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Recycled concrete in structural applications for sustainable construction practices in Australia

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Abstract

As the construction industry drives towards sustainability, recycling construction and demolition waste has become paramount. Furthermore, new construction material composed from recycled construction and demolition waste have added to these sustainable practices. The use of recycled aggregate has been explored to lead to a sustainable future as it provides an alternative to traditional natural concrete. Experimental investigations showed that concrete using recycled aggregate compared to natural aggregate have lower strength. For the construction industry to be sustainable, recycled aggregate must be widely used and even replace natural aggregate. However, research into recycled aggregate discovered the shortcomings of this material and the limiting factors to its utilisation due to its low strength. Several research studies attempt to improve the quality of recycled aggregate by either adding various additives or changing its production methods. However, the industry is still behind in the wider use of recycled aggregate using such research findings. Hence, a research question was formulated as 'what enablers and barriers affect utilisation of recycled aggregate concrete as a structural material?'. Qualitative interviews were conducted in the Australian construction industry to answer this research question, which provided useful enablers and barriers for promoting recycled aggregate as a structural material. Thereby, a "soft" analysis was conducted to motivate of building industry for using RAC. It is hoped that these findings will be useful for researchers, practitioners and policymakers who are responsible for creating a sustainable construction industry.

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Keywords: Sustainability; Recycled Aggregate; Natural Concrete; Construction industry

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1. Introduction

Nomenclature	
RA	Recycled Aggregate
RAC	Recycled Aggregate Concrete
NA	Natural Aggregate
NAC	Natural Aggregate Concrete
C&D	Construction and Demolition

The need to become sustainable in construction has become apparent with the construction industry being a large consumer of natural resources. In particular, the need for recycling construction and demolition (C&D) waste has become crucial. With concrete constituting the main C&D waste produced, and with aggregate being the main by-product of recycled aggregate concrete (RAC), the wider use of recycled aggregate (RA) has been explored so that more sustainable construction practices could be introduced. This paper offers an analysis on different ways of improving the strength of RA, so that it could be widely used in the industry. The paper first presents the literature findings and reports on the case in Australia based on several interviews conducted with builders, designers/ architect and engineers operating in the Sydney region in Australia. This consists of part of a research study undertaken at the Western Sydney University involving all the authors.

2. Key literature findings

This section is structured in three sub-sections. First, the need for sustainability practices in construction with concrete recycling for RA production is presented. Second, current RA applications and barriers for wider applications of RA are explored. Finally, the ways to improve RA for wider construction applications based on current research are discussed.

2.1. Need for sustainable construction practices and concrete recycling

Sustainability in terms of the environment implies a natural resource balance [1]. Sustainability is described as a “meeting the needs of the current generation without compromising the ability of future generation to meet their needs” which implies a precautionary approach to those activities that effect the environment to prevent irreparable damage [2]. For this reason, various research is becoming apparent into sustainable construction practices [1]. Studies conducted across the globe have shown C&D waste to have a large impact on the environment, which need urgent attention [3-6]. With C&D waste being disposed of, landfill space is quickly being depleted [7]. Besides depleting landfill space, harm is also placed on natural resources. Natural resources are being consumed at an alarming rate for the production of new construction materials, rather than recycling and reusing existing materials [8]. Therefore, the need for recycling C&D waste has become crucial for the sustainability of the construction industry.

The Australian Environment Protection Authority of New South Wales Conducted an analysis of C&D waste and their effects on landfills over a 6-year period [9]. It was discovered that concrete was the third highest landfill material, with 220,000 tonnes disposed of each year. With concrete constituting one of the main C&D waste produced, and with aggregate being the main by-product of RAC, the use of recycled aggregate (RA) has been explored to lead to a more sustainable future [7, 8].

Concrete recycling provides three benefits; lessen the need for new natural resources; reduce transportation and production cost; and, utilise C&D waste that would otherwise be discarded in landfills [7]. Recycling of concrete also lowers damages on the environment via improper disposal techniques of concrete waste [10]. However, inertia towards common waste disposal practices hinders the recycling of C&D waste. Tam [10] highlighted that only 57% of Australia’s C&D waste are recycled compared to Japan’s rate of 98%. Australia’s low percentage is owed to four main factors: i) the initial cost of equipment needed for recycling concrete, ii) lack of training and management skills; iii) limited experience with RA; and, iv) limited support [10]. With aggregate consuming 60-75% of concrete volume and RA serving as the main product produced from RAC, greater research should be conducted into the promotion and the use of recycled aggregate [8].

However, the use of RA in concrete is limited to certain applications due to its lowered properties when compared to concrete using natural aggregate (NA). Concretes using RA compared to NA have a lower tensile and compressive strength, and also a decreased durability as discussed next.

2.2. Current RA applications and limitations for wider applications in construction

The use of RA in concrete has shown to be a sustainable and economical alternative to NA and also effective in non-structural components where strength is not critical. Traditionally, RA has been used in the construction of pavements to provide an economic and sustainable alternative to NA [11]. Practical examples in China using a concrete mix proportion employing 50% RA content, have met the same requirements as concrete pavements using NA. Tosic et al. [12] reiterate that pavements and road sub-bases are the most common applications of RA. With only 1% of recycled aggregate being used in structural applications, greater benefits of RA can be seen if they are incorporated in all concrete applications [12]. Therefore, striving to make RA common in all concrete applications, especially those in structural components, the structural properties of RAC must first be established.

The performance of concrete using RA is subjected to several experimental studies. Findings by Martínez et al. [13] exposed that the RA had a negative effect on the properties of fresh and hardened concrete, compared to NA. Similarly, Heeralal et al. [14] found negative effects on concrete when using RA compared to NA. Quiasrawi and Marie [15] discovered that concrete using aggregate that had been recycled twice (2nd generation) had greater properties compared to concrete using aggregate that had only been recycled once (1st generation). Etxeberria et al. [16] suggested that RA should be sourced from recycled low strength concrete as it provides for a cleaner aggregate and that a limit of 30% RA not be exceeded. Experiments of Rao et al.[17] exposed the fact that RAC is less dense compared to concrete using NA, therefore RAC has a competitive advantage over NAC when lightweight concrete is required.

Overall, the above-mentioned research shows that RAC is inferior to NAC mainly in terms of strength, with strength decreasing as the RA content increases. However, for the construction industry to be more sustainable, RA must be widely used and even replace NA in structural applications. The next section discusses the different attempts taken by researchers to improve the strength of RAC so that it could be better utilised in structural applications.

2.3. Technology and research for improving RAC properties

For RA to be commonly used in concrete, the properties of RAC must be equal to that of NAC. However, the above research into the properties of RAC, illustrates that this is not the case. Therefore, for this to materialise, the mechanical properties of RAC must be enhanced. It is explained that with the appropriate admixtures and quality materials an RAC mix could be engineered for structural purposes. Literature shows many attempts taken to improve RAC as depicted in Figure 1 and explained one by one in the subsequent paragraphs of this section.

As previously mentioned, Martínez et al. [13] conducted a comparative analysis of RAC and NAC in Cuba, and furthered their research by experimenting on methods to improve the qualities of RAC to equal those of NAC. It was determined that limestone filler with the addition of white slag in RAC equalled the physical and mechanical properties of conventional masonry using natural aggregate. The RAC mix used, contained 3 different RA sizes to improve the grading distribution and also helped to enhance the properties of RAC. Conversely, Martínez et al. [13] highlighted that natural aggregate in Cuba is of lower quality due to a lack of natural resources. Therefore, these findings are limited, as the strength of the proposed mix used by Martínez et al. [13] may not equal NAC in other locations using a high-quality NA, such as Sydney. Knoeri and Althaus [18] added further cement to RAC to counteract the lowered mechanical quality, which allowed the RAC to equal the strength of NAC.

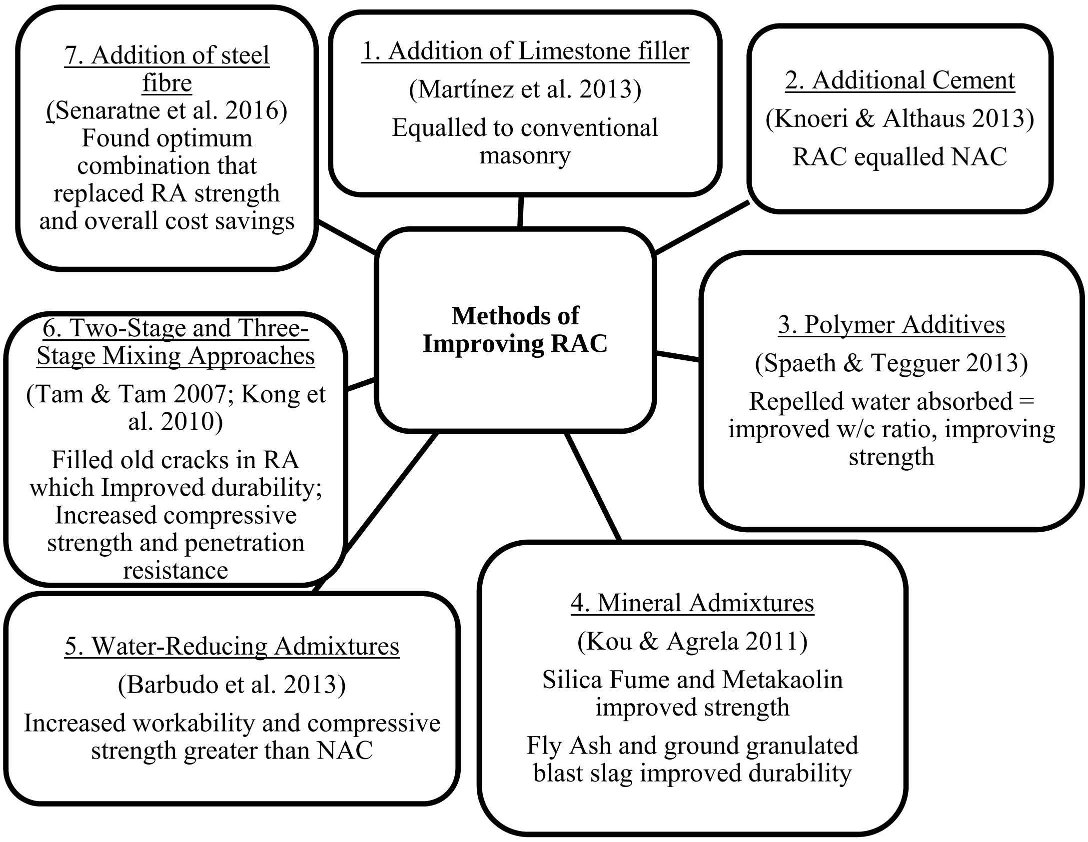

Fig. 1 Methods of Improving RAC

The use of polymers has been tested in attempts to provide a solution to the poor water absorption characteristics of RAC [19]. Using soluble sodium silicate and various silicon base additives, polymers were also used to provide better fragmentation resistance of RAC. Spaeth and Tegguer [19] found that the water repelling capabilities of polymers created a film around the mortar paste attached to the RA. Therefore, significantly reducing the water absorbing characteristics of RA and strengthening the cement matrix of RAC [19]. However, the above study does not translate findings into quantifiable strength differences of RAC with and without polymer additives. This provides the evaluation of polymers difficult to determine.

Kou and Agrela [20] explored the use of the following mineral admixtures to improve properties of RAC and NAC: with silica fumes, metakaolin, fly ash and ground granulated blast slag (GGBS). It was found that silica fumes and metakaolin improved durability and mechanical properties. Whereas fly ash and GGBS had a negative effect on mechanical properties; yet, they decreased the permeability of the concrete [20]. It was observed that the mineral admixtures showed greater improvements on RAC than NAC. As RA are more porous, one possibility for this occurring is given, as the material admixtures penetrate the RA greater [20]. Therefore, it showed a greater interfacial transition zone (ITZ) connection between the RA and the mortar paste. Overall, findings of Kou and Agrela [20] showed that NAC without these mineral admixtures shows greater mechanical properties than RAC containing these mineral admixtures.

In attempts to increase the workability of RAC using water-reducing admixtures, Barbudo et al. [21] discovered that the mechanical properties of RAC were also improved. Barbudo et al. [21] found that by using plasticisers and super-plasticisers a lower water/cement (w/c) ratio with the same workability was achievable. Plasticisers not only increase workability, they also fill the volume of voids in concrete, effectively improving the mechanical performance of concrete [21]. With the lower w/c ratio achieved, this equates to an RAC with a greater strength and increased durability.

Tam and Tam [22] explored the durability of RAC employing a two-stage mixing approach (TSMA). The two-stage mixing approach process focuses on the production process of concrete to improve the qualities of RAC, when compared to a normal mixing approach. It was found that the two-stage mixing approach improved the RAC in terms of deformation and permeability. This was owed to the cement slurry filling up old cracks in the porous old cement mortal on the RA, during the first mixing stage.

In response to the TSMA, Kong et al. [23] employed a triple-stage mixing approach to providing greater RAC properties when compared to the TSMA. The triple-stage mixing approach was used to surface coat the RA in pozzolanic particles, which proved successful in increasing the interfacial transition zone seen by the microstructure [23]. Pozzolanic particles coat the water absorbing chloride ion crystals found in old adhered mortar paste on RA. Therefore decreasing water absorbed by the RA. This indicated an increased strength in compression and penetration resistance of RAC using the triple-stage mixing approach compared to the TSMA.

According to Senaratne et al [24], by adding steel fibre to RA, a structurally sound material can be obtained. They found the optimum combination through experiments as 30% RA replacement with the addition of 0.6 % steel fibre, which also revealed significant cost savings when environmental benefits were considered.

Although these types of different studies on improving RA to match NA strength are substantially undertaken, the use of such methods is inadequate in the current practice which could be due to unknown barriers. Hence, there was a need to explore what barriers and enablers affect the use of RA as a structural material in the construction industry. This led to the research question of this study; “what enablers and barriers affect utilisation of RA as structural material? The research method used to answer this research question is explained next.

3. Research method

To gather reliable and valid results in the most efficient manner the most appropriate research method must be utilised for the research question. Among the various research methods, there are three common approaches that can be employed in construction research: qualitative, quantitative and the mixed methods [25]. Qualitative research uses non-numerical data such a people perceptions, opinions to investigate aspects of their social world. Yin [26] explained that for research to be qualitative it must be under real world conditions, present perspectives, be contextual, provide insight to new or existing concepts and use multiple sources. Hence, a qualitative approach using semi-structured interviews was considered to achieve the research question.

The data collection involved interviewing construction practitioners to determine their perspectives and enablers and barriers of introducing RA as a structural material. A stratified purposeful sample was utilised to collect these industry perspectives. Stratified purposeful sampling involves firstly identifying the particular groups to be included in the final sample [27]. The sample is then stratified into these groups and a target number of participants are purposely assisted to each group. As different professionals within the industry were targeted through this sampling technique, it assisted in highlighting the characteristics of the various groups [27] and facilitated comparisons. Accordingly, each of the following groups was interviewed: Builders; Designers/Architect; and, Engineers.

An interview guide with semi-structured questions was formulated to conduct the interviews. Qualitative interviews have been employed to gain in-depth experiences and the participants’ perspectives. As qualitative interviews are conducted in a relaxed manner, a more personal response is offered while participants are asked a series of structured open-ended questions [28]. In particular, the interview questions were targeted to gather the opinions of use of RA as a structural material and how prepared the practitioners are to recommend and use such material. Therefore, Qualitative Interviews provide the flexibility to gather rich data on observed prompts from participants. After obtaining relevant Human Research Ethical Approvals, the interview process began. Over 45 minutes, qualitative interviews assisted in gathering the perspectives of each group. Interviews were concluded once results became overly saturated and a similar theme could be seen across interviewees’ answers. This approach is consistent with qualitative interview techniques [28]. **Error! Reference source not found.** illustrates the interview sample.

The data collected from interviews were first transcribed and then analysed using maps and content analysis. In this paper, the individual cognitive maps that were drawn for each practitioner group's perspective are not provided due to space limitations; however, the overall map is offered d at the end of research findings in the next section.

Table 1:.Interview Sample.

Interview group	Company Size	Position	Experience in years
Builder 1 (Construct Only)	Tier 2	Director	25
Builder 2 (Construct Only	Tier 2	Senior Project Manager	15
Builder 3 (Construct Only)	Tier 3	Project Manager	10
Builder 4 (Design and Construct)	Tier 2	Managing Director	19
Builder 5 (Design and Construct)	Tier 2	Construction Manager	31
Builder 6 (Design and Construct)	Tier 3	Project Manager	9
Architect 1	Small	Senior Associate	29
Architect 2	Large	Principal Architect	31
Architect 3	Medium	Designer	6
Engineer 1	Large	Senior Structural Engineer	26
Engineer 2	Medium	Structural Engineer	8
Engineer 3	Small	Managing Director	17

4. Research findings

The interview findings from builders, designers/architects and engineers are summarised in this section followed by a map given in Figure 2.

Amongst builders, a common view on **cost** can be seen. Builders were concerned with the higher initial purchase cost of the RAC with added additives when compared to NAC. Builders advised that on lump sum projects in particular, all possible cost savings are exploited. Hence, they mentioned that such material would need to present some form of cost saving, either monetary or time, to be favorable amongst builders. Builders further mentioned that they are not inclined to change the **concrete specification** that had been specified by the engineer and, therefore, the perspectives of designers/architects and engineers should be sought.

Designers and Architects were **interested in the sustainable benefits** of using RA. They were quite excited about the idea of using RA in structural applications. Most Designers/Architects pressed that a structure constructed from such material could be marketed to be "green" and be appealing to clients. Furthermore, all Designers and Architects suggested that if this material were used in the construction of a new building, the building could potentially gain a **higher green rating** with the many green-rating systems available. However, they stated that they would be apprehensive to specify an alternative structural material if it had a higher initial cost. Designers and Architects argued, that if a project enter value management at design state, this material would be the first to be substituted with traditional concrete if a cost saving was possible.

Designers and Architects further predicted that this material would be appealing to residential clients and government seeking the longest possible service life of their structure. Hence, **life cycle analyses** are needed to confirm cost saving over the life span of the structure. Furthermore, Designers/Architects maintained that they would be hesitant in specifying a material that is 'far left field' as it places a great deal of risk on the Designer/Architect if the material fails structurally. Hence, more experiments are needed to confirm structural feasibility.

Engineers saw little motivation towards this material as most were **concerned with the consistency** of recycled products such as RA. Engineers stated that practitioners are interested in structural materials with good consistency. Some Engineers recommended that this material could enter the industry via **precast concrete panels,** where quality and consistency could be closely monitored. Most Engineers then suggested that if a **standard** were available for this material, practitioners would be more inclined to specify and utilise this material, and therefore tangible results are needed. Furthermore, one engineer suggested that if a standard such as RMS 3051, which is used for construction bases in New South Wales, is developed for this material, engineers would specify such a material. However, engineers too mentioned about concerns on higher initial costs.

In agreement with designers/architects, engineers proposed achieving **a higher green rating** if this material were used. One participant brought to the attention that 'GreenStar' offer a higher green rating if structural steel is sourced from Australian recycled steel. Therefore, this material should also offer a similar higher rating as it provides a recycled sustainable alternative to NAC. It was urged that structures today are commonly constructed from concrete and with many trying to achieve a high green rating this could be a major enabler to its use. Engineers saw a potential for the material on **projects that required a high environmental consideration** such as government infrastructure and construction projects. If greater durability could be achieved, most engineers suggested its use **favorable in marine construction and high weather exposed environments**. The collective perspectives from the construction practitioners are depicted in Figure 2. The next section offers conclusions of this study.

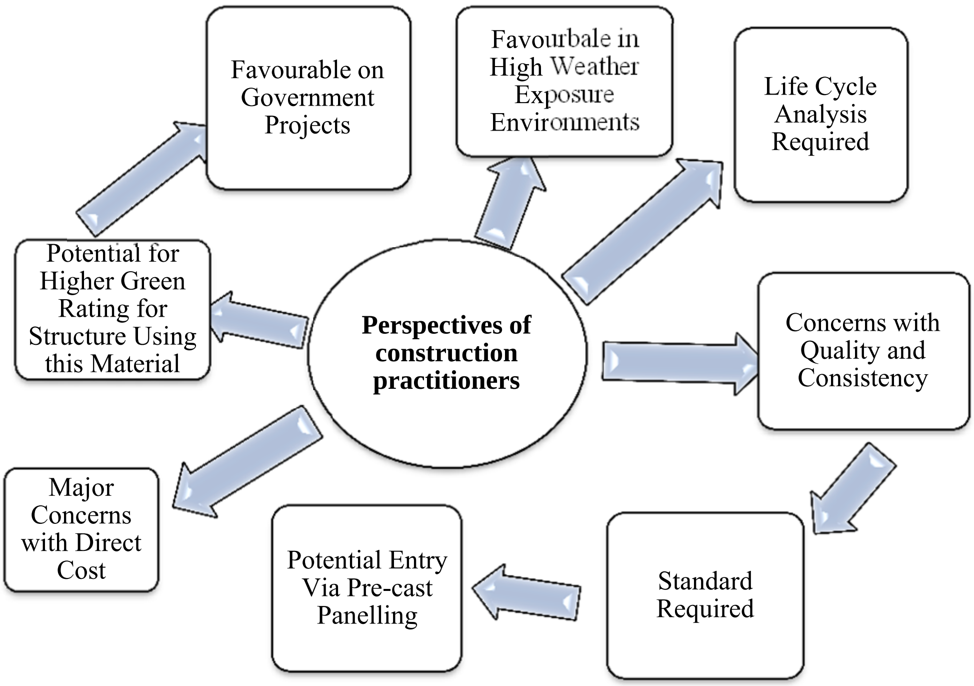

Fig. 2 Collective Perspectives of Construction Practitioners on use of RA as a structural material

5. Conclusions

With added pressure on the construction industry to continuously incorporate sustainable practices, a battle between economic and environmental elements was discovered. Recycling old concrete is a major practice that the construction industry must focus on to led to a sustainable future. The use of RA in concrete provides a sustainable alternative to NA, and has proved to be successful in structural applications by various researchers. However, lack of utilisation of RA as a structural material was observed in the industry practices. This led to carry out qualitative interviews with industry practitioners in search of barriers and enablers that affect the use of RA in structural application.

Overall, the interview results revealed that construction industry practitioners were concerned with possible higher initial purchase costs. Participants urged that a life cycle analysis is conducted to quantify potential saving from increase durability. However, practitioners where motivated by the sustainable benefits and suggested a higher green rating possible for structures using RA. It was, in particular, recommended for government projects and those with high environmental consideration. Further, entry of such material to the market could be through pre-cast panel construction as quality and consistency could be closely monitored. This research had revealed various enabling and inhibiting factors in the use of RA as a structural material and also suggest further areas of research needed such as life cycle cost analysis and experiments using pre-cast construction. In keeping with these recommendations, industry will be closer to seeing this material accepted and utilised. Further, it is important to start changing the industry attitudes towards sustainability-conscious material choices, as inertia towards traditional practices in construction is prevalent. Ultimately, it would provide another sustainable practice to the construction industry.

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This paper is based on a part of a research study undertaken at the Western Sydney University involving all the authors.

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