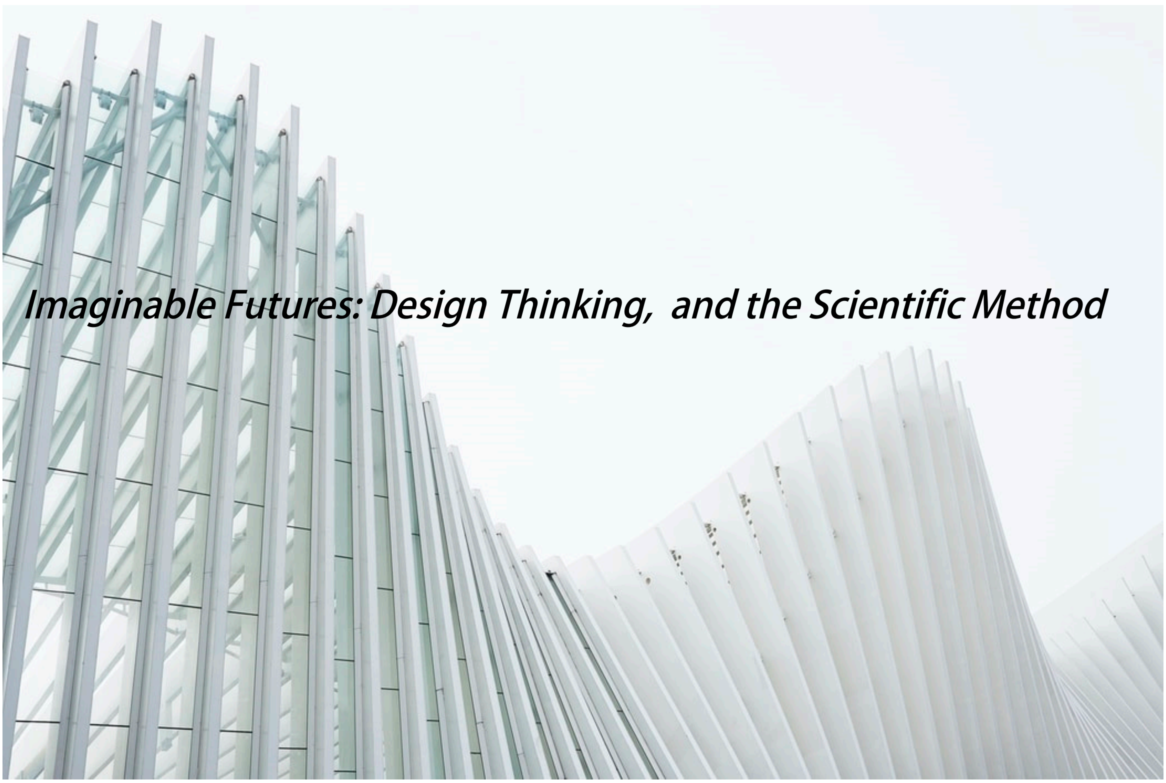
ASA

The Architectural Science Association (ANZAScA)

The 54th International Conference of the Architectural Science Association

26 & 27 November 2020



Imaginable Futures: Design Thinking, and the Scientific Method

Editors:

Ali Ghaffarianhoseini

Amirhosein Ghaffarianhoseini

Nicola Naismith

Opportunities to reduce brick waste disposal

Salman Shooshtarian[1], Tayyab Maqsood[2], Carl Barrett[3], Peter SP Wong[4], Rebecca J. Yang[5], Malik Khalfan[6]
[1, 2, 4, 5, 6]*RMIT University, Melbourne Australia*
{salman.shooshtarian, tayyab.maqsood, peter.wong, rebecca.yang, malik.khalfan}@rmit.edu.au
[3]*BGC (Australia) Pty Ltd, Perth, Australia*
cdb@bgc.com.au

Abstract: Brick is a widely used construction material in the Australian construction industry. It has different applications in construction elements, notably walls and pavements. Between 85–90% of new dwellings in Australia in 2011 were built with external brick walls and concrete flooring. Furthermore, brickwork generates an abundance of waste in construction projects each year. This paper investigates the opportunities for minimising the volume of brick waste across its supply chain based on circular economy principles. It develops a model called Brick- LoWMoR (Low of Waste, More of Resource) which can identify these opportunities across the brick supply chain from manufacturing through to design, construction and various end of life stages. This paper provides practical recommendations to improve brick waste management for construction and demolition activities. The recommendations can also inform the development of building codes and standards which impact on the construction and demolition (C&D) waste stream in Australia.

Keywords: Circular economy; construction material; waste management; resource recovery.

1. Introduction

Brick has different applications in construction elements, notably walls and pavements. They last for more than 100 years compared to contemporary lightweight alternatives which are effectively a short-term application of combustion of hydrocarbons. Bricks vary in terms of type, size and material used. Variation is primarily associated with the origin of materials used and time of the brick production. Between 2018 and 2019, the three main clay brick products in Australia were face bricks (65.5%), common bricks (22.1%), and clay pavers (12.4%) (Youl, 2018). In Australia, in 2011, between 85 and 90% of new dwellings were built with external brick walls and concrete flooring (Youl, 2018). However, this pattern has changed over the last few years, and the clay brick manufacturing industry (CBMI) is most affected. According to the latest IBISWorld data, the industry's annual revenue growth between 2016 and 2021 is -7.5% generating -16.3% annual profit growth (IBISWorld, 2020). The key demand for brick comes from house construction, multi-unit apartment and townhouse construction, bricklaying services, landscaping services, commercial and industrial building construction, institutional building construction and hardware wholesaling. Residential construction activity largely drives demand for the CBMI industry's products. This includes both new construction and repairs and alterations. Low-interest rates and population growth have caused dwelling commencements to rise over the

Imaginable Futures: Design Thinking, and the Scientific Method. 54th International Conference of the Architectural Science Association 2020, Ali Ghaffarianhoseini, et al (eds), pp. 825–834. © 2020 and published by the Architectural Science Association (ANZAScA).

past five years, supporting demand for bricks (Youl, 2018). Increasing demand from non-residential construction, such as commercial and industrial buildings, has also positively influenced the industry growth.

The increased usage of bricks due to the substantial rise in construction activities will result in a significant increase in the generation of brick waste during various stages of the supply chain including manufacturing, procurement, storage and construction. Furthermore, it is noted that brickwork can generate a large amount of waste in different construction projects each year. Globally, brick waste accounts for 50-70% of the construction waste generated in urban redevelopment and 30-50% in building operations (Al-Fakih et al., 2019). There are limited and scattered data available, showing how much brick waste is recycled or upcycled in Australia. According to the latest statistics extracted from the National Waste Report, 1,872,467 tonnes of brick waste was recycled in Australia in 2016-2017; the share of the C&D sector in this waste recovery is estimated to be 60.3%, the largest source of feedstock for brick waste recovery activities (Pickin et al., 2018). Due to its various impacts on society, economy and environment, the effective management of construction material wastes has become a high priority in Australia (Shooshtarian et al., 2020). Analysis of the clay brick lifecycle shows that there are many opportunities for minimising or redirecting brick waste from landfill. This study aims to explore these opportunities across the brick waste supply chain.

2. Development of a model

In order to identify opportunities for reduction of brick waste disposal across its supply chain, several pieces of relevant literature were collected and reviewed. These include academic outputs, industry reports and interviews, government guidelines and policies obtained from multiple research engines such as Google Scholar, Scopus and Web of Science. The basis of the review was to explore the circularity of this construction material and maximum utilisation of resources across the various supply chains. The findings resulted in the development of a model which outlines eleven opportunities to reduce waste disposal and demand for raw material excavation. The model (Figure 1), called Brick- Low of Waste and More of Resources (LoWMoR) shows how informed decisions and actions across the supply chain could determine the waste fate more sustainably. The model provides a pathway to stakeholders in the construction and resource recovery industries to reduce brick waste quantity across the supply chain.

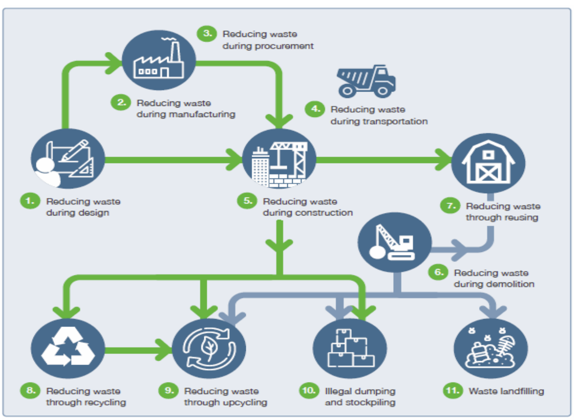


Figure 1. The integrated supply chain lifecycle model for brick waste

3. Results and discussion

The following sections explore strategies that contribute to lower brick waste disposal across the supply chain depicted in the Brick- LoWMoR model.

3.1. Manufacturing

The brick manufacturing industry is one of the efficient users of virgin resources in the production of construction materials. In Australia, there are numerous initiatives among manufacturers to reduce waste during production. For instance, Western Australia's newest clay brick manufacturer, BGC's Brikmakers® has returned all clay brick production waste back into the product mix since it was established in 2007. It also utilises wastes from its concrete and fibre cement manufacturing operations back into its concrete paver and backing block products (Scarvaci and Barrett, 2019). According to Brickworks Building Products, 2012, the Austral Bricks® plant in Victoria has markedly reduced the instance of malformed or off-specification green (unfired) bricks; it is reported that any such units are automatically recycled into the clay mix rather than going to landfill (Brickworks Building Products, 2012). Production of half bricks that are sometimes necessary for certain constructions is another strategy that can contribute to waste minimisation. It is reported that up to 75% of brick waste occurs when labourers attempt to cut bricks into half (Forsythe and Máté, 2007). Studies show that the application of lean and parallel-line manufacturing model aids in waste reduction during manufacturing (Shah and Ward, 2003). Lastly, the brick manufacturing processes can integrate other waste materials which in turn reduces the need for using brick raw materials. These include charcoal, wheat dust, oak husks and other biosolids (Scarvaci and Barrett, 2019), sewage (Tay, 1987), marble powder (Bilgin *et al.*, 2012), fly ash (Lingling *et al.*, 2005), waste glass and limestone powder waste (Turgut, 2008; Phonphuak *et al.*, 2016), spent shea waste and steel slag (Shih *et al.*, 2004) and textile sludge (Rahman *et al.*, 2015). The successful application of about 20 waste materials has previously been reported and reviewed (Murmu and Patel, 2018; Al-Fakih *et al.*, 2019).

3.2. Design, contract, and planning

Waste reduction opportunities, at this stage, are attributed to designing structures and goods that last longer, are easily repaired, upgraded or used differently in future cycles, and actively managing negative externalities such as the release of toxic substances. Ekanayake and Ofori (2000) reported that a substantial amount of C&D waste is attributed to design errors. The authors graded design changes as the most significant contributor to waste generation when construction works are in progress. It is widely known that design variations and changes can create large quantities of waste. These variations often change the type or quantity of the building materials. On the contrary, the standardisation of design is found to improve buildability and reduce the number of offcuts and waste (Dainty and Brooke, 2004).

Other design-related issues are the complexity of detailing, selection of low-quality materials and lack of familiarity with alternative products. Design for deconstruction is another strategy that can also reduce waste in future, i.e. construction and demolition. Innovative and modern designs promote the idea of reusing old bricks. Further encouragement of this opportunity is conducive to the increased uptake of old bricks in new construction projects. Dalecki (2017), who uses old bricks in designs, enumerated the benefits of using old bricks, including for aesthetic features, either in a blend with other materials or alternatively, for contrast to create a beautiful, modern building. Additionally, old bricks do not require finish (paint or render) to maintain colour or appearance, which is used as a key decorative design feature as opposed to a modern design for paving, internal floors, ceilings, built-in furniture, steps or even seating. The flow of information and dissemination of best practice to reduce design waste will require investment and publicity in technology and education to reshape societal attitudes to waste disposal. This warrants partnerships between government, industry, the media, and community organisations. In this regard, the social responsibility of architects has a pivotal role in waste minimisation practices; architects can enlighten clients about the associated financial, social and environmental benefits of such practices (Osmani *et al.*, 2008).

Errors in contract clauses or incomplete contract documents at the design stage can increase construction waste (Craven *et al.*, 1994; Bossink and Brouwers, 1996). The stage at which contractual agreement is made presents an opportunity to minimise C&D waste (CRiBE, 1999). Stakeholders can reduce waste by incorporating waste minimisation activities stipulated by specifically oriented contract tender clauses. To make this happen, some studies suggest using contractual clauses to discipline poor waste management (Dainty and Brooke, 2004). Others, such as Greenwood (2003), believe that a fully integrated waste minimisation system at the contractual stage is necessary to identify and communicate the responsibilities for waste minimisation between all project stakeholders. There is evidence that even the type of contract could influence how a waste is generated. For instance, it is reported that "Fix only" subcontracts rarely create motivation for bricklayers to reuse offcuts. Subcontract payment to bricklayers for labour only and based on the completed in-situ brick count does not provide a payment system that encourages low wastage (Forsythe and Máté, 2007).

Designing against overconsumption through a components' life extension is another waste-reducing design strategy (Oguchi *et al.*, 2010). The major barrier to design against overconsumption is the cost; if the cost of a used and adapted product is similar to the new one, the latter is preferred (Hirschl *et al.*, 2003). Bricklayers are important actors in the battle of reducing the waste if they are not disincentivised to do so. In Australia, bricklayers are contracted based on the number of bricks that arrive onsite and are thus incentivised to create waste. If they use half bricks, they get paid for a whole, and their pay is not deducted by the number of bricks left over. A contracting model similar to plastering subcontractors is perhaps the best way to control this issue and reduce waste. If the model was centred on a supply and lay approach, there would not be bricks leftover onsite, and any spare would be carried to the next job (Scarvaci and Barrett, 2019).

3.3. Procurement

Correct estimation of the bricks needed for a construction activity can save a significant quantity of unwanted materials that might have otherwise been landfilled. Inaccurate quantity take-off and/or over-ordering ultimately create extra waste. The false economy created by the structure of the brick ordering and later laying processes is a major contributor to brick wastes in the construction industry. In Australia, builders typically order 2-3% more than is required to allow for offcuts and waste etc. (Scarvaci and Barrett, 2019). However, on large jobs, the risk of over-ordering tends to be reduced because deliveries are made progressively throughout the job, and only the last order needs accurate take-off and ordering. Conversely, it can be a significant contributor in small jobs if bricks are only supplied in large order increments and only a small amount of the last order increment is required. Incremental ordering problems could potentially worsen if the brickwork is made up of small amounts of different brick types—as may be required in blended brickwork (Forsythe and Máté, 2007). An example of over-ordering is when, for a job requiring 1,100 bricks, 1,500 bricks must be ordered, which typically results in 27% waste. Just-in-time delivery of materials to a construction site should be planned to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions (BRE Group, 2019). Moreover, suppliers can be encouraged to provide more flexible "last pack" sizes—i.e. a "fractional" pallet instead of a full pallet—in order to minimise the waste because of over-ordering.

3.4. Transportation and delivery

Waste incurred through transportation can be reduced if the transportation companies typically contracted by brick manufacturers exercise good work practices. A lack of hard strap protectors at corners and edges of brick stacks and hand unloading can increase waste. Forsythe and Máté (2007) reported that an uneven landing pad for stacks could cause damage to bricks. In another study in Hong Kong, interviews with senior project managers, and experienced architects and engineers revealed that damage during transportation due to the unpacked supply is one of the two main reasons for brick wastage (Tam *et al.*, 2006). Tam and Hao (2014) suggested that waste arising out of transportation and delivery could be reduced or eliminated by replacing site bricklaying with drywall panel systems.

3.5. Construction

The second major brick waste generation occurs at the construction site and mostly during construction activities (Poon *et al.*, 2004). Researchers observed that brick waste could be reduced at all stages of the construction process (Poon *et al.*, 2004). Damaged bricks due to over-stacking in the storage area and poor products of layering are all possible causes of wastes. A field study in Australia reported that the main source of waste brick comes from inaccurate brick cutting, which is primarily done by chopping at bricks with a trowel (Forsythe & Máté, 2007). The study estimated that poor workmanship could generate up to 75% of brick waste at a construction waste.

Brick waste construction inefficiencies include handling and stacking breakages, use of bricks for scaffolding and other unintended uses, and bricks contaminated by dirt. Training of those who are directly and indirectly dealing with the brick at the construction site should be an integral part of any waste management plan. Such training courses can target labourers who are working at different stages of construction and maintenance and have a pivotal role in the reduction of brick waste generated. In Australia, there are various education providers that offer a specific course on the brick material in the construction industry. For instance, PointsBuild offers two online courses 'TBA Foundations: Brick Standards' and 'TBA Foundations: Defining a Brick' to educate bricklayers and others involved in construction activities about the various technicalities of bricks in construction with the view to reduce damages to the material during and after construction. In recent years, the emergence of brick-laying robotic systems has presented an opportunity to increase the industry productivity by reducing construction completion time, providing financial benefits, minimising work safety incidents, and reducing waste during construction (Giftthaler *et al.*, 2017). In 2018, Fastbrick Robotics, a construction company based in Perth (Australia), reported its achievement in completing a three-bedroom, two bathroom house in less than three days thanks to a robotic arm from a 3D model (Hall, 2018).

Another important strategy to assist with reducing waste during construction is to estimate the quantity of waste to be generated at a construction site (Llatas, 2011). Accurate estimation can aid in efficient prevention and management from the very beginning of a construction project. Nonetheless, prior research studies indicated that one of the main hindrances to a valid estimation of C&D waste is the lack of data, including poor documentation of waste generation rates and composition. In the past, some efforts made to model the quantity of waste generated at a construction site (Wu *et al.*, 2014) and particularly building information modelling (BIM)-based modelling in recent years (Cheng and Ma, 2013).

Proper storage of bricks at the site can also contribute to reducing waste generated during construction activities. If the construction site has enough space, bricks arriving at the site can be adequately stored away from the main traffic flow onsite (BRE Group, 2019). Application of effective construction methodologies also contributes to less waste generation. Among various methodologies, prefabrication seems to be a viable option. By definition, prefabrication is a manufacturing process that takes place in a specialised factory where different materials are brought together to form a construction component of the final installation procedure (Minunno *et al.*, 2018). Brickwork can be prefabricated off, or onsite in panels or box units lifted into position and bolted to a building frame in a similar manner to precast concrete (Minunno *et al.*, 2018). Panels that are moved into place onsite using cranes create a reduction in overall site waste. Furthermore, brick orders are placed and cancelled as required directly through the manufacturers allowing resources to be monitored and waste to be recognised and controlled.

3.6. Demolition

Brick waste during demolition is generally sourced from residential or pavement demolition. In one study in China, it was found that demolition of residential buildings generates more brick waste than it does in commercial buildings (Zhao and Rotter, 2008). However, this waste almost always comes in a mix with other C&D waste. The resource recovery market strongly prefers separation at the source for masonry materials. Such a practice leads to more straightforward, cheaper and more effective recovery. This is also favourably considered in pricing mechanisms such as gate fees, which are lower for source-separated loads (Sustainability Victoria, 2014). In most cases that waste loads are mixed, the conventional practice is to separate waste materials by labours and some mechanical equipment such as excavators and front-end loaders. There are also instances of the utilisation of fixed equipment and automated sorting systems being employed to segregate materials (Hyder, 2011). De-construction, as opposed to demolition, is a building removal technique that aims to dismantle buildings with the goal of maximising the reuse potential of its components. The benefits of deconstruction include generation of revenue from the sale of salvaged materials, reduced disposal and transports costs, lower cost of building materials for the community, lower excavation for new materials and conserving landfill space. However, the time required to deonstruct is found to hinder the adaptation of this method (Crowther, 2000).

Selective deconstruction is the advance extension of deconstruction wherein some materials are targeted for reusing and recycling. Selective deconstruction project planning involves the scheduling for dismantling targeted building components, the definition and duration of work tasks, the choice of technology, the estimation of the required resources and the identification of any interactions among the different work tasks (Sanchez *et al.*, 2019). Full demolition requires less time than deconstruction. Time taken includes the manpower (total man-hour) and active plant costs. The NSW Office of Environment and Heritage (2010) has published an information booklet wherein deconstruction and demolition were compared time-wise. The cost analysis associated with three building-removal techniques in NSW revealed that deconstruction is cheaper than demolition, by anywhere between 55% (Asbestos fibro) and 294% (full brick).

3.7. Reuse

The demolished brick or the brick that is damaged during transport, construction or renovation can be reused in construction projects without recycling. From an environmental perspective, reusing old bricks creates environmental benefits such as saving 0.5 $kgCO_2$-e that is eliminated by not manufacturing one block of a clary brick (Gamlemursten, 2019). There are initiatives to encourage the application of old bricks in new builds. Think Brick Australia is running a Brick Cleaning Course (Thinkbrick, 2019), a nationwide training course on brick cleaning, in partnership with TABMA Training. Brick cleaners can achieve accreditation by completing this course. The course covers basics of brickwork, working with contemporary bricks, planning and preparing a worksite, identifying brick stains, prevention of brickwork stains, techniques not to damage brickwork, effective cleaning of brick stains, clean up and safe storage of equipment and chemicals, and using environmentally-friendly cleaning solutions. A new European Union-funded project called REBRICK (Gamlemursten, 2019) has exemplified that an old brick is not “just a brick”. The project pursues resourceful demolition of waste through automated cleaning of clay bricks so that they can be reused. This project, which is coordinated by a Danish SME, Gamle Mursten, has developed a technology to exploit the reusing potential of old bricks. The technology involves the automated sorting of demolition wastes that separates and cleans old bricks using vibrational rasping. Reuse of the brick may take place in the form of brick waste recycling for further use in a brick production line. In Turkey, Demir *et al.* (2013) studied the use of brick waste as an additive to raw materials for brick production. They reported that up to 30% mixture of fine brick waste additives could be successfully used in new brick production. Usage of waste material in the raw mixture minimises the physical damage that may occur during brick production. The reuse of waste-brick material in brick production provides an economic contribution and helps protect the environment by less virgin resource use, and saving in water and greenhouse gas emissions associated with clay excavation, transport, and landfilling.

3.8. Recycling

Brick waste can be processed and further used in the construction industry (recycling) or in other industries (upcycling). Brick waste is highly recyclable due to the inert nature and physical reprocessing requirements, with less need for chemical processes in comparison with other materials, (Sustainability Victoria, 2014). Brick recycling practices have a long history; with the earliest evidence relates to the use of crushed brick with Portland cement in Germany in 1860 for the manufacturing of concrete products (Devenny and Khalaf, 1999). Typically, large commercial projects lend themselves to recycling moreso than small residential projects as economies of scale play a key role in the collection, separation and marketing of recovered materials (SA EPA, 2001).

A study conducted in Australia found that a common solution to brick waste management is to crush the waste and to use the final product as a landscaping aggregate or low-grade road base (Forsythe and Máté, 2007). Brick recycling techniques are not complicated (Edge Environment, 2012): the bricks are crushed, either as mixed loads or in source-separated streams. In 2011, one study conducted a comparative analysis of the economic performance of two brick waste management scenarios in Melbourne (Damptey, 2011) to reveal the suitability of recycling versus landfilling. The study found that the costs associated with recycling bricks were comparatively cheaper than those in landfill disposal. In terms of operational costs, this study reported that, for 1,000 tonnes of brick waste, the total costs for landfilling and recycling are $92,356 AUD and $29,419 AUD, respectively. Increasing landfill levy rates has further widened this cost gap (Shooshtarian *et al.*, 2020). In 2010, a study in Sydney showed that demolition was more expensive than selective and full deconstruction due to reduced costs associated with transport and landfill levy (NSW Office of Environment and Heritage, 2010). To encourage the community to contribute to C&D waste recycling, some local councils provide vouchers through rates notices to transfer a certain quantity of C&D waste to a nearby recycling facility free of charge. The utilisation of bricks waste in other applications is well documented. Brick waste can also replace raw materials used in a mixture for production of other construction materials. For instance, pozzolans that are derived from brick (powder) waste, when used as a partial cement substitute, typically improve the resistance of mortar. In Japan, demolished bricks are burned into slime burnt ash and commonly crushed to form filling materials in Hong Kong (Tam and Tam, 2006).

3.9. Illegal dumping and stockpiling

Illegal dumping and stockpiling are prevalent with all construction materials, including clay brick. It is mainly incentivised by landfill charges inclusive of government-issued landfill levy schemes. The fact that the revenue from levy charges are rarely returned back to the C&D waste sector to improve recovery rates makes it difficult to reduce these activities. There are service providers in the waste recovery industry that are labelled as cowboy operators because they offer services for skip-bins, disposal, sorting or recycling at below-market rates, undercutting the cost of legitimate and licensed businesses (Mannix *et al.*, 2019). The waste is stockpiled or dumped on rented properties or public land in the outer suburbs or regional areas. It is the public sector's duty to address illegal dumping of materials and to strengthen controls over licensed sites. State Governments and territories have created task forces to exercise restrictions on waste stockpiling which have not been effective to date (Shooshtarian *et al.*, 2019).

3.10. Landfilling

On a world-scale, the world annual production of clay bricks, which is approximately 6.25×10^8 tonnes, about 7×10^6 tonnes of brick goes to landfills each year (Adamson *et al.*, 2015). In some countries, due to different factors, including unavailability of land, the cost of landfilling has increased so substantially that recycling is considered to be more cost-effective. One study in the US showed that recycling one ton of brick costs about $21 per tonne while landfilling one tonne of the same amount would cost approximately $136/tonne (Lennon, 2005). In Australia, the lack of updated and accurate data about current activities in the field of brick waste management has made it difficult to plan for the maximum usage of the value of brick material. The only data for landfilling extracted for the study period of 2016-17 showed that, in South Australia, of 40,320 tonnes brick waste generated 11,498 tonnes was landfilled.

3. Conclusion

This study developed the Brick- LoWMoR to conceptualise the opportunities across the brick supply chain to reduce waste disposal. Drawing on this model, various waste minimising strategies were identified. The following recommendations may facilitate implementation: Design appropriate landfill levy schemes to discourage brick waste landfilling; consider building standardisation to improve buildability and reduce the number of offcuts; suppliers to provide more flexible "last pack" sizes i.e. a "fractional" pallet instead of a full pallet; use of the "Supply and Lay" model to eliminate brick leftovers on site; develop an agreement where a contractor "sells back" the recycled waste from the original material supplier; ensure the bottom layers of bricks remain useable by preventing soil contamination; store bricks in a stable flat area to avoid breakages from fall overs; determine a means for cutting bricks into half more accurately so that both halves can be used and breakages are avoided; take unwanted bricks back to the brickyard or nearest material recovery facility for crushing and reuse—this can be also complemented by offering the customer leftover (full) bricks; Include a clean-up payment in the scope of the bricklayer's subcontract to assist recycling and to discourage wasteful site practices; take brick left-overs away to use as aggregate or landscaping cover; and strengthen controls over licensed landfill sites. These recommendations can also inform building codes and standards which impact on the regulation of C&D waste streams in Australia.

References

Adamson, M., Razmjoo, A. and Poursaee, A. (2015) Durability of concrete incorporating crushed brick as coarse aggregate, *Construction and Building Materials*, 94, 426-432.

Al-Fakih, A., Mohammed, B. S., Liew, M. S. and Nikbakht, E. (2019) Incorporation of waste materials in the manufacture of masonry bricks: An update review, *Journal of Building Engineering*, 21, 37-54.

Bilgin, N., Yeprem, H., Arslan, S., Bilgin, A., Günay, E. and Marşoglu, M. (2012) Use of waste marble powder in brick industry, *Construction and Building Materials*, 29, 449-457.

Bossink, B. and Brouwers, H. (1996) Construction waste: quantification and source evaluation, *Journal of construction engineering and management*, 122(1), 55-60.

BRE Group (2019) *The true cost of waste*.

Brickworks Building Products (2012) *Build for Living: Building a platform of commitment and responsibility*, BrickWorks, Melbourne, Australia

Cheng, J. C. and Ma, L. Y. (2013) A BIM-based system for demolition and renovation waste estimation and planning, *Waste management*, 33(6), 1539-1551.

Craven, D., Okraglik, H. and Eilenberg, I. (1994) *Construction waste and a new design methodology*, Sustainable Construction: Proceedings of the 1st Conference of CIB TG, Gainesville, Fla. : Center for Construction and Environment, M.E. Rinker Sr. School of Building Construction, College of Architecture, University of Florida, 89-98.

CRiBE (1999) *Waste Minimisation through Counselling Building Project Teams & Collecting of Building Project Teams and Collecting Waste Arising*, Welsh School of Architecture, Cardiff University, United Kingdom.

Crowther, P. (2000) Building deconstruction in Australia, *Overview of deconstruction in selected countries*, 14-44.

Dainty, A. R. and Brooke, R. J. (2004) Towards improved construction waste minimisation: a need for improved supply chain integration?, *Structural Survey*, 22, 20-29.

Dalecki, J. (2017) *Reuse & Recycle Materials - Brickworks Building Products*.

Damptey, E. F. (2011) *Optimising the Use of Recycled C&D Waste Material in Civil Construction Projects*, Faculty of Engineering and Industrial Sciences, Centre for Sustainable Infrastructure, Swinburne University of Technology, Melbourne, Australia.

Devenny, A. and Khalaf, F. (1999) Use of crushed brick as coarse aggregate in concrete, *Masonry International*, 12(3), 81-84.

Edge Environment (2012) *Construction and Demolition Waste Guide - Recycling and Re-Use Across the Supply Chain*, The Department of Energy and Environment Canberra, Australia.

Ekanayake, L. and Ofori, G. (2000) Construction material waste source evaluation.

Forsythe, P. and Máté, K. (2007) Assessing brick waste on domestic construction sites for future avoidance, *41st Annual Conference of the Architectural Science Association: Towards solutions for a liveable future: progress, practice, performance, people*, Geelong, Australia, 1-8.

Gamlemursten (2019) *The REBERICK project*. Available from: <http://www.gamlemursten.eu> (accessed 5/06/2020).

Giftthaler, M., Sandy, T., Dörfler, K., Brooks, I., Buckingham, M., Rey, G., Kohler, M., Gramazio, F. and Buchli, J. (2017) Mobile robotic fabrication at 1: 1 scale: the in situ fabricator, *Construction Robotics*, 1(1-4), 3-14.

Greenwood, R. (2003) *Construction Waste Minimisation – Good Practice Guide*, CRiBE (Centre for Research in the Build Environment), Cardiff, United Kingdom.

Hall, J. (2018) *World-first': WA's Fastbrick robot builds 3x2 home in three days*. Available from: The West Australian (accessed.

Hirschl, B., Konrad, W. and Scholl, G. (2003) New concepts in product use for sustainable consumption, *Journal of Cleaner Production*, 11(8), 873-881.

Hyder (2011) *Construction and Demolition Waste Status Report: Management of Construction and Demolition Waste in Australia* Department of Energy and Environment (Department of Sustainability, Environment, Water, Population and Communities), Australia

IBISWorld (2020) *Clay Brick Manufacturing in Australia: AUSTRALIA INDUSTRY (ANZSIC) REPORT C2021*, in R. Dean (ed.), IBISWorld, Australia.

Lennon, M. (2005) *Recycling construction and demolition wastes: a guide for architects and contractors*, ed., Commonwealth of Massachusetts, Department of Environmental Protection.

Lingling, X., Wei, G., Tao, W. and Nanru, Y. (2005) Study on fired bricks with replacing clay by fly ash in high volume ratio, *Construction and Building Materials*, 19(3), 243-247.

Llatas, C. (2011) A model for quantifying construction waste in projects according to the European waste list, *Waste management*, 31(6), 1261-1276.

Mannix, L., C., V. and C., H. (2019) *The tipping point: Illegal dumping swamps the waste industry*,The Age.
Minunno, R., O'Grady, T., Morrison, G. M., Gruner, R. L. and Colling, M. (2018) Strategies for applying the circular economy to prefabricated buildings, *Buildings*, 8(9), 125.
Murmu, A. L. and Patel, A. (2018) Towards sustainable bricks production: An overview, *Construction and Building Materials*, 165, 112-125.
NSW Office of Environment and Heritage (2010) *House deconstruction fact sheet: Bricks and concrete removal*.
Oguchi, M., Tasaki, T. and Moriguchi, Y. (2010) Decomposition analysis of waste generation from stocks in a dynamic system: Factors in the generation of waste consumer durables, *Journal of Industrial Ecology*, 14(4), 627-640.
Osmani, M., Glass, J. and Price, A. D. (2008) Architects' perspectives on construction waste reduction by design, *Waste management*, 28(7), 1147-1158.
Phonphuak, N., Kanyakam, S. and Chindaprasirt, P. (2016) Utilisation of waste glass to enhance physical–mechanical properties of fired clay brick, *Journal of Cleaner Production*, 112, 3057-3062.
Pickin, J., Randell, P., Trinh, J. and Grant, B. (2018) *National Waste Report 2018*, Australian Department of the Environment and Energy, Canberra, Australia.
Poon, C.-S., Yu, A. T. and Jaillon, L. (2004) Reducing building waste at construction sites in Hong Kong, *Construction Management and Economics*, 22(5), 461-470.
Rahman, A., Urabe, T., Kishimoto, N. and Mizuhara, S. (2015) Effects of waste glass additions on quality of textile sludge-based bricks, *Environmental technology*, 36(19), 2443-2450.
SA EPA (2001) *Barriers and Opportunities for Re-use and Recycling of Clean Fill and Building and Demolition Waste*
Sanchez, B., Rausch, C. and Haas, C. (2019) Selective Deconstruction Programming for Adaptive Reuse of Buildings, in, *Computing in Civil Engineering 2019: Data, Sensing, and Analytics*, American Society of Civil Engineers Reston, VA, 225-232.
Scarvaci, V. and Barrett, C. (2019) *Brick supply and lay model*, BGC (Australia) Pty Ltd: Group Manager Energy and Environment, Brickmakers (Australia) Pty Ltd: General Manager, Perth, Australia.
Shah, R. and Ward, P. T. (2003) Lean manufacturing: context, practice bundles, and performance, *Journal of operations management*, 21(2), 129-149.
Shih, P.-H., Wu, Z.-Z. and Chiang, H.-L. (2004) Characteristics of bricks made from waste steel slag, *Waste management*, 24(10), 1043-1047.
Shooshtarian, S., Maqsood, T., Khalfan, M., Wong, S. P. and Yang, J. R. (2019) Managing construction and demolition (C&D) waste in Australia, *CIB World Building Congress 2019 'Constructing Smart Cities'*, Hong Kong, China, 17-21 June
Shooshtarian, S., Maqsood, T., Khalfan, M., Yang, J. R. and Wong, S. P. P. (2020) Landfill levy imposition on construction and demolition waste: Australian stakeholders' perceptions *Sustainability*, 12(11), 1-15.
Sustainability Victoria (2014) *Factsheet: Market summary – recycled brick, stone and concrete*, Melbourne, Australia.
Tam, V. W. and Hao, J. J. (2014) Prefabrication as a mean of minimising construction waste on site, *International Journal of Construction Management*, 14(2), 113-121.
Tam, V. W., Tam, C., Chan, J. K. and Ng, W. C. (2006) Cutting construction wastes by prefabrication, *International Journal of Construction Management*, 6(1), 15-25.
Tam, V. W. and Tam, C. M. (2006) A review on the viable technology for construction waste recycling, *Resources, Conservation and Recycling*, 47(3), 209-221.
Tay, J.-H. (1987) Bricks manufactured from sludge, *Journal of Environmental Engineering*, 113(2), 278-284.
Thinkbrick (2019) *Accreditation Courses*.
Turgut, P. (2008) Limestone dust and glass powder wastes as new brick material, *Materials and Structures*, 41(5), 805-813.
Wu, Z., Ann, T., Shen, L. and Liu, G. (2014) Quantifying construction and demolition waste: An analytical review, *Waste management*, 34(9), 1683-1692.
Youl, T. (2018) *IBISWorld Industry Report C2021. Clay Brick Manufacturing in Australia*, IBISWorld
Zhao, W. and Rotter, S. (2008) *The current situation of construction & demolition waste management in China*,2nd International Conference on Bioinformatics and Biomedical Engineering, IEEE, Tianjin, China 4747-4750.

ASA
2020

ISBN 978-0-9923835-7-2