Sustainable Concrete in Transportation Infrastructure: Australian Case Studies

Koorosh Gharehbaghi¹ᵃ, Farshid Rahmani¹ᵇ and David Paterno¹ᶜ
¹RMIT University, Melbourne, Australia

ªkoorosh.gharehbaghi@rmit.edu.au, ᵃfarshid.rahmani@rmit.edu.au, ᵃᵈavid.paterno@rmit.edu.au

Abstract. Whilst generally concrete and steel are the most common substances for civil engineering construction, new trends and development such as sustainable and green material have a lesser effect on the environment. Typically, approximately 90% of a concrete structure’s CO₂ emissions are a result of the energy consumed during its life, there is much that can be done to reduce that 10% associated with its construction. Thus, innovative engineering materials, such as Recycled Concrete (RC) have emerged with the potential to influence the future of an environmentally sustainable construction industry. This research investigates the RC as the basis of sustainable concrete for civil engineering construction such as roads, rail and so on. Furthermore, number of examples, 6 roads and 6 rail segments in Sydney, were reviewed. Overall, this research found that for the 6 road and rail case studies generally only RC is utilized as the basis of sustainable material. Although, this is a very small sample, however, a pattern can be noticed. Unfortunately, the pattern is the lack of innovative sustainable material other than concrete for such transportation infrastructure. Appropriately, further investigation is required to review the possibility of other sustainable materials including those incorporating waste-by products as the basis consolidated sustainable material usage in transportation infrastructure.

1. Introduction
The general aim of sustainable materials is to expend less energy, and to reduce environmental impacts [1-4]. Utilizing such materials is detrimental to ensure a sustainable living. An example of such material is Recycled Concrete (RC). Typically, approximately 90% of a concrete structure’s CO₂ emissions are a result of the energy consumed during its life, there is much that can be done to reduce this [5-7]. Gharehbaghi [8] noted that, within the building and construction field, concrete is the primary starting point for the CO₂ emissions reduction. This is because concrete is responsible for approximately 10% of global CO₂ emission [9-11]. For sustainable concrete, more greener forms of substance can be formed which utilizes recycled materials in its mix [12,13]. For example, crushed glass can be added, as can wood chips or slag – a byproduct of steel manufacturing. Whilst these changes do not fundamentally transform concrete, however, using such processing methods would ultimately reduce the CO₂ emissions associated such material manufacturing. As shown in Fig 1, the use of concrete is on-going regardless of its CO₂ emissions footprint.
For emerging economies including China and India, concrete is still an essential material. Such popularity is due to concrete’s performances for different conditions and climates together with its ease of use [14-16]. Nonetheless, the concrete’s environmental impact is still an on-going concern. Thus, innovative engineering materials, such as RC have emerged with the potential to influence the future of an environmentally sustainable construction product industry. Further, for the transportation infrastructure such modern material processing will be also significantly beneficial.

2. Literature review

2.1. Sustainable concrete in transportation infrastructure

Although there are various systems available to utilize in material selection, processes are not universal, and the importance of factors alters depending on the country of location [17-20]. Fehling et al. [21] identified multiple barriers to incorporate sustainability into material selection practices. These include perceived costs, time to source materials, education and training, understanding in-house experts. Akadiri [22] further investigated the barriers of implementing a sustainable selection practice and mentioned that a lack of sustainable material information, perception of extra costs being incurred, perception of extra time being incurred, perception that sustainable materials are low in quality and an unwillingness to change the conventional way of specifying are the most influential barriers affecting the incorporation of sustainable design within high-rise construction. A review of literature revealed cost figured predominantly as a barrier to achieving sustainability [2,23,24]. In selecting sustainable concrete, benefits such as the overall productivity, performance and so on need to be considered [25,3]. Chevalier et al. [26] argued that specific factors to consider when using sustainable concrete such as RC, include its functioning capabilities among others. The sustainable concrete's functioning ability aligns with its structural capabilities [27]. This includes load bearing capability, stress and strain probabilities and so on. Gharehbaghi and Georgy [28] noted that, the greatest problem facing sustainable concrete is early deformation and degradation. Transportation infrastructure and their subsequent connection systems use concrete in their assembly and configuration including structural support and so on [29]. While for roads, concrete is extensively utilized for decks and carriageway surfacing, for railways it is used for sleepers and other structural systems. Subsequently, recycled concrete aggregates would be sustainably favorable for transportation infrastructure [30]. However, one of the greatest concerns of recycled concrete is its durability and performance. Such concern also includes using recycled concrete for transportation infrastructure [31,32]. Mamlouk and Zaniewski [33] along with Sadek et al. [23] and, Singh et al. [17] noted that, some of the concerns in using recycled concrete, significant deterioration rate due to excessive exposure to substantial water, significant temperature changes and air contaminants which all are common in
transportation infrastructure. Furthermore, table 1 summarizes some risk associated with sustainable concrete in transportation infrastructure. However, based on the examination of the literature, it is therefore evident that engineers do not perceive that there is a widespread demand for sustainable concrete in transportation infrastructure. Accordingly, a review into new trends and developments for such infrastructure needs to be undertaken.

2.2. New trends and developments
Hibbeler and Vijay [34] together with Öchsner and Altenbach [35] as well as Jahan et al. [36] highlighted that traditional material selection for transportation infrastructure generally include longevity. Nonetheless, over the past few years many recycled materials including RC are been used in such infrastructure [37]. Specifically, recycled cement, plastic and asphalt are being used more and more [39]. These sustainable materials are used for low use areas such as local roads [39, 40]. However, for major arterial road together with rail networks currently, only RC seems to be the best option [41]. The reason for such limitation of material selection is based on: highly complex design of the structure together with exceedingly cost due to the size of roads and rail networks [42, 43]. For these reasons the use of sustainable concrete in transportation infrastructure is still unfortunately limited. Dejectedly this has led to lack of available sustainable materials for such infrastructure. Due to high performance concrete composition together with long-term material performance, the RC is still the only major sustainable concrete in transportation infrastructure. To support such claim 6 road and six rail segments have been studied.

3. Research methodology
The research will use qualitative method and therefore utilises Australian case studies to review new trends of sustainable concrete in transportation infrastructure. In achieve such outcome, document search was undertaken to define the sustainable concrete specifics of road and rail infrastructure.

4. Case studies
As the basis of case studies, 6 roads and 6 rail segments in Sydney, are investigated. Both tables 1 and table 2 present the overview of these case studies.

Table 1. Overview of roads case studies.

| Road segment #     | Road classification | Sustainable material and portion | Sections used             |
|--------------------|---------------------|---------------------------------|---------------------------|
| SydEast0097        | Major collector road| Recycled concrete <10%          | Bituminous layer          |
| SydNorthEast0024   | Major collector road| Recycled concrete <10%          | Bituminous layer          |
| SydSouthEast013    | Principal arterial  | Recycled concrete <3%           | Bituminous layer          |
| SydWest0016        | Minor arterial      | Recycled concrete <5%           | Bituminous layer          |
| SydSouthEast008    | Minor arterial      | Recycled concrete <5%           | Bituminous layer          |
| SydNorthEast0151   | Local road          | Recycled concrete <15% and plastic <5% | Bituminous and surface layers |
As observed, for the 6 road segments only a small portion possess sustainable materials. For such infrastructure recycled concrete were the main composition of sustainable materials. While the Bituminous base course consisted of traditional Sub-grade gravel, stones and sands; the Binder course also possessed conventional materials. On the other hand, Bituminous concrete layer is where all the sustainable material was utilised. For these six case studies, recycled concrete was the only material used. Only for SydNorthEast0081 recycle plastic was used as basis of surface covering.

Table 2. Overview of rails case studies.

| Rail segment # | Rail classification | Sustainable material and portion | Sections used |
|----------------|---------------------|---------------------------------|---------------|
| T1032          | Class 3: Local railroad | Recycled concrete <10% | Rail sleepers |
| T4016          | Class 3: Local railroad | Recycled concrete <10% | Rail sleepers |
| T5009          | Class 3: Local railroad | Recycled concrete <10% | Rail sleepers |
| T5019          | Class 3: Local railroad | Recycled concrete <10% | Rail sleepers |
| T7005          | Class 2: Switching terminal railroad | Recycled concrete <10% | Rail sleepers |
| T9037          | Class 3: Local railroad | Recycled concrete <10% | Rail sleepers |

Sydney currently has 9 main rail network lines, ranging from T1 to T9. For these, standard Australian intermediate gauge railways are used. In addition, for these 6 case studies, steel is also used as the basis of rails, while recycled concrete is utilized for sleepers along with stones for ballast. Overall, as it can be noticed, for these 6 road and rail case studies generally only RC is utilized as the basis of sustainable material. Although, this is a very small sample, however, a pattern can be noticed. Unfortunately, the pattern is the lack of innovative sustainable material other than concrete for such transportation infrastructure.

5. Conclusion and recommendations
Concrete together with steel form part of the primary materials used in transportation infrastructure. Due to ever increase in CO\textsubscript{2} emissions, new sustainable materials are sought for such infrastructure. Innovative engineering materials, including RC are the back-bone of greener propositions for such environmental considerations. Subsequently, this research found that the new trends and developments for transportation infrastructure is limited mainly to RC. To demonstrate such dilemma, 6 Australian road and six rail segments were reviewed. Due to such limitation new and improved substance other than RC are essential to embrace sustainable material specifically for transportation infrastructure. Areas for further research could include the investigation of other sustainable materials including those incorporating waste-by-products. Other sustainable materials which are in testing phase or have recently been developed, could further promote sustainability in transportation infrastructure.

6. References
[1] R. Riles, M. Bilec, N. Gokhan, and K. Needy: The Economic Benefits of Green Buildings: A Comprehensive Case Study, The Engineering Economist, Volume 51. Issue 3 (2006), pp 259-295.
[2] Z. Bribian, V. Capilla, and A. Uson: Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential’, Building and Environment, vol. 46 (2011), pp. 1133-1140.

[3] K. Gharehbaghi, and F. Rahmani: Practicalities and Developments of High-Rise Composite Structures: Case Studies, Materials and Technologies in Engineering (2018), pp 153-159.

[4] K. Reddy, C. Cameselle, and J. Adams: Engineering Practices, Sustainable Engineering: Drivers, Metrics, Tools, Engineering Practices, and Applications, Vol. 1, no.1 (2019), pp 419.

[5] J. Glasson, R. Therivel, and A. Chadwick: Introduction to Environmental Impact Assessment, Taylor and Francis, UK (2012), pp 87-96.

[6] M. Gere, and J. Goodno: Mechanics of materials, 8th edition, Stamford: Cengage Learning. (2013).

[7] A. Lukman, O. AkanbiacLukumon, O. Olugbenga, A. Akinadea, A. AyaiYaJuan, M. Davila, D. Hakeem, and A. Oowelabia: Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy, Journal of Cleaner Production, Vol. 223. (2019) pp. 386-396.

[8] K. Gharehbaghi: Advancements in concrete technology in Australia: geo-polymer concrete, International Journal of Constructed Environment, volume 7, issue 1 (2015), pp 19-29.

[9] A. Arroglu, Ï. Mahmure, D. Dhavale, and , J. Sarkis: Greenhouse gas emissions in the construction industry: An analysis and evaluation of a concrete supply chain, Journal of Cleaner Production, vol.167 (2017), pp.1195-1207.

[10] K. Gharehbaghi, and C. Scott-Young: Waste diminution in construction projects: Environmental predicaments, Earth and Environmental Science, Institute of Physics, United Kingdom, vol. 127, no. 1. (2018b) pp. 58-63.

[11] M. Eckelman, C. Brown, L. Troup, L. Wang, M. Webster, and J. Hajjar: Life cycle energy and environmental benefits of novel design-for-deconstruction structural systems in steel buildings ,Building and Environment, Vol.143 (2018), pp.421.

[12] J. Giesekam, J. Barrett, and P. Talyor: Construction sector views on low carbon building materials, Building Research & Information, vol 44 (2015) pp 423-444.

[13] K. Gharehbaghi, and R. Chenery: Fiber Reinforced Concrete (FRC) for High Rise Construction: Case Studies, Materials Science and Engineering, vol. 272 (2017), pp 223-229.

[14] E. Kocs: The Global Carbon Nation: Status of CO2 Capture, Storage and Utilization, EPJ Web of Conferences 2017, Les Ulis: EDP Sciences, Vol 148 (2017) pp. 3-31.

[15] S. Lockrey, K. Verghese, E. Crossin, and H. Nguyen: Concrete recycling life cycle flows and performance from construction and demolition waste in Hanoi, Journal of Cleaner Production, vol. 179 (2018), pp. 593-604.

[16] V. Kashintseva, W. Strielkowski, J. Streimikis, and T. Veynblender: Consumer attitudes towards industrial CO2 capture and storage products and technologies, Energies, vol. 11, no. 10. (2018).

[17] M. Singh, T. Ohji, and R. Asthana: Progress and Prospects, Green and Sustainable Manufacturing of Advanced Materials, 1stedn, (2015), pp. 3-10, Elsevier.

[18] C. Kilbert: Sustainable construction: Green building design and delivery, Hoboken, Wiley, (2016), pp 78-82.

[19] N. Bestner: Concrete for high-rise buildings: Performance requirements, mix design and construction considerations, Structural Concrete Properties and Practice, (2013), pp. 1-4.

[20] K. Gharehbaghi, and C. Scott-Young: GIS as a vital tool for Environmental Impact Assessment and Mitigation, Earth and Environmental Science, Institute of Physics, United Kingdom, vol. 127, no. 1. (2018a), pp. 52-57.

[21] E. Fehling, B. Middendorf, and J. Thiemicke: Ultra-High Performance Concrete and High Performance Construction Materials, Kassel University Press, Kassel, Germany (2016).

[22] O. Akadiri: Understanding barriers affecting the selection of sustainable materials in building projects, Journal of Building Engineering, vol. 4 (2015), 86-93, Elsevier.

[23] M. Sadek, M. El-Attar, and A. Ali: Reusing of marble and granite powders in self-compacting concrete for sustainable development, Journal of Cleaner Production, vol. 121, (2015), pp., 19-32, Elsevier
[24] B. Guerra, A. Bakchan, F. Leite, and K. Faust: BIM-based automated construction waste estimation algorithms: The case of concrete and drywall waste streams, Waste Management, Vol. 87 (2019), pp.825-832.

[25] A. Yates: Sustainable Infrastructure – Sustainable Buildings, ICE Publishing (2015), pp 121-134.

[26] Y. Chevalier, and J. Vinh Tuong: Mechanics of viscoelastic materials and wave dispersion, London : Hoboken: Wiley (2010).

[27] W. Findley, and F. Davis: Creep and Relaxation of Nonlinear viscoelastic materials, Newburyport : Dover Publications (2013).

[28] K. Gharehbaghi, and M. Georgy: Sustainable Construction by Means of Improved Material Selection Process, International journal on the Academic Research Community publication, vol 1, issue 1 (2019), pp 85-94.

[29] H. Zhou, S. Sung, G. Li, and Y. Zie: Topology optimization for microstructures of viscoelastic composite materials, Elsevier (2015).

[30] P. Xincheng: Super-high-strength high performance concrete, Hoboken: Taylor and Francis (2012).

[31] L. Ghiringhelli, M. Terraneo, and E. Vigoni: Improvement of structures vibroacoustics by widespread embodiment of viscoelastic materials, Aerospace Science and Technology, Vol.28(1), (2013), pp.227-241

[32] A. MuntasirBillah, and M. ShahriaAlam: Seismic fragility assessment of highway bridges: a state-of-the-art review, Structure and infrastructure engineering, volume 11, issue 6 (2015).

[33] M. Mamlouk, J. Zaniewski: Materials for civil and construction engineers, Third edition, Prentice Hall (2011).

[34] A. Öchsner, and H. Altenbach: Mechanical and Materials Engineering of Modern Structure and Component Design, Springer International Publishing (2015).

[35] A. Jahan, L. Edwards, and M. Bahraminasab: The importance of decision support in materials selection, Multi-criteria Decision Analysis for Supporting the Selection of Engineering Materials in Product Design (2016), pp. 1-23, Elsevier.

[36] W. Salama: Design of concrete buildings for disassembly: An explorative review, International Journal of Sustainable Built Environment, vol. 6, no. 2 (2017), pp. 617-635.

[37] L. Xing: The Rise and Potential Peak of Cement Demand in the Urbanized World Report, 'CORNERSTONE, The official Journal of world’s coal industry (2015).

[38] Gharehbaghi, K., McManus K., and Robson, K., (2019), ”Minimizing the environmental impacts of mega infrastructure projects: Australian public transport perspective”, Journal of Engineering, Design and Technology, vol. 17, issue 4, pp. 736-746.

[39] Domone, P., Illston, J., (2010), "Construction materials: their nature and behaviour", 4th edition, Spon Press.

[40] Gharehbaghi, K., Georgy, M., and Rahmani, F., (2018), ”Composite High-Rise Structures: Structural Health Monitoring (SHM) and Case Studies”, Materials and Technologies in Engineering, pp 146-152.

[41] Myers, J., (2007), ‘The Use of High Strength/High Performance Concrete in America: A Code and Application Perspective’, Department of Civil, Architectural and Environmental Engineering, vol. 1, pp. 1-10.

[42] Skrzypek, Jacek and Ganczarski, Artur: Mechanics of Anisotropic materials, Springer International Publishing (2015).