Resource circular economy: opportunities to reduce waste disposal across the supply chain

Brick

Research Report 5

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SBEnrc P1.65 A National Economic Approach to Improved Management of Construction and Demolition Waste

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EXECUTIVE SUMMARY

Bricks are produced in several ways in terms of type, size and the material used; the variation is largely associated with the origin and time of the brick's production. In Australia, in 2011, between 85–90% of new dwellings were built with external brick walls and concrete flooring. Brick has different applications in construction elements, notably walls and pavements. In 2018-19, the three main CB products in Australia were face bricks (65.5%), common bricks (22.11%) and clay pavers (12.4%). It is estimated that brick waste accounts for 50-70% of the construction waste produced by urban redevelopment and 30-50% by building operations. Analysis of the clay brick lifecycle shows that there are many opportunities for minimising or redirecting brick waste from landfill. These opportunities present themselves at brick manufacture, design, planning and contract, procurement, transportation and delivery, construction, demolition, reusing and waste recovery (recycling and upcycling). Drawing on these opportunities, this case analysis provides the following recommendations for brick waste minimisation and reduced waste landfilling:

- Consider building standardisation to improve buildability and reduce the number of off-cuts.
- Order bricks more accurately using the best take-off practice.
- 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 avoided.
- Supplier to provide more flexible "last pack" sizes i.e. a "fractional" pallet instead of a full pallet.
- Take unwanted bricks back to brickyard for crushing and re-use in brick production; 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.
- Develop an agreement where a contractor "sells back" the recycled waste from the original material supplier.
- Take brick left-overs away to use as aggregate or landscaping cover.

1 INTRODUCTION

Brick has different applications in construction elements, notably walls and pavements. According to statistics, brick waste accounts for 50-70% of the construction waste produced by urban redevelopment and 30-50% by building operations[1]. It is still regarded as a viable option for residential construction due to several reasons that are outlined by Think Brick Australia[2] and presented below:

1. **Energy efficiency:** Bricks are high-density materials, which means they have the ability to effectively absorb and store heat energy. Lightweight materials do not have this quality. Correct use of thermal mass can moderate internal temperature values, averaging out day and night temperature extremes, which make a massive difference to residents' comfort, heating and cooling needs and energy bills.
2. **Noise control[3]:** The heavy mass of clay brick masonry is ideal for acoustic insulation, particularly for low-frequency noise, and cavity masonry walls have the added benefit of isolating impact sounds. It possesses an inherent resistance to the passage of airborne sound, which makes it a superior performer in attenuating low-frequency, airborne noise caused by building mechanical systems, elevators, amplified music, traffic and aircraft. Although some alternative systems may perform as well as masonry for frequencies in the speech range, these lower mass systems have difficulty insulating against low-frequency noise.
3. **Durability:** As one of the oldest building materials, bricks remain strong and look better with age, like fine wine. For instance, the Great Wall of China is a brick structure that has maintained its strength for more than 2000 years. Bricks have kept Australian homes safe, comfortable and protect against extreme climates of heat and cold, bushfires, floods, severe storms and droughts. Bricks require little to no maintenance, saving owners thousands on upkeep compared to its lightweight construction counterparts. Building on the coast poses no issues for bricks. Exposure Grade Bricks are made to withstand high salt conditions and are the most affordable materials on the market for the job.
4. **Fire resistance[4]:** Bricks are non-combustible and do not assist the spread of fire, making them ideal for building in bushfire-prone areas. Clay bricks normally don't suffer any structural damage after a fire and can be re-used even as load-bearing walls. Bricks are made in fire in kilns (over an oven heated enclosure used for processing materials like bricks that require burning, firing and drying) at temperatures of up to 1200°C (a standard kitchen oven operates up to about 250°C). Bricks alone do not fireproof a building but are not like timber and plastic, which are flammable and glass that shatters in the heat. Building in brick ensures a strong foundation for protecting your investment.
5. **Structural capabilities:** Brick has continued to be a popular building material choice due to strong structural capabilities and intricate detailing. For any project, there are bricks to suit any building style. There are now over 800 brick colours to choose from and many different finishes, from sleek glossy blacks and metallics to rough-hewn rustic bricks with a hand-crafted appearance.

[1] Li SD. The feasibility of producing sintering building materials products using construction waste. J Brick & tile(in Chinese), 2005. 12, 36-38.

[2] Think Brick Australia> Brick Facts Thinkbrick.com.au. 2019. THINK BRICK > Brick Facts. [online] Available at: https://www.thinkbrick.com.au/WhyBrick# [Accessed 21 Aug. 2019].

[3] Think Brick Australia. 2014. Design Manual 11: Design of Clay Masonry for Sound Insulation.

[4] Think Brick Australia. 2014. Design Manual 5: Design of Clay Masonry Walls for Fire resistance.

2 CLAY BRICK INDUSTRY OVERVIEW

Bricks are produced in several ways in terms of type, size and the material used; the variation is largely associated with the origin and time of the production. In Australia, in 2011, between 85–90% of new dwellings are built with external brick walls and concrete flooring. 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 Industry Report[5], the main key economic drivers, demand and supply industries, are tabulated in Table 1.

Table 1. Key drivers and the major industries dealing with clay brick (demand & supply)

Key Economic Drivers	Demand Industries	Supply industries
Dwelling commencements	House Construction	Electricity, Gas, Water and Waste Services
Demand from house construction	Multi-Unit Apartment and Townhouse Construction	Road Freight Transport
Demand from hardware wholesaling	Bricklaying Services	Rock, Limestone and Clay Mining
Demand from the multi-unit apartment and townhouse construction	Landscaping Services	
Demand from commercial and industrial building construction	Commercial and Industrial Building Construction	
	Institutional Building Construction	
	Hardware Wholesaling	

Source: IBISWorld 2019

The IBISWorld 2019[5] report estimated that CBMI generated $870.3 m in 2018-19, which is a 7.4% decline compared to the previous financial year. This is not the only industry performance indicator that has seen a decline; others include individual added value (-8.6%), the number of establishments (-5.1%), number of enterprises (-5.7%), employment (-7.2%), export (-4.5%) and domestic demand (-7.4%). Figure 1 depicts the 6-year economic performance of CBMI with a sharp decline from 2015-16.

5 Youl, T. 2018. IBISWorld Industry Report C2021. Clay Brick Manufacturing in Australia.

6 The market value of goods and services produced by the industry minus the cost of goods and services used in production. IVA is also described as the industry's contribution to GDP, or profit plus wages and depreciation.

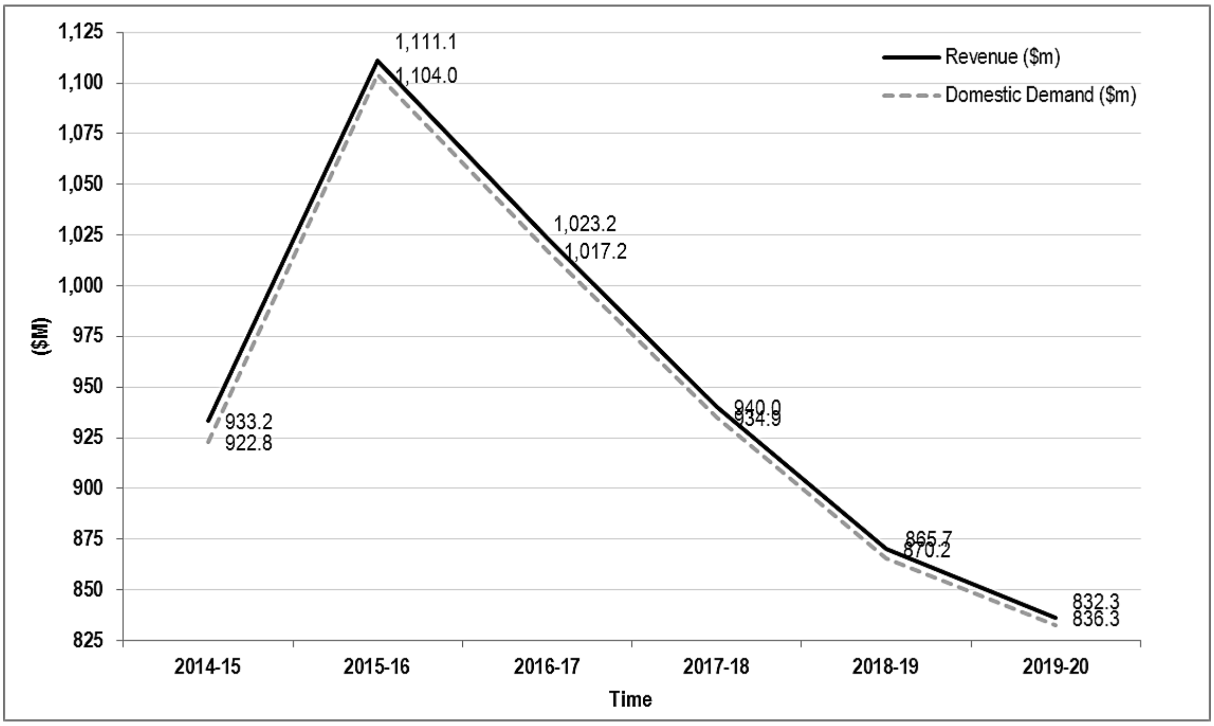

Figure 1. Statistics pertaining to CBMI (revenue and domestic demand) in Australia between 2014-15 and 2019-20
Source: IBISWorld 2019

The main reason for the decline in the CBMI economic performance is reported to be the fluctuations occurring in dwelling commencements, which heavily influences the industry's performance[5]. However, demand growth from the commercial and industrial building market provided some support to the industry's expansion. Another reason for such a decline relates to change in the pattern of housing with specific preferred masonry materials. Australians have moved away from traditional single-unit housing, which tends to have a large brick component, towards multi-unit apartments. Generally, multi-unit dwellings use alternative cladding and structural materials to brick (e.g. concrete and steel), as they provide easy-to-install and more cost-effective materials in high-rise buildings. Moreover, bricks are currently under pressure from alternative products (e.g. polyurethane cladding) in single-unit dwellings because of a shift from double brick to single brick installation. Technically, in Australia, only new detached houses can use clay bricks as the dominant form of exterior wall cladding. This reflects the limited scope for CBMI in the share of the residential housing market; notably, demand from house construction has declined versus multi-unit dwellings over the past five years.

The Australian clay brick manufacturing industry has increasingly exported to nearby countries such as New Zealand, targeting rising construction activities. However, the corresponding revenue continues to underperform. Similarly, the import has increased but remains low relative to industry revenue. The rise in imports has largely been due to major industry firms such as Brickworks finding it cheaper to import bricks from overseas countries such as Spain rather than from factories in Western Australia.

2.1 Major producers in Australia

The three main suppliers of bricks in Australia with the highest market shares are Brickworks Ltd (52.6%), CSR Limited (21.7%), Boral Limited (7.9%) following by BGC Pty Ltd (3-4%). The following graph depicts the distribution of clay brick manufacturers across Australia.

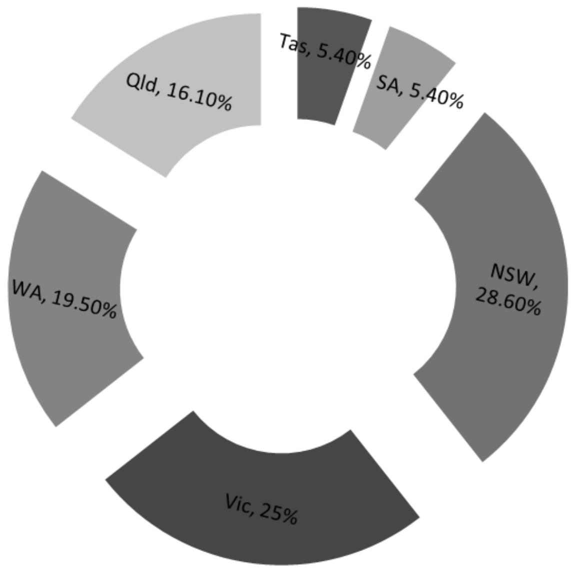

Figure 2. Location of (clay) brick manufacturers in Australia
Source: IBISWorld 2019

In response to market situations, these operators have restructured their operations over the past five years, closing inefficient plants, upgrading the existing facilities and introducing less labour-intensive production technologies. It is reported that this shift has improved efficiency and substantially reduced manufacturing (overhead) costs (e.g. wages and depreciation). This, along with increased demand in two major capital cities (i.e. Sydney and Melbourne), has contributed to the industry profit over the past five years. The new technologies particularly focus on new products (e.g. brick fascia embedded on concrete or PVC panels) in the pursuit of improvements in the competitiveness and attractiveness of CB compared to cheaper alternatives.

2.2 Demand determinants

Residential construction activity largely drives demand for the 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 past five years, supporting demand for bricks. Increasing demand from non-residential construction, such as commercial and industrial buildings, has also positively influenced industry growth.

However, brick substitution trends have adversely affected industry demand. The use of bricks for house construction has declined over the past two decades, as builders' preferences have shifted to alternate structural and cladding materials (such as cement sheets and timber). In most cases, these alternate products are cheaper and easier to use relative to bricks. Changing consumer tastes, with preferences increasingly favouring multiple forms of exterior cladding on single dwellings, have also negatively affected demand.

Despite preferences shifting towards non-brick building materials over the long term, fundamental demand remains for clay brick products. Bricks are bought for their unique structural qualities, such as thermal lag and durability, and their aesthetic appeal. As such, housing fashion trends also affect industry demand. Industry players have expanded their ranges of face bricks in response to growing consumer demand for brick finishes. This includes a trend towards using bricks in housing interiors for purposes such as feature walls.

Over the past five years, trends favouring the construction of medium- to high-density housing have constrained demand. Multi-unit dwellings have steadily increased as a proportion of new dwelling commencements over the past five years. Apartments and townhouses tend to be less brick-intensive than traditional houses. This is due to alternative materials, such as concrete panels and steel framing, being more practical to use and less labour-intensive, especially on high-rise apartment buildings. Export demand has little effect on demand for clay bricks manufactured in Australia, due to the high cost of transporting bricks overseas. Figure 4 shows the main demands for Australia clay brick.

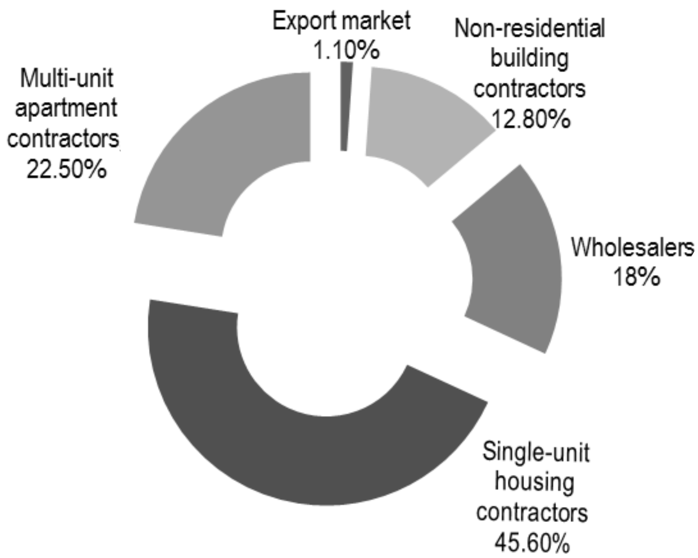

Figure 3. Main types of construction with the largest consumption of brick
Source: IBISWorld 2019

Home renovation activity also affects demand for the industry's products. Over the past five years, renovation activity has increased, as homeowners have benefited from low-interest rates to borrow funds to pay for renovations. Additionally, significant housing prices have led to consumers renovating their homes rather than buying a new property. Outdoor living spaces are one of the main areas of the home alterations and upgrades, due to their increasing popularity among individuals. This has increased demand for clay pavers.

Table 2. Key success factors applicable in the CBMI

Key success factors	Description
Having a diverse range of clients	Manufacturers that offer a range of brick and paver products that cater to diverse customer markets can better maintain a stable revenue stream.
Ability to expand and curtail operations rapidly in line with market demand	Firms must achieve profitability at low volumes of brick capacity utilisation to survive dramatic cyclical downturns in the construction sector.

Access to high-quality inputs	Manufacturers must maintain access to good-quality reserves of appropriately located clay to produce high-quality clay bricks, which provides a competitive edge.
Economies of scale	Generally companies that can produce large volumes of high-quality clay bricks from large and efficient production sites have lower costs and can boost profitability.
Ability to compete on tender	Manufacturers that can secure competitive long-term contracts with large building contractors (the primary users of clay bricks) are better able to ensure a continuous flow of revenue.

Source: IBISWorld 2019

2.3 Raw materials

Clay is one of the most abundant natural mineral materials on Earth. For brick manufacturing, clay must possess some specific properties and characteristics. Such clays must have plasticity, which allows them to be shaped or moulded when mixed with water; they must have sufficient wet and air-dried strength to maintain their shape after forming. Also, when subjected to appropriate temperatures, the clay particles must fuse together[7]. There are three major clays that are used in brick construction, as follows:

- **Surface-** This clay may be the upthrusts of older deposits or of more recent sedimentary formations. As the name implies, they are found near the surface of the Earth.
- **Shales-** This is clay that has been subjected to high pressures until it has nearly hardened into slate.
- **Fire-** This clay is usually mined at deeper levels than other clays and has refractory qualities.

Surface and fire clays have a different physical structure from shales but are similar in chemical composition. All three types of clay are composed of silica and alumina with varying amounts of metallic oxides. Metallic oxides act as fluxes promoting fusion of the particles at lower temperatures. Metallic oxides (particularly those of iron, magnesium and calcium) influence the colour of the fired brick.

The manufacturer minimises variations in chemical composition and physical properties by mixing clays from different sources and different locations in the pit. Chemical composition varies within the pit, and varying manufacturing processes compensate for the differences. As a result, brick from the same manufacturer will have slightly different properties in subsequent production runs. Further, brick from different manufacturers that have the same appearance may differ in other properties.

[7] The Brick Industry Association. 2006. Technical notes on brick construction. p.1-2.

2.4 Products overview

In 2018-19, the three main CB products in Australia were face bricks (65.5%), common bricks (22.11%) and clay pavers (12.4%)[5]. Figure 5 shows these forms of clay brick that are typically produced in the Australian CBMI.

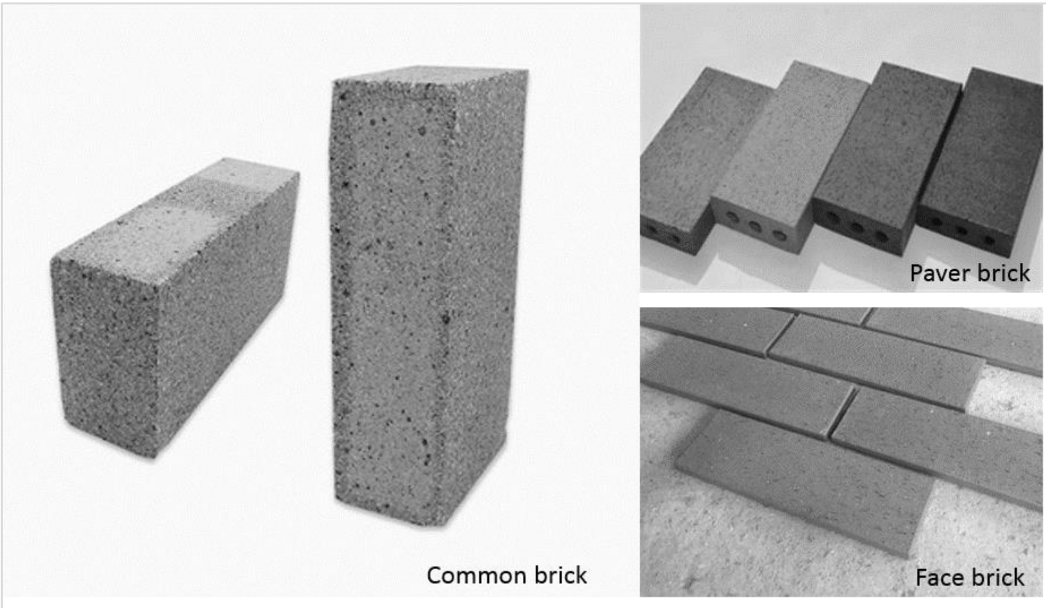

Figure 4. The main three forms of brick used in the Australian construction industry
Source: www.Alibaba.com

The following sections describe the properties of the three main bricks produced in Australia. The information on the material properties is extracted from IBIMWorld 2019 Industry report on clay manufacturing in Australia.

Face bricks

Face bricks are generally more aesthetically appealing than common bricks, as they have a smooth and accurate finish and uniform colours (Figure 4). These qualities make face bricks popular with both residential and non-residential construction. Face bricks have increased as a share of revenue over the past five years, due to rising demand from residential construction. As a result, manufacturers have produced increasing quantities of face bricks, which attract higher prices and profit margins. For example, Brickworks, the industry's largest manufacturer, has increased its production of the face and boutique bricks at the expense of other product categories. The aesthetic appeal and low maintenance costs of face bricks differentiate them from other cladding products such as timber. Face bricks are also able to better withstand the effects of wind, rain and frost.

Common bricks

Common bricks generally fail to meet consumer standards for appearance (Figure 4) but are satisfactory as non-face bricks due to their hardness and structural support qualities. Common bricks are usually hidden from view and used for internal walls and rear walls that are typically not exposed. As a result, these bricks are generally used in detached houses, which are more brick-intensive. This product segment has declined as a share of revenue over the past five years, due to subdued demand from detached housing and greater activity from less brick-intensive multi-unit residential housing.

Clay pavers

Clay pavers account for a relatively small proportion of industry revenue (12.4%) compared with other product segments. Pavers are generally used to form even floor surfaces for outdoor areas, such as driveways, patios, walkways and roads. Similarly to bricks, pavers are manufactured in a variety of colours and textures (Figure 4). Clay pavers have increased as a share of industry revenue over the past five years, due to the rising popularity of outdoor living areas. This trend has increased demand for exterior paving installed in new and existing residential properties.

2.5 Manufacturing process

Although the basic principles of manufacture are fairly uniform, individual manufacturing plants tailor their production to fit their particular raw materials and operation. Essentially, bricks are produced by mixing ground clay with water, forming the clay into the desired shape, and drying and firing. The manufacturing process has six general phases (Figure 5):

1) Mining and storage of raw materials
2) Preparing raw materials
3) Forming the brick
4) Drying
5) Firing and cooling and
6) De-hacking and storing finished products

The information regarding brick manufacturing is taken from a technical note published by the US's Brick Industry Association. The following sections describe the six phases in brick manufacturing mentioned above, illustrated in Figure 6.

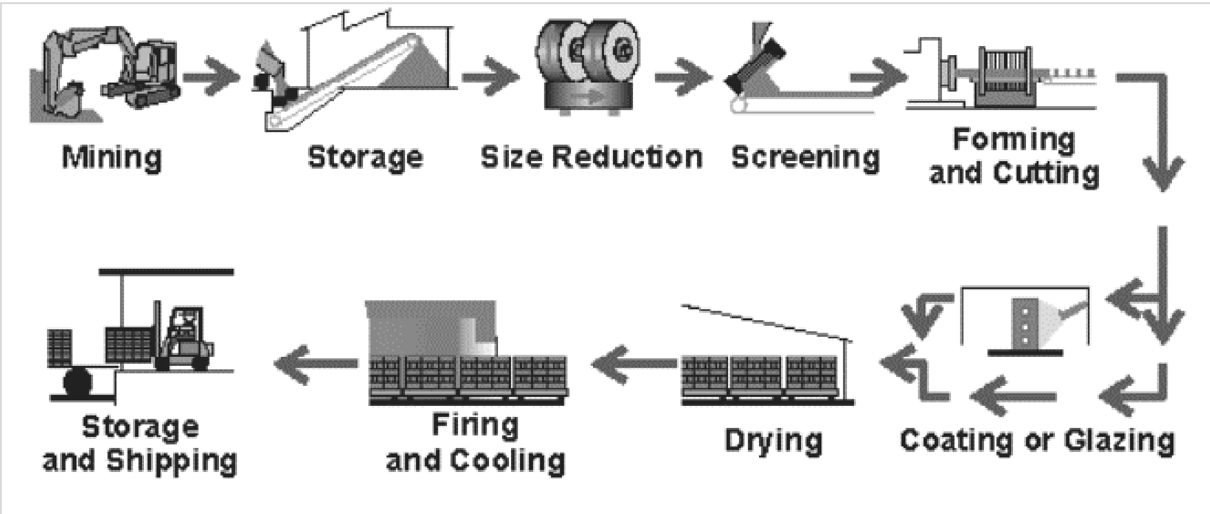

Figure 5. The typical process for brick manufacturing
Source: The US's Brick Industry Association (2006)[8]

Mining and Storage- Surface clays, shales and some fire clays are mined in open pits with power equipment. Then the clay or shale mixtures are transported to plant storage areas. Continuous brick production, regardless of weather conditions, is ensured by storing sufficient quantities of raw materials required for many days of plant operation. Normally, several storage areas (one for each

[8] The Brick Industry Association. 2006. Technical notes on brick construction.

source) are used to facilitate blending of the clays. Blending produces more uniform raw materials, helps control colour and allows raw material control for manufacturing a certain brick body.

Preparation- To break up large clay lumps and stones, the material is processed through size-reduction machines before mixing the raw material. Usually, the material is processed through inclined vibrating screens to control particle size.

Forming- Tempering, the first step in the forming process, produces a homogeneous, plastic clay mass. Usually, this is achieved by adding water to the clay in a pug mill, a mixing chamber with one or more revolving shafts with blade extensions. After pugging, the plastic clay mass is ready for forming.

There are three principal processes for forming brick: stiff-mud, soft-mud and dry-press.

1) **Stiff-Mud Process-** In the stiff-mud or extrusion process, water in the range of 10 to 15 per cent is mixed into the clay to produce plasticity. After pugging, the tempered clay goes through a de-airing chamber that maintains a vacuum of 38 to 73 cm of mercury. De-airing removes air holes and bubbles, giving the clay increased workability and plasticity, resulting in greater strength. Next, the clay is extruded through a die to produce a column of clay. As the clay column leaves the die, textures or surface coatings may be applied. An automatic cutter then slices through the clay column to create the individual brick. Cutter spacing's and die sizes must be carefully calculated to compensate for normal shrinkage that occurs during drying and firing.
2) **Soft-Mud Process-** The soft-mud or moulded process is particularly suitable for clays containing too much water to be extruded by the stiff-mud process. Clays are mixed to contain 20 to 30 per cent water and then formed into a brick in moulds. To prevent clay from sticking, the moulds are lubricated with either sand or water to produce "sand-struck" or "water-struck" brick. Brick may be produced in this manner by machine or by hand.
3) **Dry-Press Process-** This process is particularly suited to clays of very low plasticity. Clay is mixed with a minimal amount of water (up to 10%), then pressed into steel moulds under pressures from 500 to 1500 psi (3.4 to 10.3 MPa) by hydraulic or compressed air rams.

Drying- Wet brick from melding or cutting machines contain 7 to 30 per cent moisture, depending upon the forming method. Before the firing process begins, most of this water is evaporated in dryer chambers at temperatures ranging from about 38 °C to 204 °C. The extent of drying time, which varies with different clays, usually is between 24 to 48 hours. Although heat may be generated specifically for dryer chambers, it usually is supplied from the exhaust heat of kilns to maximise thermal efficiency. In all cases, heat and humidity must be carefully regulated to avoid cracking in the brick.

Hacking- Hacking is the process of loading a kiln car or kiln with brick. The number of bricks on the kiln car is determined by kiln size. The bricks are typically placed by robots or mechanical means. The setting pattern has some influence on appearance. Brick placed face-to-face will have a more uniform colour than bricks that are cross-set or placed face-to-back.

Hacking- Bricks are fired between 10 and 40 hours, depending upon kiln type and other variables. There are several types of kilns used by manufacturers. The most common type is a tunnel kiln, followed by periodic kilns. Fuel may be natural gas, coal, sawdust or methane gas from landfills or a combination of these fuels. In a tunnel kiln, bricks are loaded onto kiln cars, which pass through various temperature zones as they travel through the tunnel. The heat conditions in each zone are carefully controlled, and the kiln is continuously operated. A periodic kiln is one that is loaded, fired, allowed to cool and unloaded, after which the same steps are repeated. Dried bricks are set in periodic kilns according to a prescribed pattern that permits circulation of hot kiln gases.

Firing may be divided into five general stages:

1) Final drying (evaporating free water);
2) Dehydration;
3) Oxidation;
4) Vitrification; and
5) Flashing or reduction firing.

All except flashing are associated with rising temperatures in the kiln. Although the actual temperatures will differ with clay or shale, final drying takes place at temperatures up to about 200 °C, dehydration from about 150 °C to 980 °C, oxidation from 540 °C to 980 °C and vitrification from 870 °C to 1315 °C. Clay, unlike metal, softens slowly and melts or vitrifies gradually when subjected to rising temperatures. Vitrification allows the clay to become a hard, solid mass with relatively low absorption. Melting takes place in three stages:

1) Incipient fusion, when the clay particles become sufficiently soft to stick together in a mass when cooled;
2) Vitrification, when extensive fluxing occurs and the mass becomes tight, solid and non-absorbent; and
3) Viscous fusion, when the clay mass breaks down and becomes molten, leading to a deformed shape.

The key to the firing process is to control the temperature in the kiln so that incipient fusion and partial vitrification occur but viscous fusion is avoided. The rate of temperature change must be carefully controlled and is dependent on the raw materials, as well as the size and coring of the brick being produced. Kilns are normally equipped with temperature sensors to control firing temperatures in the various stages. Near the end, the brick may be "flashed" to produce colour variations.

Cooling- After the temperature has peaked and is maintained for a prescribed time, the cooling process begins. Cooling is an important stage in brick manufacturing because the rate of cooling has a direct effect on colour.

De-hacking- De-hacking is the process of unloading a kiln or kiln car after the bricks have cooled, a job often performed by robots. Brick are sorted, graded and packaged. Then they are placed in a storage yard or loaded onto rail cars or trucks for delivery. The majority of brick today are packaged in self-contained, strapped cubes, which can be broken down into individual strapped packages for ease of handling on the construction site. The packages and cubes are configured to provide openings for handling by forklifts.

3 REGULATIONS, POLICIES AND GUIDELINES

Bricks are the subject to two Australian Standards, AS/NZS 4455[9] and AS/NZS 3700[10]. These two standards outline the key characteristics of a brick. Currently, there is no EPR scheme in place in Australia for brick waste, and manufacturers are not involved in such schemes. However, Brickworks Building Products declares that they run an initiative that post-production waste is collected and crushed for return. GBCA and ISCA, two current environmental rating tools, are deemed to have an impact on better management of C&D waste in Australia[11]. These two tools provide credits for applying the best possible waste management options in construction projects. Discrepancies between regulations impact the brick waste is treated. Inconsistent regulations between jurisdictions make it difficult to manage brick waste between Australian states and territories.

Furthermore, there are policies implemented by some jurisdictions that advocate the use of waste management option that is more environmentally preferred. For instance, in Victoria, the Waste management policy indicates that "*the Authority may prohibit certain wastes from being disposed to landfill if there is a higher waste management option practicably available or the waste poses an unacceptable risk to the environment*"[12].

Another issue with the current policies is the unreasonable requirements set that rule out the usage of recycled brick waste in the new or renovation construction projects. Sometimes it is difficult to meet these requirements, which act as push back for those who are involved in brick waste recovery activities. These policies should be motivated in favour of the usage of more brick waste.

[9] BD-026 (Masonry Units, Pavers, Flags and Segmental Retaining Wall Units). 2008. Masonry units, pavers, flags and segmental retaining wall units - Masonry units.

[10] BD-004 (Masonry Structures). 2018. Masonry Structures.

[11] Shooshtarian, S. T, Maqsood, PeterSP Wong1, M, Khalfan, R. Yang. Green Construction and Construction and Demolition Waste Management in Australia. 43rd AUBEA Conference: Built to Thrive: Creating Buildings and Cities That Support Individual Well-Being and Community Prosperit. November 2-4. Noova. Australia.

[12] Victorian Government Gazette. 2004.

4 BRICK WASTE GENERATION

4.1 How much brick waste is generated

Previous studies have shown that brick and concrete waste can account for 75% of C&D waste from a construction site[13,14]. In Singapore, a study[15] found that the waste average percentage of brick is about 13% of the amount purchased. In Australia, limited studies have investigated the constitution of waste generated at construction and demolition sites. For instance, in WA[16], it was found that bricks accounted for the main loose waste onsite (by weight) in this state. In NSW, the comparative analysis of four dwellings showed the potential recovery of brick and concrete recovery[17] during building removal (Figure 6).

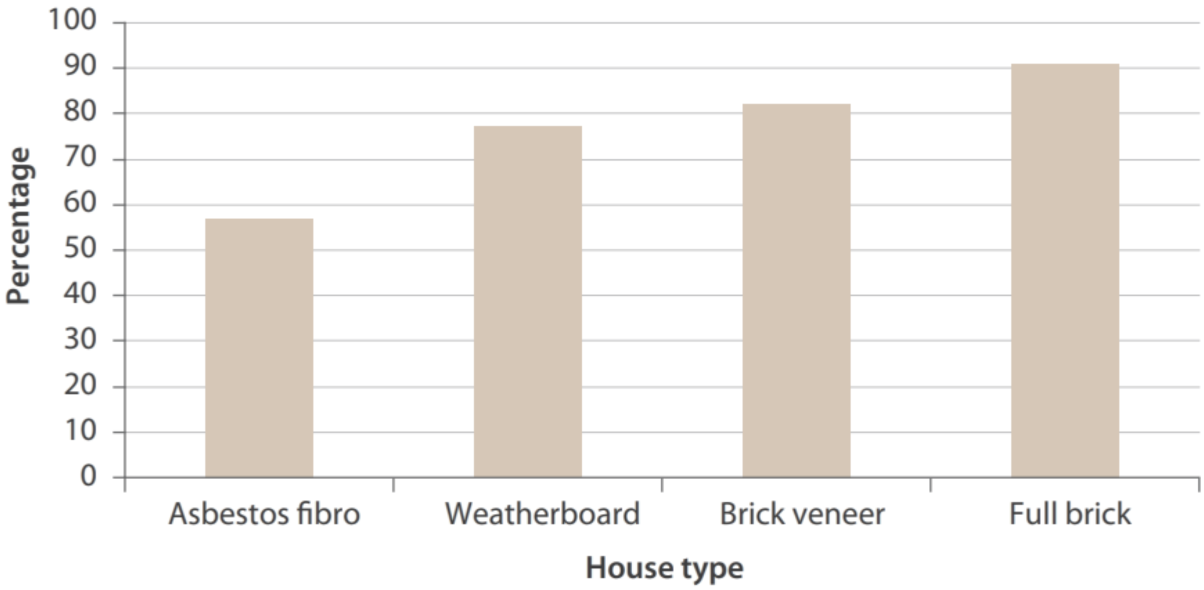

Figure 6. Percentage of bricks and concrete in house removal activities
Source: Office of Environment and Heritage (2010)[19]

Table 3 summarises the waste data reports on the national and jurisdictional timber waste in various waste streams in 2016-17[18]. As can be seen in the table, there is limited data about generation and management methods of brick waste. According to data, the period reported 1,872,467 tonnes of brick waste was recycled. 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. Among the jurisdictions, almost 95% of brick waste recycling took place in NSW and Vic combined in 2016-2017.

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[13] Crowther, P. 2000. Building Deconstruction in Australia, Kibert, Charles J., Chini, Abdol, R., eds., "Overview of Deconstruction in Selected Countries" CIB Report No. 252, 18-19.

[14] Formoso, C.T., Soibelman, L., De Cesare, C. and E.L. Isatto, 2002. Material waste in building industry: main causes and prevention. Journal of Construction Engineering and Management, 128(4), 316-325.

[15] Kang Y. Wastage in bricks. Dissertation, National University of Singapore, unpublished.

[16] Forsythe, P, Máté, K. 2007. Assessing brick waste on domestic construction sites for future avoidance. In 41st Annual Conference of the Architectural Science Association ANZAScA.

[17] Office of Environment and Heritage. 2010. House deconstruction fact sheet: Bricks and concrete removal.

[18] Department of Environment and Energy. 2018. P863 National waste data and reporting cycle 2017-19. https://www.environment.gov.au/system/files/resources/7381c1de-31d0-429b-912c-91a6dbc83af7/files/national-waste-report-2018-data.xlsx

Table 3. Brick waste data in various jurisdictions

	Waste generation				Waste landfill				Waste recycling			
State	**MSW**	**C&I**	**C&D**	**TOTAL**	**MSW**	**C&I**	**C&D**	**TOTAL**	**MSW**	**C&I**	**C&D**	**TOTAL**
ACT	-	-	-	-	-	-	-	-	-	-	-	10,638
NSW									12,907	90,600	1,087,881	1,191,388
NT	-	-	-	-	-	-	-	-	-	-	-	-
QLD	-	-	-	-	-	-	-	-	-	-	-	41,908
SA	-	189	11,498	11,687	-	-	189	11,498	840	840	40,320	42,000
TAS	-	-	-	-	-	-	-	-	-	-	-	-
VIC	-	-	-	-	-	-	-	-	-	2,000	0	584,157
WA	-	-	-	-	-	-	-	-	0	713	1,663	2,376
TOTAL												**1,872,467**

5 BRICK WASTE MANAGEMENT

5.1 Waste during manufacturing

Brick manufacturing is one of the most efficient uses of materials to produce a product. Brick plants are typically located close to raw material sources. Processed clay and shale removed in the forming process before firing are returned to the production stream. Bricks not meeting standards after firing are culled from the process and ground for use as grog in manufacturing brick or crushed for use as landscaping material. There is virtually no waste of raw materials in manufacturing brick.

Brick manufacturing uses readily available raw materials, including some waste products. The primary ingredient, clay, has been termed an "abundant resource" by many authorities including the American Institute of Architects[19], confirming that depletion of clay is not a concern. Nonhazardous waste products from other industries are sometimes used. Examples include using bottom- and fly-ash from coal-fired generators, using other ceramic materials as grog, using lubricants derived from processing organic materials in the forming of brick and using sawdust as a burnout material. While natural gas is the most frequently used energy source for brick manufacturing, many manufacturers are using waste products, such as methane gas from landfills and sawdust, for brick firing.

There are opportunities to reduce the impact of waste during brick manufacturing; some studies have demonstrated this possibility using various waste materials. Table 4 presents a selection of these studies and their findings.

Table 4. Application of other C&D wastes in the production of brick

Waste material	Summary of study	Reference
Marble powder	The results showed that the marble dust additive had a positive effect on the physical, chemical and mechanical strength of the produced industrial brick	Bilgin et al. (2012)
Fly ash (substitute for clay)	The results showed that bricks with a high-volume ratio of fly ash are of high compressive strength, low water absorption, no cracking due to lime, no frost and high resistance to frost-melting.	Lingling et al. (2005)
Waste glass powder and limestone powder waste	The results indicated that the samples containing waste glass powder and limestone powder waste combinations provide better results for the potential of producing economical new brick materials.	Turgut (2008)
Waste glass	Waste glass addition enhances the physical and mechanical properties of fired clay brick	Phonphuak et al. (2016)
Spent shea waste	This research has therefore provided compelling evidence that could create a new-found route for the synergistic eco-friendly reuse of spent shea waste to enhance clay brick construction aside being a potential mainstream disposal option	Adazabra et al. (2017)
Steel slag	Bricks with a steel slag addition of less than 10% and a firing temperature above 1050°C would fit CNS3319 third-class brick for builders	Shih et al. (2004)

19 American Institute of Architects, Environmental Resource Guide, The American Institute of Architects, Canada, 1998.

Textile sludge (substitute for clay) and waste glass	The recycling of textile sludge for brick production, when combined with waste glass additions, may thus be promising in terms of both product quality and environmental aspects	Rahman et al. (2015)

Note: while there are multiple pieces of literature demonstrating the successful use of waste materials from various waste streams (i.e. MSW and C&I)[20] this table only presents the literature investigating the use of the C&D waste stream.

A comprehensive review of the waste (all waste streams) materials used in brick production has already been conducted[21,22,23] wherein more than 20 various materials applied were identified with satisfactory results for clay brick production. There is a wide array of indications for the successful application of various waste materials in brick production in the relevant studies; the major indications include compressive strength, flexural strength, unit weight, water absorption and uptake, abrasion resistance, freezing-thawing (F-T) resistance, heavy metal leaching rate, drying shrinkage, density and thermal conductivity. The main standards that are used as a benchmark for testing the applicability of using various waste material in brick production include 'EN Standard EN13892-3'[24], 'ASTM C 779'[25], 'BS6073''ROC CNS 1127'[26] and 'CNS 3319'[27]. Notwithstanding, the prerequisite for their use is that they must be not only technically suitable but also environmentally friendly[28].

In Australia, Brickworks Building Products® asserts that their member companies are constantly striving to eliminate production waste. In 2012, this company declared that all production waste is returned to the mix. For example, the new Austral Bricks® plant in Victoria has markedly reduced the instance of malformed or off-specification green (unfired) bricks. Any such units are automatically recycled into the clay mix rather than going to landfill[29]. It also plans to investigate products that produce excessive waste and look for ways in which these can be reduced. One efficient waste minimisation practice that takes place during the manufacturing phase is to produce half bricks that are sometimes necessary for certain constructions. It is reported that up to 75% of brick waste occurs when labourers attempt to cut bricks into half[16]. A very popular management style that can assist the construction material manufacturing industry with reducing waste is the lean and parallel-line manufacturing model[30].

5.2 Waste reduction opportunities during the design, planning and contract

This involves designing goods to last longer and to be 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 closely attributed to design errors. The authors graded design changes as the most significant contributors to waste generation when construction works are in progress and the lack of information on the drawings. The other design-related waste causes that were identified in this study were the complexity of detailing,

[20] Raut, S.P., Ralegaonkar, R.V. and Mandavgane, S.A., 2011. Development of sustainable construction material using industrial and agricultural solid waste: A review of waste-create bricks. *Construction and Building Materials*, 25(10), 4037-4042.

[21] Zhang, L., 2013. Production of bricks from waste materials–A review. *Construction and Building Materials*, 47, 643-655.

[22] Murmu, A.L. and Patel, A., 2018. Towards sustainable bricks production: An overview. Construction and Building Materials, 165, 112-125.

[23] Al-Fakih, A., Mohammed, B.S., Liew, M.S. and Nikbakht, E., 2018. Incorporation of waste materials in the manufacture of masonry bricks: an update review. *Journal of Building Engineering*. 21, 37-54.

[24] EN13892-3 .2004. Methods of test for screed materials. Determination of wear resistance-Bohme.

[25] ASTM C 779 .2005. Standard test method for abrasion resistance of horizontal concrete surfaces. American Society for Testing and Materials, Philadelphia, PA.

[26] CNS Catalog. 2017. Beurue of Standards, Meteorology and Inspection. China. ISSN: 1561-8668.

[27] Ibid.

[28] Alonso-Santurde, R., Coz, A., Viguri, J.R. and Andrés, A., 2012. Recycling of foundry by-products in the ceramic industry: Green and core sand in clay bricks. *Construction and Building Materials*, 27(1), 97-106.

[29] Build for Living. 2012. Building a platform of commitment and responsibility.

[30] Shah, R. and Ward, P.T., 2003. Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management*, 21(2), 129-149.

selection of low-quality materials and lack of familiarity with alternative products. Waste can also occur during the design stage due to errors in contract clauses or incomplete contract documents[31,32].

Notably, it is widely known that design variations and changes can result in a meaningful quantity of design-generated waste. These variations often change the type or quantity of the building materials. On the same note, the standardisation of design is found to be a solution to variation in construction. Standardisation can improve buildability and reduce the number of off-cuts[33].

Design for deconstruction also is another design strategy to reduce waste at construction and demolition sites. In the case of brick, one Australian study[29] found that waste from set-out can design not to bond. Brick on edge was used instead of stretcher bond when trying to create a level first course on an uneven footing.

There has been a trend among modern architects in reusing old bricks in innovative designs. Further encouragement of this trend can lead to increased uptake of old bricks in new construction projects. For instance, James Dalecki of Dalecki Designs[34] enumerated the benefits of using old bricks. He stated that the benefits of using natural building materials such as clay bricks are not only related to their incredibly long life but also the beautiful way they age. He also mentioned that, depending on the style of building, an old brick can either be used to blend in with other materials or, alternatively, can contrast to create a beautiful modern building. Furthermore, Dalecki argued "*that clay products require no finish (paint or render) to maintain their colour or appearance*... *this makes them a great product to reuse as it means they can easily be removed from their first application and reused without any treatments required (other than a possible clean)... A beautiful heritage brick can serve as a key design feature in contrast to a modern design...They can be used for feature paving, internal floors, ceilings, built-in furniture, steps or even seating, the options are truly endless.*"

In another case reported by the Edge Environment[35] on six luxury eco-friendly buildings in NSW, the use of recycled materials including 40t of bricks was encouraged and inspired by the client's commitment to ecological sustainability. Their goal was to create interesting buildings that would attract people and create a place with a unique character. Michael Hennessey, the owner of the resort where these buildings were built, described his principal driver as *'Mother Nature and my daughter'.*

Another strategy that impacts waste minimisation during the design phase is related to the social responsibility of designers in the promotion of activities leading to waste minimisation. This can include bringing the associated financial benefits to the attention of the client[36]. 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 will involve partnerships between the national government, local authorities, industry, the media and community organisations.

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31 Craven, D.J, Okraglik, H.M. & Eilenberg, I.M. 1994. Construction waste and a new design methodology. Proc. of the 1st Conference of CIB TG 16 on Sustainable Construction, ed. C.J. Kibert, Tampa: Florida, 89–98.

32 Bossink, B.A.G. & Brouwers, H.J.H. 1996 Construction waste: quantification and source evaluation. *Journal of Construction Engineering and Management*, 122(1), 55–60.

33 Dainty, A.R.J. & Brooke, R.J., 2004.Towards improved construction waste minimisation: improved supply chain integration. Structural Survey, 22(1), 20-29.

34 Dalecki, J. 2017. Reuse & Recycle Materials - Brickworks Building Products. [online] Brickworks Building Products. Available at: https://brickworksbuildingproducts.com.au/reuse-recycle-materials/ [Accessed 19 Aug. 2019].

35 Edge Environment. 2012. Construction and Demolition Waste Guide-Recycling and Re-use Across the Supply Chain.

36 Osmani, M., A. D. F. Price & J. Glass.2007. Potential for construction waste minimisation through design. *WIT Transactions on Ecology and the Environment*, 84, 575-584.

Waste can also occur during the design stage due to errors in contract clauses or incomplete contract documents[37,38]. The stage at which contractual agreement is made presents an opportunity to minimise C&D waste[39]. Stakeholders can reduce waste by incorporating waste minimisation activities specified by specifically-oriented contract tender clauses. On that note, to eventuate this, some studies[40] suggest using contractual clauses to discipline poor waste management. Others, such as Greenwood[41], 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 can influence the way that waste is generated. For instance, in Australia,[42] it was found that "Fix only" subcontracts rarely create motivation for bricklayers to re-use off-cuts. 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.

Two of the strategies to reduce material consumption are through components' life extension or design against overconsumption[43]. 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[44].

Bricklayers are important people in the battle of reducing the waste if they are not disincentivised to do so. In Australia, the bricklayers are contracted based on the number of bricks arrived onsite and are incentivised to create waste[45]. If they use half bricks, they get paid for a whole, and their pay is not deducted by the number of bricks left over. Contracting model with plastering subcontractors perhaps is the way to control this issue and reduce waste. If the model was “supply and lay” there would not be a brick left over onsite, and any spare would be carried to the next job.

5.3 Reducing waste during the procurement

Correct estimation of brick needed for a construction activity can save a huge quantity of unwanted materials that might have otherwise been mixed with waste going to landfill or illegally stockpiled. Inaccurate quantity take-off and/or over-ordering ultimately create extra waste. Furthermore, 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. Builders in Australia will typically order 2-3% more than is required for allowance of off-cuts and waste etc[46]. 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 the bricks are only supplied in large order increments and only a small amount of the last order increment is required. Incremental ordering problems will potentially worsen if the brickwork is made up of small amounts of different brick types—as may be required in blended

[37] Craven, D.J, Okraglik, H.M. & Eilenberg, I.M., Construction waste and a new design methodology. Proc. of the 1st Conference of CIB TG 16 on Sustainable Construction, ed. C.J. Kibert, Tampa: Florida, 89–98, 1994.

[38] Bossink, B.A.G. & Brouwers, H.J.H., Construction waste: quantification and source evaluation. *Journal of Construction Engineering and Management*, 122(1), 55–60, 1996.

[39] CriBE, Waste Minimisation Through Counselling Building Project Teams & Collecting of Building Project Teams and Collecting Waste Arising. Welsh School of Architecture: Cardiff University, 1999.

[40] Dainty, A.R.J. & Brooke, R.J., Towards improved construction waste minimisation: improved supply chain integration. *Structural Survey*, 22(1), 20-29 , 2004.

[41] Greenwood, R., Construction Waste Minimisation –Good Practice Guide, CriBE: Cardiff, 2003.

[42] Forsythe, P. and Máté, K., 2007. Assessing brick waste on domestic construction sites for future avoidance. In 41st Annual Conference of the Architectural Science Association ANZAScA.

[43] Oguchi, M., Tasaki, T., 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, 627–640.

[44] Hirschl, B., Konrad, W., and G. Scholl, 2003. New concepts in product use for sustainable consumption. *Journal of Cleaner Production*. 11, 873–881.

[45] Barrett, C. 2019. BGC (Australia) Pty Ltd: Group Mnager Energy and Environment. Personal communications.

brickwork[16]. 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[35].

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[46]. Moreover, suppliers can be convinced 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.

5.4 Reducing waste during transportation & delivery

Waste during transportation can be significantly reduced if the suppliers do due diligence and exercise standard work practices. In the case of brick, an Australian study[38] found that no hard strap protectors at corners and edges of stacks and hand unloading might increase waste. They reported that an uneven landing pad for stacks could cause damage to bricks. In another study in Hong Kong, senior project managers, architects and engineers with more than 15 years of experience reported that damage during transportation due to the unpacked supply is one of the two main reasons for brick wastage[47]. 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.

5.5 Reducing waste during construction

The second major brick waste generation occurs during the construction of buildings and other infrastructures. One case study in Hong Kong[48] identified the possibilities wherein generation of brick waste occurred at a construction site. The researchers observed that it is likely to have brick wasted at all the stages of the construction process, starting from the transportation to the completion of the layering work on the site. Loss during loading and unloading, damaged bricks due to over-stacking in the storage area and poor products of layering were all possible causes of wastes. There were even cases of over-ordering.

In Australia, a field study[37] found that the main source of waste brick comes from inaccurate brick cutting, which is primarily done by chopping at bricks with a trowel. The researchers estimated that around 75% of brick waste generated because of the improper operation of brick cutting. Table 4 identifies the main reasons why a brick turns into waste at a construction site.

[46] BRE Group. 2014. The true Cost of Waste. Accessed September 5 2019. http://www.smartwaste.co.uk/ filelibrary/ True%20Cost%20of%20Waste/Brick_information_page.pdf

[47] Tam, V. W. Y. C. M. Tam, John K. W. Chan & William C. Y. Ng. 2006. Cutting Construction Wastes by Prefabrication. *International Journal of Construction Management*. 6(1), 15-25.

[48] 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.

Table 5. Causes of waste during construction

Cause of waste	Description
Cut bricks (i.e. off-cuts and breakages are rarely reused).	• Bricklayers often use a trowel instead of a bolster to cut bricks in half. This practice is used because it is faster but may cause multiple bricks to shatter before getting the desired half-brick. • Bricks that are brittle or do not cut cleanly will increase the problem. • Some subcontractors are resistant to using a brick saw as they find it slow, changes their normal work processes, requires them to get off scaffolding, the equipment is expensive to purchase and maintain, and creates the need for an extra labourer to operate the saw. • Cutting increases with larger than normal amounts of sills, window reveals, raking cutting, offset walls or closing bond at the ends of blade walls. • Poor "off-cuts" are not often suitable in "face" walls.
Handling and stacking breakages	• Bricks delivered on inclined surfaces can cause leaves in the brick stack to fall and break. • Muddy areas make handling more difficult and create a risk of dirt contamination of bottom bricks. • The more re-stacking and barrowing, the higher the expected breakages.
Use of bricks for scaffolding and other unintended uses	• Takes place mainly due to poor site control.
Bricks contaminated by dirt	• The bottom layer of the stack can be affected, but the bricks stacked on pallets are less likely to be affected.

Training of those who are directly and indirectly dealing with the brick at the construction site is an integral part of the brick 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 a brick in the construction industry. For instance, PointsBuild offers two online courses' TBA Foundations: Brick Standards 'and 'TBA Foundations: Defining a Brick '. These two courses aim to educate bricklayers and others involved in construction activities about various technicalities of brick in construction with the view to reduce damages to this material during and after construction.

For the first time, Think Brick Australia is running a Brick Cleaning Course[49], a nationwide training course on brick cleaning, in partnership with TABMA Training. Brick cleaners can achieve a brick cleaning industry accreditation by completing this course. The course covers the 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. Another important strategy to assist with reducing waste during construction is to have a rough

[49] Thinkbrick.com.au. 2019. THINK BRICK > Accreditation Courses. [online] Available at: https://www.thinkbrick.com.au/BrickCleaning /AccreditationCourse [Accessed 22 Aug. 2019].

estimation of waste that is expected to be generated at a construction site[50]. Accurate estimation can aid in efficient prevention and management from the very beginning of a construction project. However, previous studies indicated that one of the main hindrances to a valid estimation of C&D waste prior to the construction and renovation phases is the lack of data including poor documentation of waste generation rates and composition. There have been some efforts to model the quantity of waste generated at a construction site[51,52,53] and particularly BIM-based modelling in recent years[54].

Proper storage of bricks at the site can also contribute to reducing waste generated in 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[55].

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 facility where various materials are joined together to form a component of the final installation procedure[56]. Brickwork can be prefabricated off, or onsite in panels or box units lifted into position[57] and bolted to a building frame in a similar manner to precast concrete[58]. Panels that are moved into place onsite through the use of 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[59]. Some examples of buildings with prefabricated bricks are shown in Figure 7.

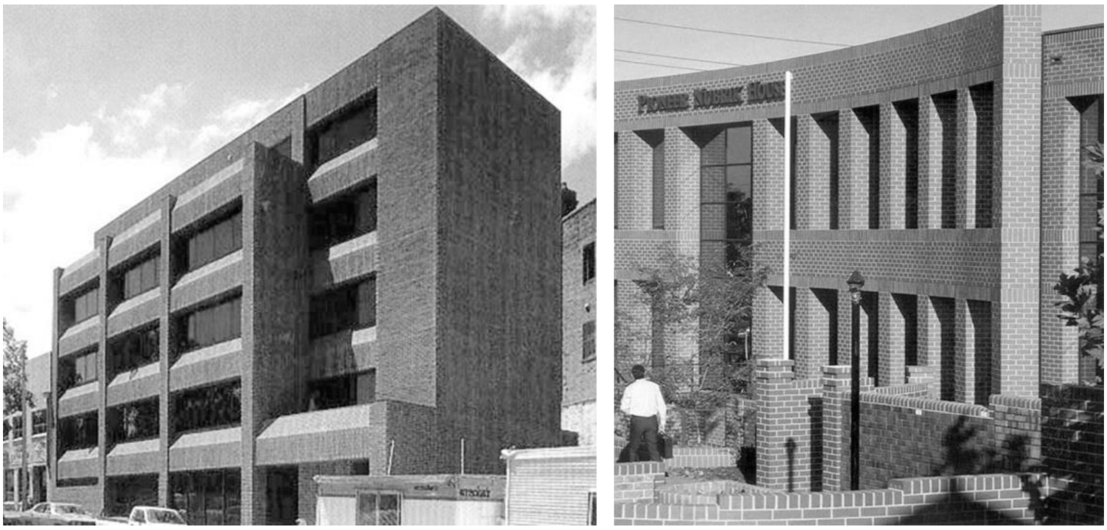

Figure 7. Examples of prefabricated brickwork in Australia

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

51 Ibid.

52Lu, W., Webster, C., Peng, Y., Chen, X. and Zhang, X., 2017. Estimating and calibrating the amount of building-related construction and demolition waste in urban China. *International Journal of Construction Management*, 17(1), 13-24.

53 Wu, Z., Ann, T.W., Shen, L. and Liu, G., 2014. Quantifying construction and demolition waste: An analytical review. W*aste Management*, 34(9), 1683-1692.

54 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.

55BRE Group. 2014. The true Cost of Waste. Accessed September 5 2019. http://www.smartwaste.co.uk/ filelibrary/ True%20Cost%20of%20Waste/Brick_information_page.pdf

56 Minunno, R., O'Grady, T., Morrison, G., Gruner, R. and Colling, M., 2018. Strategies for applying the circular economy to prefabricated buildings. *Buildings*, 8(9), 1-14.

57 Lane, W.J., Lane Wallace J, 2004. Prefab brickwork. U.S. Patent 6,763,640.

58 Clay Brick and Paver Institute. The University of Sydney. 2019. Prefabricated brickwork.

59 Roberts, J.J., Hogg, J. and Fried, A.F., 2001, June. Prefabricated Brickwork a review of recent applications. In Proceedings of the ninth Canadian Symposium, Hamilton. June 2001.

Left: Anderson House (1980) in the Melbourne suburb of Carlton (The brick panels are a single leaf, reinforced vertically and horizontally at about 600 mm centres, and contribute to the fire protection of the structural steel framing). Right: Pioneer Nubrik House in Adelaide (1990), Most of the brickwork was laid on site, but the brick soffits were prefabricated by the bricklayer in a building next to the site. **Source:** Clay Brick and Paver Institute, University of Sydney.

There are several advantages of brickwork prefabrications, some of which are listed below[60]:

- Work is protected from changeable weather conditions.
- Design features that may be too costly or labour intensive onsite can be carried out in the factory.
- More control can be exercised over materials used and construction work carried out to ensure superior quality.
- Project time is shortened due to speedy erection of wall panels leading to earlier occupancy of the building.
- No need for storage onsite as panels can be delivered 'just in time'.
- Need for scaffolding is reduced dramatically.
- Waste reduction

The reduction in waste, including brick waste using prefabrication technologies, has been documented in various contexts. Table 6 summarises the evidence of brick waste reduction using prefabrication reported by various studies.

Table 6. Studies providing evidence for waste minimisation through prefabrication

Reference	Context and data collection method	Result description
Zhou et al. (2014)	China, simulation	Brick waste occurring bricklaying tend to be minimised.
Begum et al. (2010)	Malaysia, interview and onsite monitoring	This study confirms that a huge amount of material wastage can be reduced by the adoption of prefabrication. The total brick waste generated is very much higher in the conventional project, i.e., 0.04 tones 100 m^{-2} compared to the prefabricated/IBS project of 0.63 tones 100 m^{-2}. This study also revealed that the rates of reused and recycled waste materials are relatively higher in projects that adopt prefabrication. Based on the total waste generated at each site, it is observed that 94% of waste generated at the IBS site is reused and recycled compared to only 73% at the conventional project site.
Jaillon et al. (2009)	China, a case study	The reduction percentage of brick waste through prefabrication is 56.1% reduction in brick waste.

Despite the proven benefits of prefabrication in reducing C&D waste, this construction technology is only successful when builders and clients can enjoy cost savings. In one study on the use of prefabrication, the interviewees suggested that cost was the key factor[61]. Another study found that

60 Fisher, K. 1992. Prefabricated brickwork panel system. Redland Brick, September 1992.

61 Tam, V.W. and Hao, J.J., 2014. Prefabrication as a mean of minimizing construction waste on site. *International Journal of Construction Management*, 14(2), 113-121.

the resistance to adopting prefabricated techniques was often seen in companies that had not carried out detailed studies on the potential economic savings achievable through waste reduction, specific to their activities and processes[62]. There are three other enablers that encourage the use of prefabrication as outlined by some investigators[63,64]:

(1) Environmental issues: When more stringent environmental control and regulations are forthcoming, prefabrication is one of the ways to facilitate long-term waste minimisation and reduction; (2) Construction costs: Introducing more productive and lean construction methods can reduce the construction cost-effectively and reduce the burden incurred due to high initial investment (Shen & Tam, 2002); (3) Government incentives: Granting relaxation to the gross floor areas for projects employing prefabrication elements, e.g., discounting the area occupied by facade units (Hong Kong Government – Environmental Protection Department 2006), will encourage the use of prefabrication. Moreover, tighter control on workmanship, allowable tolerances, homogeneity and allowable rework will favour the adoption of prefabrication.

5.6 Reducing waste during 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 generally generates more brick waste than it does in commercial buildings[65]. However, this waste often comes in a mix with other C&D waste. There is a strong preference within the reprocessing market for masonry materials to be separated at the source. This enables much simpler, cheaper and more effective processing. This is reflected in pricing mechanisms such as gate fees, which are lower for source-separated loads[66]. Where loads are mixed, the most common approach is for operators to segregate materials using manual labour, coupled with mechanical equipment such as excavators and front-end loaders. There are limited examples of fixed equipment and automated sorting systems being employed to separate materials[67]. 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.

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 choice of technology, the definition of work tasks, the estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks[68]. Full demolition requires less time than deconstruction. Time taken includes the manpower (total man-hour) and active plant costs. The NSW

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62 Cox, A.G. and Piroozfar, P., 2011, April. Prefabrication as a source for co-creation: An investigation into potentials for large-scale prefabrication in the UK. In Proceedings of the 6th Nordic Conference on Construction Economics and Organisation, Copenhagen, Denmark, 13-15.

63 Ho OST. 2001. Construction waste management – a contractor's perspective. The Hong Kong Institute of Builders.

64 Poon CS, Yu TW, Ng LH. 2001. On-site sorting of construction and demolition waste in Hong Kong. *Resources, Conservation and Recycling*. 32(2) 32157– 32172.

65 Zhao, W. and Rotter, S., 2008, May. The current situation of construction & demolition waste management in China. In 2008 2nd International Conference on Bioinformatics and Biomedical Engineering (4747-4750). IEEE.

66 Sustainability Victoria. 2014. Factsheet: Market summary – recycled brick, stone and concrete.

67 Hyder Consulting and EnCycle Consulting & Sustainable Resource Solutions. 2011. Construction and Demolition Waste Status Report: Management of Construction and Demolition Waste in Australia, Department of Sustainability, Environment, Water, Population and Communities and Queensland Department of Environment and Resource Management.

68 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 (225-232). Reston, VA: American Society of Civil Engineers.

Office of Environment and Heritage has published a factsheet[69] wherein deconstruction and demolition were compared time-wise (Figure 8).

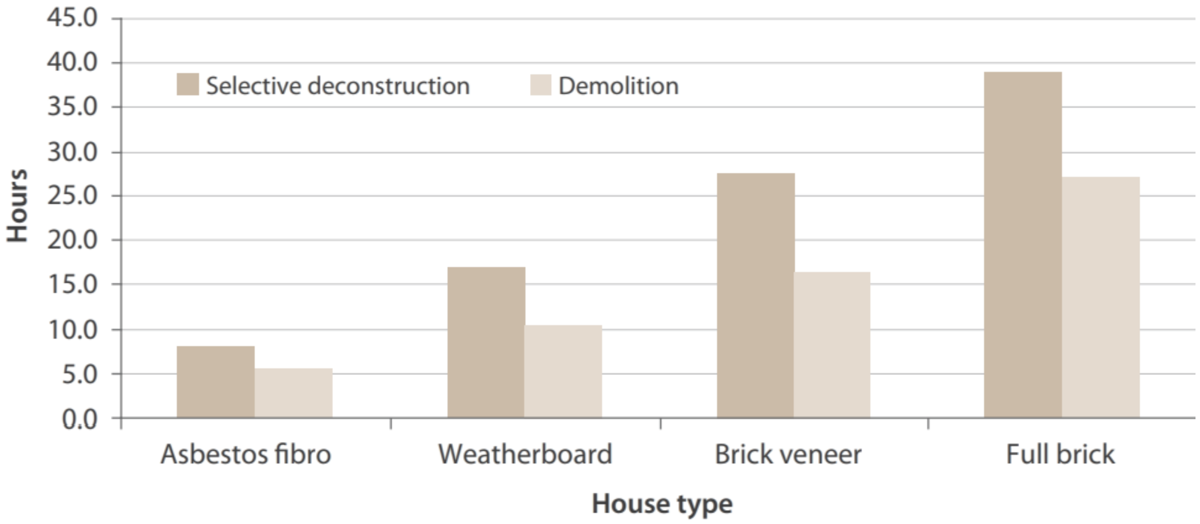

Figure 8. Time comparison for brick and concrete removal
Source: EPA NSW, House deconstruction fact sheet (2010).

The cost analysis associated with three building removal techniques in NSW revealed that deconstruction is cheaper than demolition, by anywhere between 55% (Asbestos fibro) to 294% (full brick)[72].

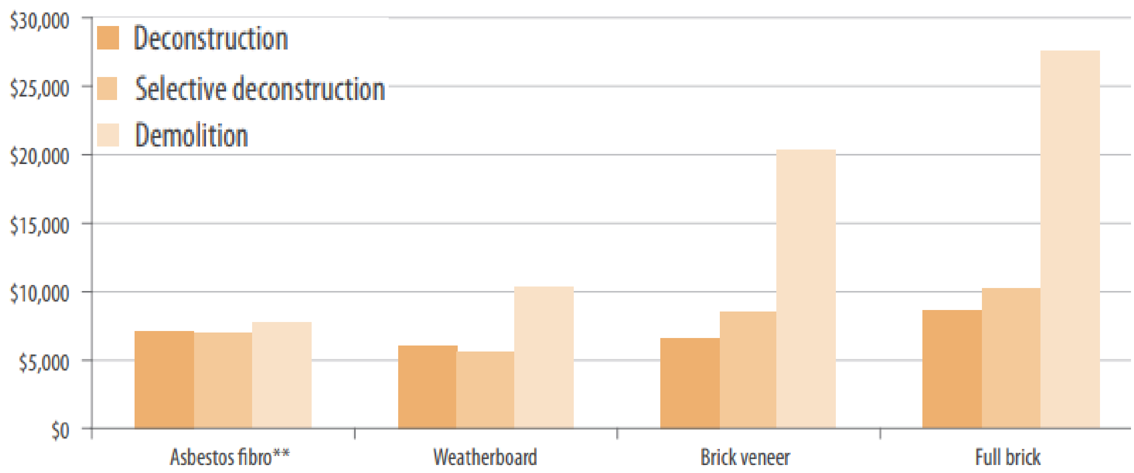

Figure 9. Cost comparison between three methods of building removal

69 Office of Environment and Heritage. 2010. House deconstruction fact sheet: Bricks and concrete removal.

5.7 Reducing waste through reusing

The demolished brick or the brick that is damaged during transport, construction or renovation can be re-used in construction projects without recycling. Recycled bricks are one of the most popular materials to incorporate into a building. From an environmental protection perspective, it is believed re-using old bricks provides a great opportunity to save 0.5 K CO_2 that comes with the production of one block of a clary brick. Therefore, there are a few attempts to encourage the application of old bricks in new builds.

A new European Union-funded project is called REBRICK[70] and has demonstrated that an old brick is not "just a brick". This 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, in the past year has developed a technology to exploit the reusing potential of old bricks. This technology involves the automated sorting of demolition wastes that separates and cleans old bricks using vibrational rasping. The main EBRICKS objectives are as follows:

a) Develop and modify the current brick cleaning technology to fulfil regional requirements
b) Explore the market possibilities for reused bricks in Europe
c) Market the use of reused bricks to key stakeholders in Europe

Figure 10. EBRICKS project operation and some examples of building with re-used (cleaned) bricks
Source: *www.en.gamlemursten.dk*

Furthermore, the re-use of brick may take place in the form of brick waste recycling for further use in a brick production line. In Turkey, two researchers, Demir and Orhan (2003)Demir and Orhan (2003)[71], studied the use of brick waste as an additive to raw materials for brick production. They reported that test results indicate a mixture of up to 30% fine waste brick additives can be used in 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 also helps protect the environment.

70 Gamlemursten.eu. 2019. Rebrick :: Rebrick. [online] Available at: http://www.gamlemursten.eu/ [Accessed 19 Aug. 2019].
71 Demir, I. & Orhan, M. 2003. Reuse of waste bricks in the production line. *Building and Environment*, 38, 1451-1455.

5.8 Waste recovery (recycling and upcycling)

The brick waste can be processed and further used in the construction industry (recycling) or in another industry (upcycling). Brick wastes are highly recyclable due to their inert nature and predominantly physical reprocessing requirements, with lesser need for chemical processes compared to other materials[72]. Brick recycling practice has a long history; the earliest evidence relates to the use of crushed brick with Portland cement in Germany in 1860 for the manufacturing of concrete products[73]. However, the first significant use of crushed brick as aggregates in new concrete has been recorded for reconstruction after the World War II[74]. In Denmark, only 2% of concrete and bricks generated are landfilled, with the remainder reused and recycled[75]. Large commercial projects lend themselves to recycling more so than small residential projects as there are significant economies of scale in collection, separation and marketing of recovered materials[76]. Waste bricks are also applied as powder materials in some countries.

The demolished bricks are burned into slime burnt ash in Japan and are commonly crushed to form filling materials in Hong Kong (Tam and Tam, 2006). Waste brick can also replace raw materials used in a mixture for production of other construction materials. For instance, pozzolans that are derived from wastes, when used as a partial cement substitute, typically improve the resistance of mortar. Table 7 presents a selection of studies wherein the successful application of brick waste in the production of masonry materials is documented.

Table 7. Summary of studies investigating the applications of recycled brick waste

Application	Summary of findings	Reference
Replacement of cement in mortar	A substitution of cement by 10% of waste brick increased mechanical strengths of mortar. The results of the investigation confirmed the potential use of this waste material to produce pozzolanic cement.	Naceri and Hamina (2009)
Pozzolanic materials	Experimental results revealed that waste brick has potential as a pozzolanic material in the partial replacement of cement or concrete to sulphate attack.	Lin et al. (2010)
Mineral filler in asphalt concrete mixture	The results show that the mixtures prepared with recycled brick powder have better mechanical properties than the mixtures with limestone filler. Thus, it is promising to use recycled brick powder as a mineral filler in asphalt mixture.	Chen et al. (2011)
The brick powder as cementitious material replacing Portland cement	The results show the mortars containing bricks powder show good performance.	Corinaldesi et al. (2002)
The brick powder (dust) as a stabiliser	The results obtained showed that partial substitution of the dust with PFA resulted in stronger material compared to using it on its own. The blended stabilisers achieved better performance.	Kinuthia and Nidzam (2011)
Crushed brick waste as a	The results indicated that only recycled crushed brick with a moisture ratio of around 65% is a viable material for usage in pavement subbase applications. The geotechnical	Arulrajah et al. (2011)

72 Sustainability Victoria.2014. Factsheet: Market summary – recycled brick, stone and concrete.
73 Devenny, A. & Khalaf, F. 1999. Use of crushed brick as coarse aggregate in concrete. *Masonry International*, 12, 81-84.
74 London, E. and F.N. Spoon.1992. Recycling of Demolished Concrete and Masonry, in: T.C. Hansen (Ed.), RILEM.
75 Residua .1999.Construction and Demolition Waste", Information Sheet in Warmer Bulletin, Issue 67, July 1999.
76 SA EPA. 2001. Barriers and Opportunities for Re-use and Recycling of Clean Fill and Building and Demolition Waste. NOLAN-ITU Pty Ltd. file:///C:/Users/Salman%20Shooshtarian/Desktop/8449_nolan_recycling_clean_fill.pdf

pavement subbase material	testing results indicate that crushed brick may have to be blended with other durable recycled aggregates to improve its durability and to enhance its performance in pavement subbase applications.	
Crushed brick as a coarse aggregate in concrete	The results demonstrated the durability of crushed bricks as a natural aggregate replacement at 25 and 50% and recommended to use the bricks in unreinforced concrete.	Adamson et al. (2015)

There are limited and scattered data available, showing how much brick waste is recycled or upcycled in Australia. In WA, a report[77] showed that 10.86t brick was recycled in 2005/2006. In Victoria, in 2012, the quantity of brick that was recycled was reported to be 390kt (median)[78]. According to the latest statistics, in 2016-2017, 1,872,467 tonnes of brick waste was recycled in Australia[18]. 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. Among the jurisdictions, almost 95% of brick waste recycling took place in NSW and Vic combined in 2016-2017. However, several states and territories did not report their brick waste management activities (Table 3).

A study[79] conducted in Australia found that a common solution to the brick waste problem is to crush the waste and to use the final product as a landscaping aggregate or low-grade road base. Brick recycling techniques are not complicated[80]; the bricks are crushed, either as mixed loads or in source-separated streams. In Australia, one study conducted a comparative analysis of the economic performance of two brick waste management scenarios in Melbourne[81] 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. Clearly, the cost savings of recycling far outweighed landfill disposal and virgin gravel production. In terms of operational costs, this study reported that, for 1000t of brick waste, the total costs are $92,356 and $29, 419 in the case of landfilling and recycling, respectively. The same results were found in a study conducted in NSW wherein demolition is more expensive than selective and full deconstruction due to reduced costs associated with transport and landfill levy. Some of the local council provides voucher through the rates notices to encourage the community to get their waste, including some C&D waste materials, recovered at the nominated recycling facilities.

Case Study 1 – Australian experience: Midland Brick

In June 2006, Midland Brick announced a brick recycling initiative aimed at reducing the amount of material being sent to landfill. Midland Brick, in association with Pindan Construction, formed a partnership that would see all waste bricks from a number of Pindan construction sites be returned to Midland Brick for recycling. Midland Brick has also set up recycling centres at a number of their yards throughout the metropolitan area (Cannington, Jandakot, Joondalup, Osborne Park and Middle Swan) that can be used by the general public for brick disposal. Commercial loads can be disposed at the Middle Swan yard. Plastic strapping from the brick and paver packs can also be recycled. At present, approximately 7,000 tonnes of brick has been recycled. This is on top of approximately 80,000 tonnes of imperfect product made at the Middle Swan and Cannington sites being re-introduced into the process. Midland Brick also has a partnership with Capital Demolition in Balcatta that recycles waste

[77] Cardno. 2008. Detailed investigation into existing and potential markets for recycled construction and demolition materials. Job No. V7038. https://www.wasteauthority.wa.gov.au/media/files/documents/investigationmarketsforrecycledcndmaterials.pdf

[78] Sustainability Victoria.2014. Factsheet: Market summary – recycled brick, stone and concrete.

[79] Forsythe, P. and Máté, K., 2007. Assessing brick waste on domestic construction sites for future avoidance. In 41st Annual Conference of the Architectural Science Association ANZAScA.

[80] Edge Environment . 2012. Construction and Demolition Waste Guide-Recycling and Re-use Across the Supply Chain.

[81] Damptey, E.O. 2011. Optimising the Use of Recycled C&D Waste Material in Civil Construction Projects. PhD thesis. Faculty of Engineering and Industrial Sciences. Swinburne University, Melbourne. Australia.

bricks from its recycling operations. Midland Brick has indicated that they are looking to increase the amount of waste brick material being recovered over the next few years; however, there is a maximum proportion the firing process can accept whilst maintain product specification.

Case Study 2 - Australian experience: SA construction companies

Responses from 12 SA based construction companies that have been involved in the recycling of construction materials to a survey showed that about 78% of brick waste was recycled[82]. Brick was found to be among the four top waste materials that were recycled; the other three materials included concrete, soil/sand and metal. Figure 11 shows the variation of materials recycled by these twelve companies.

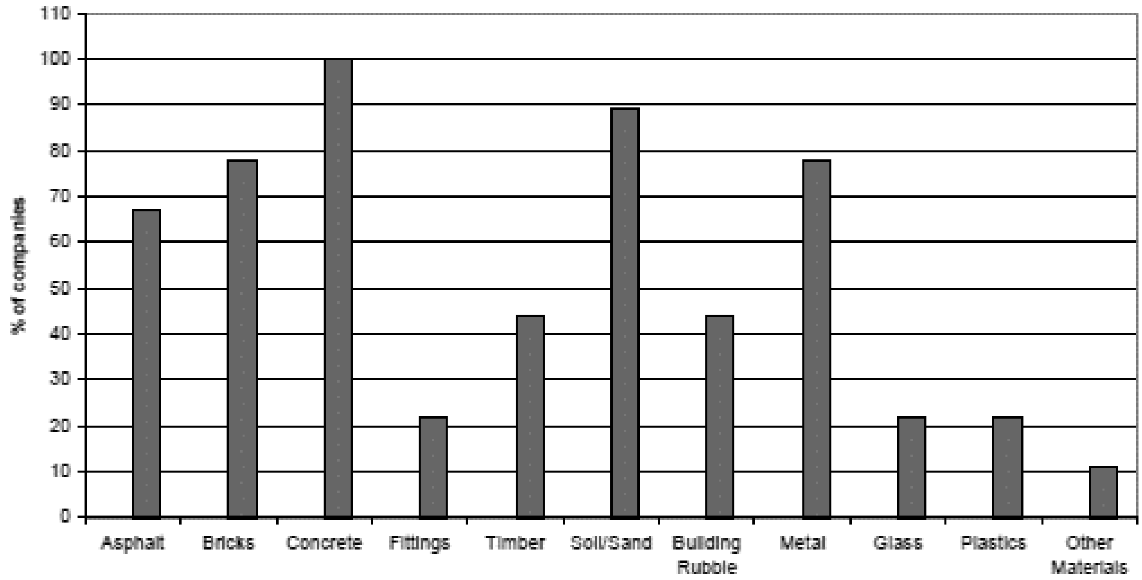

Figure 11. Materials recycled by construction companies surveyed

5.9 Illegal dumping and stockpiling

Illegal dumping and stockpiling is a prevalent incidence with respect to clay brick. Indeed, illegal dumping is a lucrative and extremely difficult practice to stop. There are service providers that are called Cowboy operators[83] in the waste recovery industry that offer services for skip-bins, disposal, sorting or recycling at below-market rates, undercutting the cost of legitimate and licensed businesses. 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. The following is a case study of brick waste illegal dumping in Australia.

Case Study 1- Hughes Demolition in North-west of Melbourne

Recently, a large demolition company, operating in a north-west suburb of Melbourne, was charged for the illegal dumping of a large quantity of C&D waste, most of which was bricks (Figure 12), on land that was not licenced to accept it. The company was ordered to fund the removal of about 2800 cubic

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[82] SA EPA. 2001. Barriers and Opportunities for Re-use and Recycling of Clean Fill and Building and Demolition Waste. NOLAN-ITU Pty Ltd. file:///C:/Users/Salman%20Shooshtarian/Desktop/8449_nolan_recycling_clean_fill.pdf

[83] Mannix,L., Vedelago C. and C. Houston. 2017. The tipping point: Illegal dumping swamps the waste industry. [online] The Age. Available at: https://www.theage.com.au/national/victoria/the-tipping-point-illegal-dumping-swamps-the-waste-industry-20170806-gxq8m0.html [Accessed 16 Aug. 2019].

metres of C&D waste from a property in Prima Court, Tullamarine[84]. In visiting this dumping site, Peter Kerr, the metro EPA manager, indicated that illegal dumping of C&D materials is costing Victoria over $30 million a year in clean-up costs. He also stated, "*That is particularly disappointing, given that much of it can be processed for productive reuse in building and construction*".

Figure 12. A clean-up worker amid waste illegally dumped at a field in Prima Court, Tullamarine, by demolition company Monark Industries, trading as Hughes Demolition
Source: The Age (2019)[84]

5.10 Landfilling the waste

On world-scale, considering the world annual production of clay bricks, which is approximately 6.25×10^8 ton, about 7×10^6 ton bricks go to landfills each year[85]. In some countries, due to various reasons including unavailability of land, the cost of landfilling has increased substantially such that recycling is more cost-effective. One study in the US[86] showed that recycling one ton of brick costs about $21 per tonne while landfilling one ton of the same would cost approximately $136/tonne in 2005. In Australia, a large quantity of brick waste is generated that needs careful attention for adequate management. However, the lack of update 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 SA, 11,498 tonnes of brick waste was landfilled (Table 3).

84Carolyn W.C. 2017. Companies fined for illegal dumping of waste after EPA swoop. [online] The Age. Available at: https://www.theage.com.au/national/victoria/companies-fined-for-illegal-dumping-of-waste-after-epa-swoop-20170821-gy0z5k.html [Accessed 16 Aug. 2019].

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

86 Lennon, M. 2005. Recycling Construction and Demolition Wastes, A Guide for Architects and Contractors.

6 BRICK WASTE MARKET, BARRIERS AND STRATEGIES

There is a good market for cleaned second-hand bricks for reuse, particularly red bricks[87]. However, there are several market barriers for waste-derived materials that are outlined in Objective 3 (Identifying the economic factors and drivers that govern the disposal and reduction/reuse/recycling of construction and demolition waste). Specific to clay brick, Sustainability Victoria has identified the specific market barriers for brick waste, including labour costs, changes in building technology and low demand[88]. Table 8 provides a summary of strategies identified to overcome barriers in the development of the market for brick waste.

Table 8. Strategies to remove barriers to market development for brick waste

Reference	Strategies to remove barriers to market development for brick waste
Sustainability Victoria	Improved separation onsite to sort brick waste from other C&D waste; developing educational materials for designers and builders about material choice and waste management; and increased promotion of the use of BSC in pavement construction.
Department of Environment and Conservation / Cardno[89]	Market instruments that could be used to remove barriers include education and communication, procurement policies, landfill levy increases, potential landfill bans on mixed materials, increase enforcement at inert landfills and compulsory waste management plans for the industry before undertaking C&D activities
Edge Environment[90]	Increased supply—if the supply of reclaimed materials from demolition could be increased, the continuity of supply would improve, and the opportunity for incorporating materials into designs would be greater. Increased knowledge—as tradesmen gain experience working with reclaimed materials, knowledge in the industry increases, new methods of construction can be tried and tested, and time savings can be achieved. There is a shortage of tradespeople who are able to work with the inconsistencies of reclaimed and recycled materials; training is required.
Eunice Ofeibea Damptey[91]	To effectively maintain demand for recycled RC and brick materials, the introduction of higher landfill fees, taxes on virgin products, and subsidies for recycled products such as RC and bricks, is required.

6.1 Integrated supply chain

According to Sustainability Victoria,[92] costs associated with transport are major factors in determining whether the material will be recycled or landfilled. Similarly, the generally low value of end product (per cubic metre or by tonnage) means that transportation of products to end-users is similarly impacted by the relative distance that the recycled product must be transported vs. a substitute product. As such, the location of facilities for reprocessing is of particular importance, as they are the

87 SA EPA. 2001. Barriers and Opportunities for Re-use and Recycling of Clean Fill and Building and Demolition Waste. NOLAN-ITU Pty Ltd. file:///C:/Users/Salman%20Shooshtarian/Desktop/8449_nolan_recycling_clean_fill.pdf
88 Sustainability Victoria. 2014. Factsheet: Market summary – recycled brick, stone and concrete.
89 Cardno. 2008. Detailed investigation into existing and potential markets for recycled construction and demolition materials
90 Edge Environment. 2012. Construction and Demolition Waste Guide-Recycling and Re-use Across the Supply Chain.
91 Damptey, E.O. 2011. Optimising the Use of Recycled C&D Waste Material in Civil Construction Projects. PhD thesis. Faculty of Engineering and Industrial Sciences. Swinburne University, Melbourne. Australia.
92 Ibid.

determinant of the total haulage distance from collection to recycled product end-user. Currently, there are companies across Australia that specialise in the removal and collection of brick waste generated from demolition, construction or renovation projects. The following table summarises some of these companies management practice. These companies operate in different jurisdictions, and the business information is extracted through direct contact with their sale and technical teams.

Table 9. Supply chain characteristics of the waste collector

Business name	State	Pricing mechanism	Others
1300 Rubbish Recycle	Multiple	\$ 250 per m^3 in Sydney and Melbourne \$ 220 per m^3 in Adelaide and Brisbane	Waste is transported to transfer stations
Bingo Industries	NSW and Vic	Disposal: NSW: \$40 per tone + \$600 per week for skip bin Vic: \$ 40 per tone landfill + \$420 per week for skip bin	Waste is transferred to landfill or recycling facilities

Note: *the prices tabulated above are current as of November 2019.*

6.2 Brick lifecycle models

There are various models that are outlined to provide insight into the brick material lifecycle. The first lifecycle model is put forward by REBERICK project, which provides information on brick waste management from the point that brick turns into waste until it becomes a construction material. This model depicts four stages with the relevant stakeholders that can contribute to building a strong integrated supply chain. The Gamle Mursten, the Danish company that created this model, believe that this model is a platform where the value that is created and shared across many stakeholders and markets. It is like a sound organism in an ecosystem contributing and cooperating widely to turn waste into nutrition, internally as well as externally.

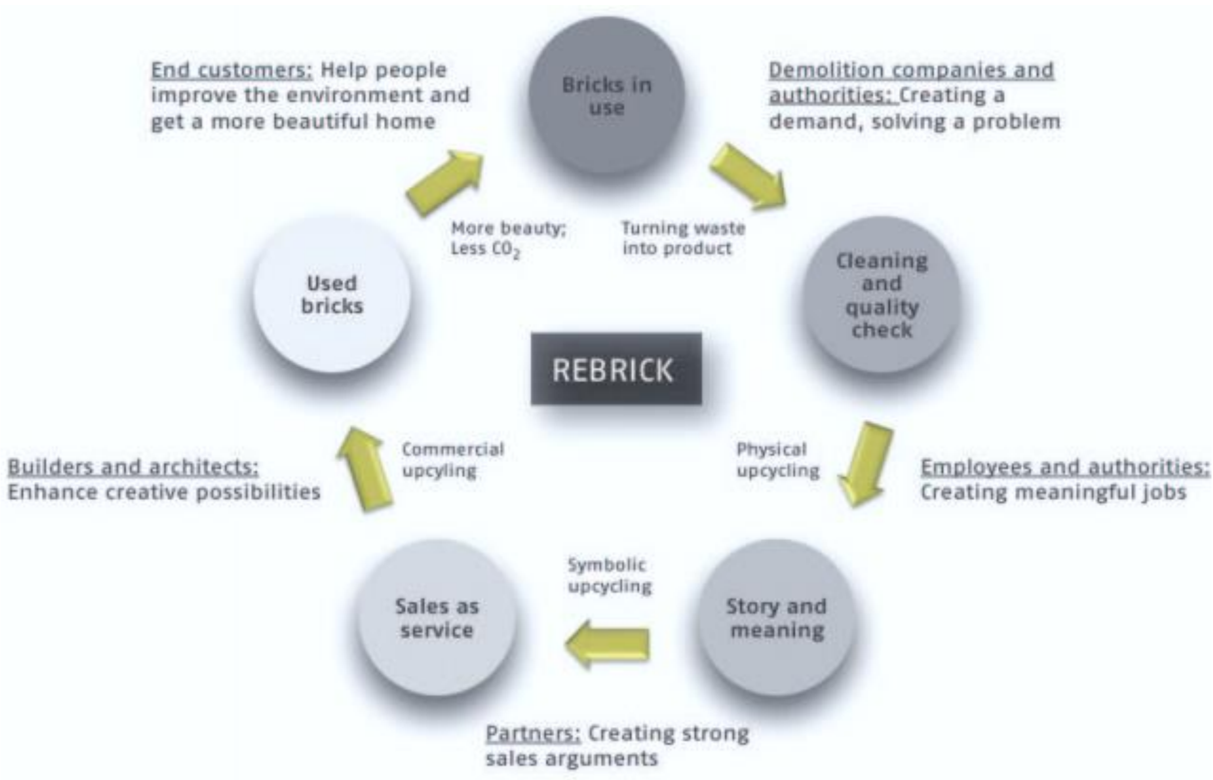

Figure 13. The REBERICK value system.

Source: Gamle Mursten Company (http://www.gamlemursten.eu/)

According to the opportunities identified for waste minimisation and sustainable practices to redirect waste from landfill, an integrated supply chain life cycle model is developed. In this model, there are11 points wherein brick waste can be efficiently managed. Figure 14 depicts these opportunities and the relationships between them.

Figure 14. The integrated supply chain lifecycle model for brick waste

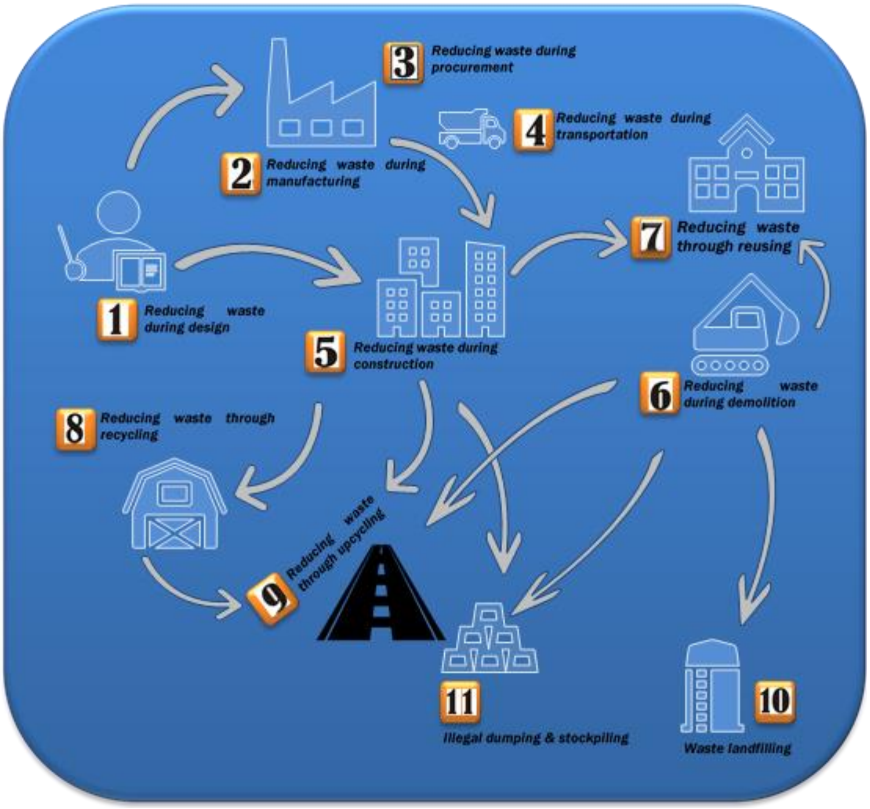

Table 10 shows the role of the main players in the management of brick waste corresponding to the developed integrated supply chain. The key players identified below are believed to have a major contribution to the effective management of brick waste. Their contribution could be translated into waste minimisation or reduced waste landfilling, directly or indirectly.

Table 10. The role of various stakeholders in the effective management of brick waste

No.	Stage	Stakeholder(s)	Contributions
1	Design	Designers, construction firms, clients	• Reuse an existing building instead of a new one; • Design a new building to facilitate its re-use in the future • Consider precast brick walls in the designs • Consider building standardisation to improve buildability and reduce the number of off-cuts
2	Manufacturer	Manufacturers, recyclers, suppliers	• Develop an agreement where a contractor "sells back" the recycled waste from the original material supplier • Participate in the extended producer responsibility and product stewardship schemes
3	Procurement and contract	Construction firms, quantity surveyors, government	• Construction firms should order bricks more accurately using the best take-off practice. • Supplier to provide more flexible "last pack" sizes, i.e. a "fractional" pallet instead of a full pallet • Alter the public contracts (purchasing) for brick waste-based materials usage in public projects
4	Transportation & delivery	Construction firms, transporters, recycling companies	• Just-in-time delivery of materials to construction to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions • Do due diligence and exercise standard work practices • Use hard strap protectors at corners and edges of brick stacks and reduce hand unloading
5	Construction	Construction firms, sub-contractors, waste collectors, recyclers	• 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 avoided • Take unwanted bricks back to brickyard for crushing and re-use in brick production it 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.

6	Demolition	Demolition contractors, waste collectors, recyclers	• Consider selective deconstruction to maximising the reuse potential of its components.
7	Reusing	Construction firms, state and territory governments, EPAs and other equivalent organisations, waste collectors	• Facilitate market development • Adjust specifications in favour of more usage of brick waste-based materials in new constructions project
8	Recycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Take brick left-overs away to use as aggregate or landscaping cover • Facilitate market development • Fund the development of waste recovery infrastructure • Adjust specifications in favour of more usage of brick waste-based materials in new constructions project
9	Upcycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Facilitate market development • Adjust specifications in favour of more usage of brick waste-based materials in new constructions project • Facilitate market development • Fund the development of waste recovery infrastructure
10	Stopping illegal dumping and stockpiling	State and territory governments, EPAs and other equivalent organisations	• Reinforce activities that stop illegal dumping and stockpiling • Set stricter regulations with a higher rate of penalty fees to discourage illegal dumping and stockpiling • Strengthen controls over licensed landfill sites
11	Landfill	State and territory governments, EPAs and other equivalent organisations	• Design appropriate landfill levy schemes to discourage brick waste landfilling

6.3 Relevant industry associations

In addition to the key players identified above, the industry associations and training foundations are reported to have a meaningful impact on sustainable brick waste management. In this section, the relevant industry associations that specifically work towards better management of brick and the waste associated with brick are identified. These associations are to collaborate with the public sector towards recognising opportunities for further reducing, reusing and recycling the brick waste in Australia. Table 11 summarises the main industry associations with a focus on clay brick in Australia.

Table 11. Industry associations relevant to the management of brick waste

Associations	Scope	Vision	Website
Think Brick Australia	National	It represents Australia's clay and pave manufacturers	https://www.thinkbrick.com.au/

National Brick Layers Association	National	The National Bricklayers Association was set up to make the building industry better for both employees and employers, by dealing with issues that affect the industry	https://www.nationalbricklayersassociation.com.au/
Australian Brick & Blocklaying Training Foundation Ltd	National	ABBTF aims to ensure there is an adequate and competent bricklaying and blocklaying workforce to support the market and also to improve the standing of bricklayers and blocklayers within the industry	https://www.becomeabricklayer.com.au/
Masonry Contractors Australia	NSW & ACT	MCA is dedicated to improving the quality, reliability and integrity of the masonry (brick and block-laying) industry	https://masonrycontractors.com.au/

7 RECOMMENDATIONS

- Consider building standardisation to improve buildability and reduce the number of off-cuts
- Design appropriate landfill levy schemes to discourage brick waste landfilling
- Strengthen controls over licensed landfill sites
- Construction firms should order bricks more accurately using the best take-off practice.
- 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 avoided
- Supplier to provide more flexible "last pack" sizes, i.e. a "fractional" pallet instead of a full pallet
- Take unwanted bricks back to brickyard for crushing and re-use in brick production it 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
- Develop an agreement where a contractor "sells back" the recycled waste from the original material supplier
- Take brick left-overs away to use as aggregate or landscaping cover

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