination (BUD) for waste material following demonstrable applications.

2.1.4 Areas for further investigation

The proposed framework identifies the factors affecting C&D waste recycling to produce RA and RCA and the interrelationships among them. The quantification of the movement of C&D waste and concrete and fine waste along the waste supply chain needs to be done. The quantification will need to simulate the output of demolition and recycling processes specifically when different techniques and methods are used.

Demolition waste is a general stream, which constitutes of demolition waste from roads, commercial buildings, residential buildings and other infrastructure. The demolition waste from these could differ significantly, as in the case of road demolition waste, which consist of asphalt and bitumen in the waste. More specific study on waste sources may be needed to derive conclusive results from the above analysis and quantification.

RCA are not always used as a commodity product when it is used as a building material. Various innovate applications requiring RCA are being tested at small and medium scale, both by the industry and by local councils of Australia. Therefore, there are other businesses creating the pull for RCA which may not be covered in the quantification done above.

One of the main barriers identified in use of RCA is its seasonality in generation, which affects a continuous and reliable supply from the perspective of recycled building material user. RCA and RA derived from various sources vary, it being a processed waste material and there is a need for an intermediary to match the supply to demand by maintaining storage, mixing to meet the specifications and quality control of the product user. This area not comprehensively covered in the demolition supply chain and is marked for further investigation.

3. Concluding Remarks

There is opportunity for improvement of recycling rates to produce RCA for concrete, by recycling demolition waste from reinforced concrete buildings. Demolition is a process which has some degree of control over the waste generated, when looked at from a waste generation point of view. In order to optimise use of RCA for concreting, the waste management supply chain needs to be looked at as a whole to identify products, properties, costs and processes to optimise RCA production and the external factors such as market drives and economic factors, regulations and standards prevailing to support RCA use.

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