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1 **“Assessing the role and use of recycled aggregates (RAs) in the sustainable management**
2 **of construction and demolition (C&D) waste via a mini-review and a case study”.**

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25

1 **Abstract**

2

3 Rapid industrial development, mega construction projects and increased immigration are
4 some of the reasons that the State of Qatar has recently generated an unprecedented amount
5 of construction and demolition (C&D) waste in the country. The State is racing towards the
6 FIFA World Cup 2022, a fact that requires additional construction, for which is expected to
7 increase the rate of waste generation. Compared to other regions, there are relatively few
8 studies in literature that report on the C&D waste management issues of the country. The
9 present work begins to address this gap by providing insights into the current state of C&D
10 waste management practices in Qatar and by providing a mini-review on the benefits of using
11 recycled aggregates (RAs); only recently allowed locally by Qatar Construction Standards
12 (QCS). A SWOT analysis has been implemented, using data and information from various
13 sources including governmental reports, industries, local waste management companies, as
14 well as reported interviews with relevant stakeholders. Finally, several strategies were
15 proposed and developed that could potentially be implemented by stakeholders and decision
16 makers, so as to improve the current status by encouraging more sustainable and viable
17 practices.

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21 **Keywords:** C&D waste; circular economy; solid waste; Qatar; recycled aggregates; recovery
22 and recycling

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ABBREVIATIONS

approx.	Approximately
C&D	Construction & demolition
ca.	Circa (Latin term for “approximately” or “about”)
CE	Circular economy
DSWMC	Domestic solid waste management centre
EC	European commission
GHG	Greenhouse gas
GSAS	Global sustainability assessment system
LEED	Leadership in energy and environmental design
LAs	Local authorities
NA	Natural aggregate
NAC	Natural aggregate concrete
QCS	Qatar construction standards
QDVC	Qatar diar vinci construction
RAs	Recycled aggregates (i.e. aggregates of any quality made from C&D waste)
RAC	Recycled aggregate concrete (i.e. concrete made with recycled aggregates)
RCA	Recycled concrete aggregate (i.e. a subset of RA of sufficient technical quality for the manufacture of concrete)
SDGs	Sustainable development goals
SoC	Substances of concern
SWM	Solid waste management
TRL	Transport research laboratory
UN	United nations
WFD	Waste framework directive

1 **Introduction**

2
3 The concept of Circular Economy (CE) as a response to our unsustainable use of
4 finite resources is gaining momentum, having received significant governmental, academic,
5 and organizational attention in recent years (Dumlao-Tan and Halog, 2017; Ellen MacArthur
6 Foundation, 2016; Ranta et al., 2018). In CE, products are kept in service for as long as
7 possible and designed so that their component materials can be recycled with minimal energy
8 input at the end of their life, eventually eliminating waste and its social impacts (Iacovidou et
9 al., 2017; Velenturf and Purnell, 2017). The European Commission (EC) CE action plan links
10 the relevant legislative proposals with the United Nations (UN) Sustainable Development
11 Goals (SDGs) adopted in 2015, in particular Goal 12 regarding sustainable consumption and
12 production (European Commission, 2016). The EC has classified construction and demolition
13 (C&D) waste amongst the five priority areas where progress needs to be made towards a
14 circular reality (with food waste, plastics, critical raw materials, and biomass and bio-based
15 products being the other four) (European Commission, 2016).

16 The C&D sector is one of the major resource-consumers and waste-producers in our
17 modern society, using –on average- more than 40% of the total raw materials extracted on a
18 global scale (Krausmann et al., 2017), generating about 35% of the world's solid waste and
19 accounting for approx. 33% of the total CO₂ and greenhouse gas (GHG) emissions (Peng,
20 2016; Schrör, 2011; Ürge-Vorsatz and Novikova, 2008; Yuan et al., 2012). With over 20
21 billion tonnes manufactured globally each year, concrete is the world's most widely used
22 composite, thus producing similar quantities of C&D waste (Purnell and Dunster, 2009).

23 The definition and composition of C&D waste are not clearly defined, varying
24 significantly due to the wide variety of materials and construction techniques in use
25 (European Commission, 2018; Llatas, 2013). On average, it mostly consists of crushed

1 concrete, gypsum, tiles and traces of wood, metals, bricks, asbestos, glass, plastic and
2 cardboard (European Commission, 2018; Kucukvar et al., 2014).

3 Sustainable C&D waste management is still at a rudimentary stage in many countries,
4 rendering landfilling the most common final destination of C&D waste (Marzouk and Azab,
5 2014; Silva et al., 2017). Numerous environmental, economical, technical and societal
6 barriers have been reported in literature that restrict the circularity in the C&D sector
7 (Dumlao-Tan and Halog, 2017; Esa et al., 2017; Mittal and Sangwan, 2014; Ranta et al.,
8 2018; Ritzén and Sandström, 2017; Yuan, 2017). The lack of coherent recycled materials
9 quality standards in the Waste Framework Directive (WFD 2008/98) has led most EU
10 countries to fulfil the requirement to recycle C&D waste many times by diverting it to lower-
11 grade applications; for instance, producing aggregates for road base and filling materials in
12 road construction (BIO Intelligence Service, 2013; European Commission, 2008; Hu et al.,
13 2013; Weil et al., 2006). This is known as “cascaded recycling” or “downcycling” (Allwood,
14 2014; European Commission, 2008; Huysman et al., 2015) and does not fully contribute to
15 the CE way of thinking, as it lowers the quality and value of the recycled material.

16 The most common recycling practice for C&D waste is as a feedstock for the
17 production of recycled aggregates (RAs) that can replace natural aggregate (NA) in various
18 applications and provide a more sustainable alternative by avoiding landfilling of waste and
19 depletion of NA resources. RA is mainly obtained via crushing and processing of previously
20 used inorganic construction materials, and while it normally contains a high proportion of
21 concrete, it may also contain bricks, tiles, metals, glass and other miscellaneous materials
22 such as paper, plastic, wood, and other debris (Kisku et al., 2017). RA that is to be used to
23 manufacture structural concrete must be of a specific quality, free from such contaminants, in
24 particular sulphates (e.g. from plaster), clays (e.g. from bricks or tiles) or excessive fine
25 material. Such aggregate is classified as recycled concrete aggregate (RCA) and careful

1 control and monitoring of its quality is fundamental to ensure a high-performing concrete and
2 ensure adequate properties, such as compressive strength and durability (Purnell and Dunster,
3 2009). RCA is generally derived from the crushing of isolated previously-used concrete
4 structural elements. In general, unfamiliarity with RA and RCA and their use leads NA to be
5 considered of higher quality; however, from a generic environmental point of view the
6 impacts of RA/RCA are much lower than that of NA (Blengini, 2009; Blengini and
7 Garbarino, 2010; Bovea and Powell, 2016; Ding et al., 2016; Estanqueiro et al., 2018;
8 Hossain et al., 2016; Ortiz et al., 2010; Rosado et al., 2017; Silva et al., 2017; Vieira et al.,
9 2016; Vilches et al., 2017), whereas when it comes to the economic viability of a C&D
10 recycling plant, the scientific views are divided (Braga et al., 2017; Coelho and de Brito,
11 2013a; Nunes et al., 2007; Zhao et al., 2010).

12 RA contaminated by unsound materials such as mortar, metals or plastics results in an
13 aggregate with diminished mechanical properties; contamination with chemical impurities,
14 especially sulphates which disrupt the hydration of the concrete and clays which increase the
15 water demand for a given workability (increasing the water-cement ratio, which controls the
16 strength and durability properties of all concretes) will result in aggregates unsuitable for
17 structural concrete (Ann et al., 2009; Behera et al., 2014; Butler et al., 2011; McNeil and
18 Kang, 2013). Thus, applying several recycling techniques (selective demolition, more
19 accurate sorting, etc.) is imperative in order to minimise the presence of contamination in the
20 produced RA and especially RCA (de Juan and Gutiérrez, 2009; Estanqueiro et al., 2018).
21 While in theory RA can be used as aggregate for structural concrete, in practice this is
22 reserved for RCA and RA is used for other applications (Rafi et al., 2014; Rafi, 2018, 2019;
23 Rafi et al., 2011). The use of RCA derived from concretes of unknown composition is
24 restricted to characteristic strengths below 50 MPa, while RCA derived from concretes of

1 known composition may be used in higher-strength concrete (Purnell and Dunster, 2009;
2 WRAP, 2004).

3 The State of Qatar is a peninsula located on the southwest shore of the Arabian Gulf.
4 It lies between latitudes 24° and 27°N and longitudes 50° and 52°E and possesses a hot desert
5 climate. In 2017, Qatar's total population was approx. 2.6 million: 313,000 Qatari citizens
6 and 2.3 million expatriates. In addition, the country has been undergoing rapid development
7 and increased immigration over the last twenty years. Qatar is a high-income economy,
8 backed by the world's third-largest natural gas and oil reserves.

9 Recent sources report that in the State of Qatar, C&D waste accounts for more than
10 75% of all solid waste generated (Reid et al., 2016). Several current mega construction and
11 development projects (such as the Qatar Rail and Lusail City) are expected to create
12 significant amounts of C&D waste, presenting challenges with regards to the removal,
13 transport and reuse of excavated materials. In addition, the country continues its quest for
14 fulfilling the ambitious targets set in Qatar's vision 2030 (GSDP, 2008). The Qatari Transport
15 Research Laboratory (TRL) has recently completed a study of innovative uses of RA in
16 construction, noting that use thereof has only been allowed by Qatar Construction Standards
17 (QCS) since 2014 (QCS, 2014). With the increasing demand for aggregates in the run-up to
18 the 2022 FIFA World Cup, maximising the use of RAs is of utmost importance and could
19 potentially divert huge quantities of these materials from landfill, thereby reducing the carbon
20 footprint by up to 50%, in relation to importing primary NAs (Clarke et al., 2017; Hassan,
21 2015).

22 Recognising the need for high quality recycling as an effort to increase circularity and
23 recovery of resources from waste and reduce reliance on imports, via this research article, the
24 authors attempt to delineate the Qatar current status on C&D waste and communicate, as well

1 as highlight, the various opportunities and challenges of using RAs in general, and in this
2 region, in particular (via a SWOT analysis).

3

4 **Overview of C&D waste practices in Qatar; properties and significance of the use** 5 **of RAs and recycled aggregate concretes (RACs)**

6

7 *Current status of C&D waste management in the State of Qatar*

8 The phenomenal development rates of the Qatar C&D sector have compelled its
9 construction companies to grapple with critical waste management issues, especially over the
10 last 5 years and in the run up to the 2022 World Cup. According to estimates from the Qatar
11 Ministry of Environment, the C&D sector was responsible for approx. 56% of the generated
12 waste in 2015 (11.7 kt out of the 21 kt generated on a daily basis) (MDPS, 2017). The
13 majority of it was composed from excavated soil and sand, concrete and other mixed non-
14 hazardous waste.

15 Current C&D waste management practices in the State of Qatar lag behind both
16 regional, as well as international benchmarks. This lag could be attributed to a number of
17 reasons. Qatar lacks precise and detailed C&D regulations, directives and standards, therefore
18 the construction industries do not have adequate references and guidelines. It was not until
19 recently that the Global Sustainability Assessment System (GSAS) was implemented to a
20 number of new construction projects and the use of RAs was allowed by the QCS (Kader,
21 2016; QCS, 2014). In addition, a study on green building rating systems performed in Qatar
22 showed that scores from C&D waste management sub-criteria in both GSAS and Leadership
23 in Energy and Environmental Design (LEED) are considerably different (Mohamed and
24 Musharavati, 2016). For example, for new building constructions LEED requirements
25 demand a minimum of 50% of the C&D waste produced from the construction site to be

1 salvaged and/or recycled, while in GSAS the sub-criteria related to C&D waste management
2 require only submitting the respective plan (Abulebdah and Musharavati, 2017).
3 Consequently, there are neither any rigorous requirements nor any follow-ups to enforce
4 them. In addition, the relative sub-criteria specify only that waste should be collected and
5 removed from the construction site. No stringent requirements are in place to recycle or reuse
6 any of the waste generated, nor are there pre-requisites or mandatory requirements for C&D
7 waste management, which means this aspect of projects will not be evaluated. Considerations
8 of environmental management issues that incorporate C&D waste management are thus not a
9 priority with contractors when undertaking construction projects in Qatar (Abulebdah and
10 Musharavati, 2017). For instance, huge projects like Qatar Rail and Lusail City create
11 immense amounts of C&D waste; but the players involved in these projects are the least
12 interested in removing, transporting or reusing any excavated materials; however, in 2015 the
13 23 contractors involved in the two aforementioned projects reported that approx. 3.5t of solid
14 waste (steel, plastic, cardboard) and ca. 8,700l of waste oil were recycled, thus creating
15 contradictions and ambiguities in the information obtained (Clarke et al., 2017). In this
16 regard, the Transport Research Laboratory (TRL) conducted a study in 2017 concerning the
17 use of RAs, suggesting it as a priority and as a mean to avoid the use of NAs and, thus reduce
18 the carbon footprint by up to ca. 50% (Clarke et al., 2017; Hassan, 2015).

19 Some construction companies, such as Qatar Diar Vinci Construction (QDVC) who
20 employ thousands of people and deals with mega-structure projects, do implement more
21 sustainable environmental policies. The “green programme” of QDVC includes commitments
22 to efficient waste management, mitigation of any potential environmental impacts, green
23 procurement techniques, application of clean technologies, investing in R&D and conserving
24 natural resources (QDVC, 2016). The company managed to reuse approx. 643 m³ of
25 excavated soil and concrete during 2014 and recycle more than 3Mt of metals, paper and

1 plastic with the help of several other companies (Al Suwaidi Paper Factory, Doha Plastic,
2 Lucky Group and Al Haya Waste Management) (QDVC, 2016).

3 Moreover, in tower blocks at the Pearl-Qatar area (a Riviera-style island), an ENVAC
4 waste management system has been implemented able to transport up to 3,700t of
5 commingled waste, on a monthly basis, via underground pipes to a transfer station and from
6 there to the Domestic Solid Waste Management (DSWM) facility, at Mesaieed, south of
7 Doha (Clarke et al., 2017). This facilitates the residents that mostly live in high-rise buildings
8 that do not contain inbuilt recycling facilities. Unfortunately, in Qatar most tower blocks do
9 not contain specific waste collection spaces or points on every floor; in some cases they don't
10 even have temporary storage facilities for recyclable materials.

11 In order to take further steps towards a CE, the State of Qatar needs a multi- and inter-
12 disciplinary waste strategy. It must encourage the elimination of waste from the system
13 through design for reuse and refurbishment as well as improved resource recovery and
14 recycling. It must also tackle the wasteful attitudes, thought processes and mind-sets that
15 generate the waste in the first place; and, in turn, to replace them with the CE view of treating
16 and thinking of "waste" as valuable resources. This implies that in the future, SWM
17 technologies need to go hand in hand with tangible and sustainable programmes that
18 encourage innovative solid waste elimination at source. To this end, social media platforms
19 should be fully utilised in Qatar to propel waste to the top of the public agenda and get the
20 subject of waste "trending". The recently formed environmental organisation Doha Oasis is
21 one vehicle through which these ideas and innovations can be promoted (Dohaoasis, 2018).

22

23 ***Significance of RAs and RACs; how to enhance their mechanical and durability***
24 ***properties. A mini literature review***

25

1 *Generic properties of RAs and RACs*

2 The concept of using RAs as an alternative for the replacement of NAs first emerged
3 in England during World War II, where RAs were mostly used for pavement construction
4 ([CCANZ, 2011](#)). The difference between RA and virgin aggregate is the hardened cement
5 paste and/or mortar that remains attached to the individual coarse aggregate particles. It is the
6 porosity of this material that causes the RA to have a higher water absorption capacity
7 ([Gómez-Soberón, 2002](#); [Katz, 2003](#); [Martín-Morales et al., 2011](#)) which increases even more
8 with an increase in the size of aggregate ([Martín-Morales et al., 2011](#)). The lower mechanical
9 strength of the RACs in comparison to NAC may be partly attributed to this adhered layer of
10 old mortar ([Martín-Morales et al., 2011](#)) and partly to the increased water-cement ratio
11 necessitated by the increase of water absorption by the aggregate, which limits strength
12 development during hydration. The durability of RACs depends mainly on the chemical
13 properties of the RA/RCA, in particular the presence of sulphates and chlorides. Excessive
14 chloride content may lead to corrosion of the reinforcement steel ([Debieb et al., 2009](#);
15 [Nagataki et al., 2004](#)), although the majority of RAs contains chloride in the acceptable
16 range; in any case, a water immersion could be employed as a countermeasure ([Debieb et al.,](#)
17 [2009](#)). Excessive sulphate will disrupt the hydration of the cement, causing unwanted
18 expansion and cracking in the concrete. There are also other properties to consider, such as
19 workability (slump test) or wet density that depend on various parameters of the aggregate
20 (e.g. moisture content, size, shape, texture) ([Debieb et al., 2010](#); [Evangelista and de Brito,](#)
21 [2010](#); [Henschen et al., 2012](#); [Kou and Poon, 2013](#); [Malešev et al., 2010](#)). Since the porosity
22 of RA is higher than that of the virgin aggregate, the workability of the RAC mix is lower
23 than the NA's (given the same water content). However, the use of chemical admixtures
24 commonly used with concrete such as super-plasticisers can increase the workability of RAC

1 (Matias et al., 2014) and can easily be used to reduce the water-cement ratio to a level where
2 the effects of increased water-cement ratio on strength and durability can be eliminated.

3 Several studies have demonstrated that mixing RAs with various other industrial
4 waste such as fly ash, coal bottom ash, blast slag, silica fume, plastics, rubber tyres, etc. can,
5 in some cases, be proved beneficial (Arulrajah et al., 2016; Arulrajah et al., 2017; Bravo and
6 de Brito, 2012; Figueiredo and Mavroulidou, 2010; Foti, 2011; Hansen and Lauritzen, 2004;
7 Kasai, 2004; Kim and Lee, 2011; Kim et al., 2010; Meyer, 2009; Özkan et al., 2007; Park et
8 al., 2009; Son et al., 2011) in much the same way as such admixtures have been extensively
9 investigated for use in traditional concrete.

10 Below a short literature review is attempted on the various properties of RAC and
11 how these are affected by the individual parameters-factors involved in the overall procedure.

12

13 *Mechanical Properties*

14 Compressive strength

15 The compressive strength of concrete is its most important property, and many other
16 properties such as tensile/flexural strength, durability, permeability and stiffness are inferred
17 therefrom. Variables that cause a change in compressive strength will normally induce a
18 proportional change to these other properties. The same is true for RAC. The compressive
19 strength of any concrete, including RAC, depends upon many factors, in particular the water
20 binder ratio but also aggregate types, mixing ratios, properties of admixtures used and the age
21 of the concrete; for RAC the different characteristics of RAs and e.g. the adhered mortar will
22 also be important. It has been reported that an increase in the proportion of RA at the same
23 w/c ratio leads to decrease in compressive strength, generally up to 10% lower than that of
24 virgin aggregate concrete (González-Fonteboa and Martínez-Abella, 2008; Kou and Poon,
25 2008; Rahal, 2007). However, other researchers observed that the compressive strength of

1 concrete remains unaffected, or increases slightly (up to 25%) with the replacement of NA by
2 RA (Abd Elhakam et al., 2012; Etxeberria et al., 2007; Fonseca et al., 2011; Huda and Alam,
3 2015). In either case, the compressive strength of RAC can easily be adjusted to match that of
4 NA concrete via the application of several common concrete mix design methods, such as
5 usage of admixtures (Abd Elhakam et al., 2012; Kou and Poon, 2012; Limantono et al., 2016;
6 Mukharjee and Barai, 2014; Oner et al., 2005; Vinay Kumar et al., 2017), increase in the
7 cement content (Etxeberria et al., 2007; González-Fonteboia and Martínez-Abella, 2008) or
8 usage of plasticizers (Tam et al., 2005; Tam and Tam, 2007, 2008).

9

10 Split tensile strength

11 The split tensile strength of RAC is dependent upon multiple factors, such as RA
12 quality and replacement ratio, water-binder ratio, type of cement and curing age. Several
13 studies report that split tensile strength decreases with an increase in RA replacement ratio
14 (Abd Elhakam et al., 2012; Kou and Poon, 2013; Zega and Di Maio, 2011), although other
15 researchers have found that for a replacement ratio of up to 30%, RAC's tensile strength is
16 the same or even in some cases exceeds that of virgin aggregate concrete (Dilbas et al., 2014;
17 Mas et al., 2012; Padmini et al., 2009; Pereira et al., 2012). In addition, the split tensile
18 strength is improved as the curing age increases (Etxeberria et al., 2007; Kou and Poon, 2008;
19 Sagoe-Crentsil et al., 2001), whereas the use of slag cement and the addition of super-
20 plasticizers has also been reported to enhance the tensile strength of RAC by 25% (or more)
21 (Dilbas et al., 2014; Mas et al., 2012; Pereira et al., 2012). Similarly to compressive strength,
22 the tensile strength of RAC is generally lower than that of NAC. Nonetheless, many studies
23 have demonstrated that the tensile strength tends to become constant as the replacement ratio
24 reaches 100% (Abd Elhakam et al., 2012; Ryu, 2002).

25

1 Flexural strength

2 Flexural strength is closely related to tensile strength. It has been documented that the
3 flexural strength of RAC decreases with an increase in the RA replacement ratio (Katz, 2003;
4 Malešev et al., 2010; Padmini et al., 2009; Topçu and Şengel, 2004). The reduction in
5 flexural strength of RAC, with regards to conventional concrete, is dependent on the target
6 strength. The higher the strength of concrete, the higher the reduction in the flexural strength
7 of RAC is, mainly due to the addition of RA (Limbachiya et al., 2000; Padmini et al., 2009).

8

9 Modulus of elasticity

10 Modulus of elasticity has been reported to be negatively affected by the incorporation
11 of RA (Fonseca et al., 2011; Kou and Poon, 2013; Pereira et al., 2012; Zega and Di Maio,
12 2011). Curing has high impact on modulus of elasticity, whereas the use of high compressive
13 strength parent concrete has also been shown to favour the elastic modulus. Other researchers
14 reported that fly ash takes considerable time to show its effect on modulus of elasticity
15 (Anastasiou et al., 2014; Corinaldesi and Moriconi, 2009; Kou and Poon, 2013), whereas the
16 use of super plasticizers leads to increase of the elastic modulus (Corinaldesi and Moriconi,
17 2009; Pereira et al., 2012).

18

19 *Durability properties*

20 Durability of concrete (including RAC) is defined as the ability of concrete to
21 withstand external environmental and physical pressure, as well as chemical reactions (Kisku
22 et al., 2017). According to Domone and Illston (2010) it is the ability of a material to remain
23 serviceable for at least the required lifetime of the structure of which it forms a part (Domone
24 and Illston, 2010). There are various factors that affect the durability, such as mixing ratios
25 (particularly the water-binder ratio, small increases in which can cause drastic increases in

1 permeability), placing and curing methods and associated quality control, ingredients
2 involved, etc. Usually the permeability of the concrete (which controls the rate at which
3 carbonation occurs, water & air permeability, and chloride penetration) and its resistance to
4 long-term deformation (owing to drying shrinkage and creep) are the main characteristics that
5 determine its durability. Furthermore, degradation of concrete can be caused by static and
6 dynamic external environments (e.g. shrinkage caused by drying, creep caused by long-term
7 loading freeze-thaw cycles, accidental overloads) or internal chemical reactions (e.g. alkali-
8 aggregate reaction). It is important to understand the difference between degradation of the
9 concrete, and any diminution of its ability to protect steel in reinforced concrete. In this latter
10 role, concrete must: resist the ingress of substances deleterious to the steel (particular water
11 and chlorides) by remaining impermeable and not suffering excessive cracking; and retain its
12 chemical characteristics – i.e. resist reduction of its alkalinity by reaction with CO₂
13 (carbonation) in the atmosphere – which prevent corrosion of the steel.

14 It has not been clearly documented in literature whether RAC possess a lower
15 durability than that of natural aggregate concrete (NAC). It is known that the sulphate and/or
16 clay fraction in many potential RAs renders them chemically unsuitable for durable concrete,
17 which is why there are strict limits on which RAs can be used as RCAs. Any inherent
18 additional durability issues caused by using RCA could potentially be improved by
19 incorporating appropriate adjustments to mixing approaches and amounts of admixtures when
20 preparing RAC. A short discussion on the different properties that influence durability is
21 provided in the subsections below.

22

23 Carbonation depth

24 The carbonation phenomenon is mostly attributed to the interaction between
25 atmospheric CO₂ and unhydrated Ca(OH)₂ in the hardened cement paste that binds concrete

1 together. Carbonation reduces the buffering capacity of the pore solution in the concrete by
2 converting the alkaline calcium hydroxide into calcium carbonate. As the alkali metals in the
3 pore solution also react with carbon dioxide, this results in lowering of the pH. If the pH
4 drops below 10, and the carbonation depth reaches the steel reinforcement, the steel may
5 become depassivated, increasing the likelihood of corrosion. Due to the high porosity of
6 many RAs the carbonation depth of RAC, compared to NA concrete at a given time,
7 increases with an increase in the replacement ratio of NA with RA. Studies have shown an
8 almost 100% increase in the carbonation depth of RAC samples where there has been a 100%
9 replacement of virgin aggregate with RA (Debieb et al., 2009; Kou and Poon, 2013; Levy and
10 Helene, 2004; Matias et al., 2014; Silva et al., 2015; Somna et al., 2012; Xiao et al., 2012;
11 Zhu et al., 2013). The use of fly ash, as a partial replacement of cement, has been reported to
12 increase the carbonation depth (Kou and Poon, 2012). High strength concretes will carbonate
13 more slowly than low strength concretes (Purnell and Dunster, 2009). Other researchers
14 reported that the addition of super plasticizers tend to lower initial carbonation rates in RAC
15 compared with NAC; however, this effect fades with time and at the end carbonation of RAC
16 exceeds that of NAC (Matias et al., 2014).

17

18 Long-term deformation

19 Long-term deformation of concrete refers to changes in: deformation additional to
20 that induced by the initial loading; shape; and appearance of the existing cracks in concrete,
21 without any increment in the external forces. It is usually assumed to be related to two
22 parameters; drying shrinkage and creep. The former is caused by transfer of water from the
23 concrete into the environment that leads to a reduction in volume, while the latter describes a
24 strain increase caused by visco-elastic deformation of the calcium silicate hydrates in the
25 hardened cement paste under a sustained stress. It has been reported that the increasing use of

1 recycled coarse aggregates in RAC increases the rate of drying shrinkage of RAC (Gómez-
2 Soberón, 2002; Matias et al., 2014; Tam and Tam, 2007; Thiery et al., 2013). This happens
3 because of an increase in the paste volume (i.e. old adhered mortar and new paste) in RAC
4 compared to NAC for a given strength class. As far as the creep is concerned, it increases
5 with an increase in the RA content (Kou and Poon, 2008; Kou and Poon, 2012; Tam and
6 Tam, 2007).

7

8 Permeability

9 Permeability is the ability of the concrete to permit flow of materials such as water,
10 air (oxygen, carbon dioxide) and chlorides through the pore structure of the concrete. Low
11 permeability is strongly correlated with good durability. The majority of researchers report
12 that permeability of the RAC made with fully and/or partial replacement of NA by RA, is
13 higher than that of NAC, mostly due to the higher amount of porosity and cracks existing in
14 the adhered mortar, and/or the increased water-binder ratio that may be required to preserve
15 workability. Water permeability increases with the substitution level of RAs, w/c ratio and
16 age due to an increase in the volume of the interfacial transition zone between the cement
17 paste and the aggregate (Bravo and de Brito, 2012; Thomas et al., 2013; Villagrán-Zaccardi
18 et al., 2008). Permeability of concrete is greatly reduced when using e.g. fly ash or bagasse as
19 partial replacement of cement; in some cases, the effect was observed to be more significant
20 than that for NAC (Mousa et al., 2015; Somna et al., 2012).

21

22 Chloride penetration

23 Chloride penetration refers to the depth to which chloride ions can penetrate into
24 concrete over a given time scale. The transport mechanism of chloride ions is rather complex
25 and involves water diffusion, impregnation and capillary absorption (Matias et al., 2014).

1 Several studies have shown that it depends on factors like the NA replacement (Ann et al.,
2 2009; Kou and Poon, 2012; Lotfy and Al-Fayez, 2015; Sim and Park, 2011; Villagrán-
3 Zaccardi et al., 2008), w/c ratio (Lotfy and Al-Fayez, 2015; Vázquez et al., 2014; Villagrán-
4 Zaccardi et al., 2008) and curing period (Bravo and de Brito, 2012). Chloride penetration
5 increases in RAC with the increase in NA replacement owing to the increased permeability
6 (see above). The addition of lime as a chemical admixture could potentially favour the
7 chloride penetration, whereas the use of fly ash reduces it. As the fly ash content increases,
8 the chloride penetration decreases (Kou and Poon, 2013; Lotfy and Al-Fayez, 2015; Sim and
9 Park, 2011; Somna et al., 2012). The use of super plasticizers have exhibited positive results
10 on the prevention of chloride penetration (as they allow lower water-binder ratios to be
11 achieved). The addition of pulverized fuel ash and ground blast furnace slag appears to
12 increase the chloride resistance (Tam and Tam, 2008), probably via similar mechanisms. In
13 all cases though, the percentages of increase in chloride penetration of RAC compared to
14 NAC were relatively small and could be compensated for easily by appropriate mix design.

15

16 Freeze and thaw resistance

17 Freeze and thaw resistance have been shown to greatly affect durability and strength
18 of concrete. Literature review suggests that freeze and thaw resistance of RAC is poorer than
19 that of NAC and it decreases with an increase in RA replacement ratio (Medina et al., 2013;
20 Richardson et al., 2016; Tuyan et al., 2014). Reduction of adhered mortar content has been
21 observed to increase the freeze thaw resistance of RAC, as does the addition of additives such
22 as meta-kaolin (Gokce et al., 2004).

23

24 *General conclusions on the use of RAs vs NAs*

1 Based on the aforementioned results comparing the performance of a NAC to that of a
2 RAC of the same strength class, (Corinaldesi and Moriconi, 2009; Corinaldesi and Moriconi,
3 2010; Sani et al., 2005) the RAC exhibits: a lower tensile strength (of approx. 10%), a lower
4 elastic modulus (almost 20%), similar bond strength with the steel reinforcement, similar
5 vulnerability to shrinkage cracking, equivalent durability characteristics in terms of resistance
6 to freeze-thawing and unwanted penetration of various agents, and no leaching of any
7 substances of concern (SoC) to the environment. These relatively minor differences could, if
8 required, be easily corrected by adapting mix designs using normal methods (e.g. using
9 super-plasticisers to reduce water-binder ratio and/or increase workability, increasing cement
10 contents, or adapting coarse-fine aggregate ratios) or making minor adjustments to structural
11 design parameters. This should encourage increased use of RAs as a replacement for NAs, to
12 help achieve goals, technical regulations, guidelines and recommendations set by
13 international organisations e.g. the EU (European Commission, 2010), that can be
14 summarised in the following:

- 15 - limitation of C&D waste disposed to landfills;
- 16 - incentives for waste selection at source and implementation of 3R (reduce/reuse/recycle)
- 17 strategy;
- 18 - development of recycled materials;
- 19 - inclusion of waste management as an integral part of building and demolition permit; and,
- 20 - incentives for use of recycled materials in public works.

21

22 **SWOT analysis on C&D waste practices in the State of Qatar**

23

24 *Generic overview on C&D waste in Qatar and usefulness of SWOT analysis*

1 Compared to other countries worldwide (Coelho and de Brito, 2013b; Kumbhar et al.,
2 2013; Lu and Yuan, 2010; Rodríguez et al., 2015), the practices of C&D waste management
3 in the State of Qatar are rather limited and still at an infant stage; this merely reflects the fact
4 that the use of RAs has only been allowed in the QCS since 2014. Hence, there is a big
5 knowledge and implementation gap in comparison to other regions globally. In addition,
6 scientific literature on C&D waste techniques and methods (if any) implemented in Qatar is
7 very limited. The present work aims at contributing to bridging this gap by providing useful
8 insight into the current status of C&D waste management in Qatar with the use of a SWOT
9 analysis.

10 SWOT analysis has been extensively used in literature for the analysis and
11 effectiveness of a business or plan. In the waste management sector, SWOT analysis has been
12 used to identify Strengths, Weaknesses, Opportunities and Threats in various municipalities
13 around the world (Pardo Martínez and Piña, 2017; Shahba et al., 2017; Yuan, 2013) either to
14 discover the potentials and ways for initiating and successfully implementing an effective
15 SWM program, or to prove the importance of implementing a viable and sustainable waste
16 management sector, in order to resolve environmental concerns, regarding the pollution and
17 protection of natural resources.

18 19 *SWOT analysis on C&D waste management practices in Qatar*

20 The SWOT analysis attempt performed is briefly depicted in Fig. 1 and further
21 analysed in detail in the results and discussion section, below. The steps that were followed
22 throughout the entire procedure were: a) collection and evaluation of data and information
23 from relevant stakeholders, governmental entities (Public Work Authority and the Waste
24 Treatment Centre in the Ministry of Municipality and Urban Planning), relative companies,
25 construction industries, and individuals, b) classification of the collected information into the

1 four SWOT factors, in order to complete the relative matrix and develop the relevant
 2 strategies. Strengths and weaknesses of the current C&D waste management practices in the
 3 State of Qatar were considered as “internal factors”, whereas threats and opportunities both
 4 locally as well as globally were considered as “external factors” (Halla, 2007; Kajanus et al.,
 5 2012). The matrix shown in Fig. 1 was also used to identify and formulate any potential
 6 strategies that would most possibly improve the current state of C&D waste customs and
 7 behaviours in Qatar.



9
 10 **Fig. 1** SWOT analysis of C&D waste management in the State of Qatar.

11
 12 **Results and discussion**

13
 14 ***Strengths***

15 Several factors have been identified as potential strengths that could lead to an
 16 improved and successful C&D waste management system in the State of Qatar. Some of

1 these factors which are analysed in detail below are: geographical and economical location,
2 future urban planning, future local vision, awareness from local authorities (LAs).

3 *S1_Geographical and economical location:* It is well-known worldwide that
4 throughout the years Qatar has become one of the most economically developed countries of
5 the Gulf Co-operation Council (GCC). This is a great achievement that the country can be
6 based on to develop a proper, viable and sustainable future plan for the management of C&D
7 waste. With existing availability in resources, the only thing that remains is the will to build
8 an appropriate infrastructure and relative mechanisms that will see this plan through.

9 *S2_Future urban planning:* For years, Qatar has shown evidence of rapid
10 development and growth in infrastructure, via the successful completion of mega structural
11 projects and its direct quest and intention of being amongst the countries that seek the
12 implementation of the concept of “smart cities”. Modern buildings, advanced and “green”
13 transportation systems (new railway is about to be given in circulation within the year 2019),
14 expressways roads, etc. are just a few examples of the country’s trajectory towards modern
15 urbanization. However, it is common sense that all these activities create huge amounts of
16 C&D waste, rendering their sound management imperative.

17 *S3_Future vision of the country:* The Qatar's National Vision (QNV2030) underlines
18 an unequivocal commitment to maintaining harmony between the three inter-dependent
19 pillars of sustainable development: economic growth, social development and environmental
20 management. Managing, therefore, the waste in a sustainable manner is of utmost
21 importance. In addition, Qatar has already demonstrated its commitment to achieving this
22 objective by engaging in a number of waste related activities, for other streams of waste, such
23 as DSWM, creating and involving into this the relative center (DSWMC).

24 *S4_Awareness of LAs:* Since 2010, the local government has been promoting
25 programs and projects with the intention to minimize all waste streams throughout the

1 country. However, it has been advocated in literature that individuals do tend to respond to
2 waste management issues only when they perceive it as a threat to their own well-being.
3 Training, therefore, these individuals about household waste management is one of the
4 actions could further help to reduce waste and encourage recycling.

5

6 ***Weaknesses***

7 The successful implementation of any sustainable and economically viable C&D
8 waste management plan in the State of Qatar would require a set of regulations and
9 legislations that cover all necessary steps for a proper treatment of C&D waste e.g.
10 generation, collection, sorting, recovery, recycling and landfilling (as a last alternative).
11 Nonetheless, the country is currently suffering from the lack of such regulations and, as such,
12 the following weaknesses have been identified:

13 *W1_Lack of regulations and legislations:* Many of the stakeholders, industrial
14 partners and individuals claimed that they are in need for proper legislations to follow and
15 abide, while others expressed their concerns on the support and commitment of the LAs on
16 that matter.

17 *W2_Non-existent or limited source separation of C&D waste:* The majority of our
18 data sources indicated that for the time being there is no source separation of C&D waste, at
19 the generation points (e.g. construction sites). What usually occurs is the transportation of
20 mixed waste mostly to landfills.

21 *W3_Lack of a waste management infrastructure system:* Currently, the country lacks a
22 proper, viable and integrated system for C&D waste with few transfer stations, processing,
23 recovery and recycling facilities.

24 *W4_No implementation of waste hierarchy and 3R strategies:* There is a general lack

1 of awareness from some decision makers and stakeholders on the multiple benefits gained
2 when implementing waste hierarchy and the 3R strategies for C&D waste. A proper training
3 of all these delegates should take place, incentivising also the public so as to practically
4 contribute to any effort attempted on this part.

5

6 ***Opportunities***

7 Out of the literature review performed for this research article and the correspondence
8 we had with several stakeholders, governmental entities, companies, etc. we identified the
9 following two opportunities:

10 *O1_Urgent need for a waste management system:* Due to the country's run up for the
11 2022 World Cup and to the rapid urbanization and development, there are a lot of mega
12 structural projects currently going on, which they will continue for the years to come. It is,
13 therefore, of utmost importance to put in place techniques, methods and strategies to create
14 waste management infrastructure that can properly deal with C&D waste. Qatar can easily
15 mobilize resources to that direction and support all efforts required for a successful
16 implementation of that plan.

17 *O2_Governmental and industrial support:* From our correspondence, some
18 stakeholders revealed that for a long period of time, C&D waste management problems have
19 gained attention from the Qatari government, as well as from the related industry
20 associations.

21

22 ***Threats***

23 In the State of Qatar a number of threats were identified with regards to the proper
24 management of C&D waste:

1 *T1_Limited number of landfills already filled with other types of waste:* Although the
2 country has enough space that can be used for landfilling, statistics for 2014, 2015 and 2016
3 show that there was a huge generation of approx. 7.1, 9.3 and 9.7 million tonnes of C&D
4 waste respectively, most of which (approx. 67%) ended up in open dumpsites. Naturally,
5 some of these dumpsites have already been closed, whereas new ones were created, some of
6 which are, in fact, controlled landfills.

7 *T2_No applicable discharge fee:* At the moment, there are no charges imposed for
8 landfilling of C&D waste in the country. Therefore, contractors can freely deposit their waste.

9 *T3_A local market for recycled C&D waste is yet to be developed:* It is only since
10 2014 that QCS has allowed the use of recycled materials in the construction sector. Hence,
11 the market for C&D recycled materials in Qatar is still under development. This fact provides
12 limited or no incentives at all for stakeholders to venture and invest into C&D waste
13 recycling projects.

14 *T4_Lack of substantial research in the area of C&D waste:* Compared to the EU or
15 other regions globally, there has been relatively limited research on C&D waste management
16 both in the State of Qatar, as well as in the Middle East. This fact creates no reference point,
17 for the region, to initiate a viable and sustainable C&D waste management plan for the
18 country.

19 20 ***Proposed strategies***

21 The strategies (abbreviated below as: ***Str#***) proposed in this section were developed
22 based on the principle of: “maximizing strengths and opportunities, overriding weaknesses
23 through strengths, mitigating threats through strengths, and overriding weaknesses by
24 avoiding threats”. Based on the SWOT analysis depicted in [Fig. 1](#), the proposed strategies
25 were then classified in four categories, as shown in [Fig 2](#).

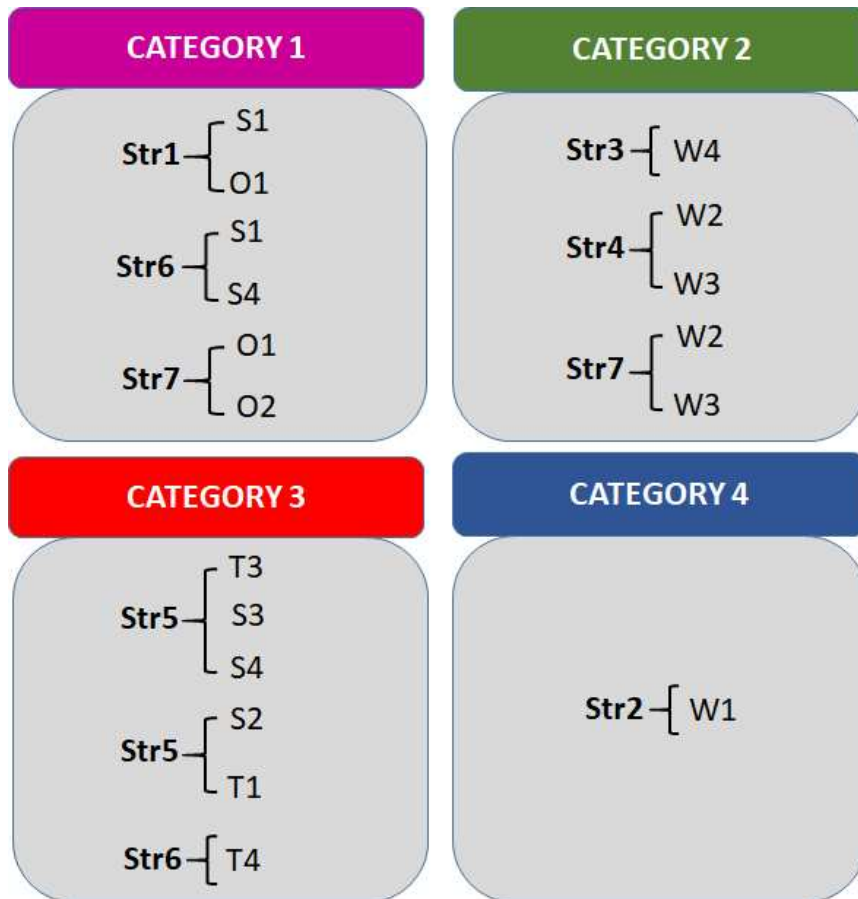


Fig. 2 Classification of C&D waste management proposed strategies (Str#), based on the SWOT analysis implemented, for the State of Qatar.

Str1: it is apparent that it is of utmost importance to clearly define C&D waste management plans in the country and engage all parties and entities involved so as to implement any potential mechanisms. Any specific responsibilities and roles should be clearly divided and assigned to the respective players. Combining the incentives that promote any reuse/recycle of C&D materials together with the provision of specialised education, skills and training could potentially transform the way this sector currently operates, creating at the same time opportunities for new business development (Iacovidou and Purnell, 2016).

Str2: there is, also, a need for establishing and broadcasting in all available media detailed regulations and directives relevant to C&D waste management practices in Qatar.

1 These should be supported by law enforcement and penalties for not abiding to them, to
2 ensure adherence and compliance of all stakeholders involved.

3 **Str3:** furthermore, current reports and information available on C&D waste is rather
4 vague and not properly documented. Thus, there is an inherent need to establish effective and
5 reliable communication links among all stakeholders to avoid any discrepancies and
6 ambiguities of data and information on C&D waste. Contractors and project planners should
7 establish reliable means of recording the amounts of C&D waste generated from various
8 projects in the State of Qatar. This can help in formulating any potentially effective waste
9 management system and/or facility.

10 **Str4:** LCAs studies should be conducted to obtain a better view on the C&D waste
11 management future plans.

12 **Str5:** promoting, establishing and developing a market of recycled C&D materials in
13 Qatar should be a priority.

14 **Str6:** there is a need to create facilities, mechanisms and incentives for promoting
15 interest in research on that sector.

16 **Str7:** finally, relative stakeholders should increase the awareness about C&D waste
17 management through education, training and promotion campaigns. A truly successful
18 implementation of any strategy and/or plan relies on the active engagement of all involved
19 stakeholders, including the ordinary citizens.

20 As it can be seen from [Fig. 2](#) the matching of the proposed strategies to the SWOT
21 analysis can be done either uniquely (one-to-one) or in a multifaceted way (one-to-many).

22

23 **Conclusions**

24

1 The aim of this work is to provide insights into the benefits of using RAs as a
2 replacement for NAs and to delineate the current state of C&D waste management practices
3 in the State of Qatar via a SWOT analysis method.

4 Analysis of tests on RAC show that, if proper regard is taken to ensure that RAs are of
5 suitable quality for concrete, the structural and durability properties of RAC are broadly
6 comparable to those of NAC and any deficiencies could be easily rectified by relatively
7 minor changes in mix design or structural detailing. This should encourage the greater use of
8 RAs in concrete, reducing the social and environmental impact of the concrete fraction of
9 C&D waste.

10 In addition, with regards to the State of Qatar, the results indicated that the country
11 needs to maximize any strengths and opportunities in order to deal properly with the
12 enormous amounts of C&D waste generated and formulate a viable and sustainable system
13 for its proper management. The development and enforcement of clear directives, legislations
14 and regulations is considered a necessity, so as to proactively address any issues associated
15 with the generation and accumulation of C&D waste. Key issues in any proposed agenda or
16 strategy should include: active involvement of all relevant stakeholders, increased awareness
17 and enforcement of all legal formalities around C&D waste management and practices in
18 Qatar, establishment of effective and reliable communication and coordination links among
19 all players involved, an LCA implementation approach, and finally a market promotion of
20 recycled construction materials in and out of Qatar, as well. The authors firmly believe that
21 the proposed strategies could provide a starting point for local decision-makers to plan the
22 development and implementation of a sound C&D waste management system in the country.

23 24 **References**

1 Abd Elhakam, A., Mohamed, A.E., Awad, E., 2012. Influence of self-healing, mixing method
2 and adding silica fume on mechanical properties of recycled aggregates concrete.
3 *Construction and Building Materials* 35, 421-427.

4 Abulebdah, A.T., Musharavati, F., 2017. A SWOT Analysis Of The Construction And
5 Demolition Waste Management Practices In Qatar., *Sustainable Development and Planning*
6 VIII. WITpress, pp. 749-759.

7 Allwood, J.M., 2014. Chapter 30 - Squaring the Circular Economy: The Role of Recycling
8 within a Hierarchy of Material Management Strategies, in: Worrell, E., Reuter, M.A. (Eds.),
9 *Handbook of Recycling*. Elsevier, Boston, pp. 445-477.

10 Anastasiou, E., Georgiadis Filikas, K., Stefanidou, M., 2014. Utilization of fine recycled
11 aggregates in concrete with fly ash and steel slag. *Construction and Building Materials* 50,
12 154-161.

13 Ann, K.Y., Ahn, J.H., Ryou, J.S., 2009. The importance of chloride content at the concrete
14 surface in assessing the time to corrosion of steel in concrete structures. *Construction and*
15 *Building Materials* 23, 239-245.

16 Arulrajah, A., Mohammadinia, A., Phummiphon, I., Horpibulsuk, S., Samingthong, W., 2016.
17 Stabilization of Recycled Demolition Aggregates by Geopolymers comprising Calcium
18 Carbide Residue, Fly Ash and Slag precursors. *Construction and Building Materials* 114,
19 864-873.

20 Arulrajah, A., Yaghoubi, E., Wong, Y.C., Horpibulsuk, S., 2017. Recycled plastic granules
21 and demolition wastes as construction materials: Resilient moduli and strength
22 characteristics. *Construction and Building Materials* 147, 639-647.

23 Behera, M., Bhattacharyya, S.K., Minocha, A.K., Deoliya, R., Maiti, S., 2014. Recycled
24 aggregate from C&D waste & its use in concrete – A breakthrough towards sustainability in
25 construction sector: A review. *Construction and Building Materials* 68, 501-516.

1 BIO Intelligence Service, 2013. Service contract on management of construction and
2 demolition waste SR1, in: Commission, E. (Ed.),
3 [https://publications.europa.eu/en/publication-detail/-/publication/0c9ecefcd07a492e-a7e1-](https://publications.europa.eu/en/publication-detail/-/publication/0c9ecefcd07a492e-a7e1-6d355b16dde4/language-en)
4 [6d355b16dde4/language-en](https://publications.europa.eu/en/publication-detail/-/publication/0c9ecefcd07a492e-a7e1-6d355b16dde4/language-en).

5 Blengini, G.A., 2009. Life cycle of buildings, demolition and recycling potential: A case
6 study in Turin, Italy. *Building and Environment* 44, 319-330.

7 Blengini, G.A., Garbarino, E., 2010. Resources and waste management in Turin (Italy): the
8 role of recycled aggregates in the sustainable supply mix. *Journal of Cleaner Production* 18,
9 1021-1030.

10 Bovea, M.D., Powell, J.C., 2016. Developments in life cycle assessment applied to evaluate
11 the environmental performance of construction and demolition wastes. *Waste Management*
12 50, 151-172.

13 Braga, A.M., Silvestre, J.D., de Brito, J., 2017. Compared environmental and economic
14 impact from cradle to gate of concrete with natural and recycled coarse aggregates. *Journal of*
15 *Cleaner Production* 162, 529-543.

16 Bravo, M., de Brito, J., 2012. Concrete made with used tyre aggregate: durability-related
17 performance. *Journal of Cleaner Production* 25, 42-50.

18 Butler, L., West, J.S., Tighe, S.L., 2011. The effect of recycled concrete aggregate properties
19 on the bond strength between RCA concrete and steel reinforcement. *Cement and Concrete*
20 *Research* 41, 1037-1049.

21 CCANZ, 2011. Best practice guide for the use of “RAs in new concrete”. Technical report
22 TR 14, Cement & Concrete Association of New Zealand (CCANZ), October 2011.

23 Clarke, S.F., Nawaz, W., Skelhorn, C., Amato, A., 2017. Towards a more sustainable waste
24 management in Qatar: Retrofitting mindsets and changing behaviours. *QScience Connect* 4.

1 Coelho, A., de Brito, J., 2013a. Economic viability analysis of a construction and demolition
2 waste recycling plant in Portugal – part I: location, materials, technology and economic
3 analysis. *Journal of Cleaner Production* 39, 338-352.

4 Coelho, A., de Brito, J., 2013b. Environmental analysis of a construction and demolition
5 waste recycling plant in Portugal – Part II: Environmental sensitivity analysis. *Waste
6 Management* 33, 147-161.

7 Corinaldesi, V., Moriconi, G., 2009. Influence of mineral additions on the performance of
8 100% recycled aggregate concrete. *Construction and Building Materials* 23, 2869-2876.

9 Corinaldesi, V., Moriconi, G., 2010. Characterization of Mechanical and Elastic Behaviour of
10 Concretes Made of Recycled-Concrete Aggregates, in: eds, A.N.a.H.L. (Ed.), *The Third
11 International Conference on Engineering for Waste and Biomass Valorisation (WasteEng10).
12 Ecole des Mines d'Albi-Carmaux, Albi, France, Beijing, China.*

13 de Juan, M.S., Gutiérrez, P.A., 2009. Study on the influence of attached mortar content on the
14 properties of recycled concrete aggregate. *Construction and Building Materials* 23, 872-877.

15 Debieb, F., Courard, L., Kenai, S., Degeimbre, R., 2009. Roller compacted concrete with
16 contaminated recycled aggregates. *Construction and Building Materials* 23, 3382-3387.

17 Debieb, F., Courard, L., Kenai, S., Degeimbre, R., 2010. Mechanical and durability
18 properties of concrete using contaminated recycled aggregates. *Cement and Concrete
19 Composites* 32, 421-426.

20 Dilbas, H., Şimşek, M., Çakır, Ö., 2014. An investigation on mechanical and physical
21 properties of recycled aggregate concrete (RAC) with and without silica fume. *Construction
22 and Building Materials* 61, 50-59.

23 Ding, T., Xiao, J., Tam, V.W.Y., 2016. A closed-loop life cycle assessment of recycled
24 aggregate concrete utilization in China. *Waste Management* 56, 367-375.

1 Dohaoasis, 2018. Redco Construction ALMANA. Available at:
2 https://www.redcoalmana.com/?page_id=8.

3 Domone, P., Illston, J., 2010. Construction Materials. Their nature and behaviour, 4th edition
4 ed. Spon Press, London.

5 Dumlao-Tan, M.I., Halog, A., 2017. Moving Toward a Circular Economy in Solid Waste
6 Management: Concepts and Practices, Advances in Solid and Hazardous Waste Management,
7 pp. 29-48.

8 Ellen MacArthur Foundation, 2016. Circular Economy – UK, Europe, Asia, South America
9 & USA. Available at: <http://www.ellenmacarthurfoundation.org/circulareconomy>.

10 Esa, M.R., Halog, A., Rigamonti, L., 2017. Developing strategies for managing construction
11 and demolition wastes in Malaysia based on the concept of circular economy. Journal of
12 Material Cycles and Waste Management 19, 1144-1154.

13 Estanqueiro, B., Dinis Silvestre, J., de Brito, J., Duarte Pinheiro, M., 2018. Environmental
14 life cycle assessment of coarse natural and recycled aggregates for concrete. European
15 Journal of Environmental and Civil Engineering 22, 429-449.

16 Etxeberria, M., Vázquez, E., Marí, A., Barra, M., 2007. Influence of amount of recycled
17 coarse aggregates and production process on properties of recycled aggregate concrete.
18 Cement and Concrete Research 37, 735-742.

19 European Commission, 2008. Directive 2008/98/EC of The European Parliament And of The
20 Council on Waste and Repealing Certain Directives. Official Journal of the European Union,
21 L312, pp. 3–30.

22 European Commission, 2010. Service Contract on Management of construction and
23 demolition waste – SR1. May 2010. Available at:
24 [https://publications.europa.eu/en/publication-detail/-/publication/0c9ecefcd07a-492e-a7e1-](https://publications.europa.eu/en/publication-detail/-/publication/0c9ecefcd07a-492e-a7e1-6d355b16dde4)
25 [6d355b16dde4](https://publications.europa.eu/en/publication-detail/-/publication/0c9ecefcd07a-492e-a7e1-6d355b16dde4).

1 European Commission, 2016. Closing the loop. New circular economy package. Available at:
2 [http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573899/EPRS_BRI\(2016\)573899](http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573899/EPRS_BRI(2016)573899)
3 [_EN.pdf](#).

4 European Commission, 2018. Construction and Demolition Waste (CDW). Available at:
5 http://ec.europa.eu/environment/waste/construction_demolition.htm.

6 Evangelista, L., de Brito, J., 2010. Durability performance of concrete made with fine
7 recycled concrete aggregates. *Cement and Concrete Composites* 32, 9-14.

8 Figueiredo, J., Mavroulidou, M., 2010. Discarded Tyre Rubber as Concrete Aggregate a
9 Possible Outlet for Used Tyres. *Global NEST Journal* 12, 359-367.

10 Fonseca, N., de Brito, J., Evangelista, L., 2011. The influence of curing conditions on the
11 mechanical performance of concrete made with recycled concrete waste. *Cement and*
12 *Concrete Composites* 33, 637-643.

13 Foti, D., 2011. Preliminary analysis of concrete reinforced with waste bottles PET fibers.
14 *Construction and Building Materials* 25, 1906-1915.

15 Gokce, A., Nagataki, S., Saeki, T., Hisada, M., 2004. Freezing and thawing resistance of air-
16 entrained concrete incorporating recycled coarse aggregate: The role of air content in
17 demolished concrete. *Cement and Concrete Research* 34, 799-806.

18 Gómez-Soberón, J.M.V., 2002. Porosity of recycled concrete with substitution of recycled
19 concrete aggregate: An experimental study. *Cement and Concrete Research* 32, 1301-1311.

20 González-Fonteboa, B., Martínez-Abella, F., 2008. Concretes with aggregates from
21 demolition waste and silica fume. Materials and mechanical properties. *Building and*
22 *Environment* 43, 429-437.

23 GSDP, 2008. Qatar National Vision 2030. Available at:
24 https://www.mdps.gov.qa/en/qnv/Documents/QNV2030_English_v2.pdf, in: Planning,
25 G.S.f.D. (Ed.).

1 Halla, F., 2007. A SWOT analysis of strategic urban development planning: The case of Dar
2 es Salaam city in Tanzania. *Habitat International* 31, 130-142.

3 Hansen, T., Lauritzen, E.K., 2004. Concrete waste in a global perspective, in: Liu TC, Meyer
4 C (Eds.), *Recycling concrete and other materials for sustainable development*. American
5 Concrete Institute, pp. 35-45.

6 Hassan, K.E.-G., 2015. Recycling in Qatar's Construction Industry. Available at:
7 http://issuu.com/firefly-communications/docs/qcn_2.2_february2015_web/17?e0

8 Henschen, J., Teramoto, A., Lange, D.A., 2012. Shrinkage and Creep Performance of
9 Recycled Aggregate Concrete. Springer Netherlands, Dordrecht, pp. 1333-1340.

10 Hossain, M.U., Poon, C.S., Lo, I.M.C., Cheng, J.C.P., 2016. Comparative environmental
11 evaluation of aggregate production from recycled waste materials and virgin sources by LCA.
12 *Resources, Conservation and Recycling* 109, 67-77.

13 Hu, M., Kleijn, R., Bozhilova-Kisheva, K.P., Di Maio, F., 2013. An approach to LCSA: the
14 case of concrete recycling. *The International Journal of Life Cycle Assessment* 18, 1793-
15 1803.

16 Huda, S.B., Alam, M.S., 2015. Mechanical and Freeze-Thaw Durability Properties of
17 Recycled Aggregate Concrete Made with Recycled Coarse Aggregate. *Journal of Materials in
18 Civil Engineering* 27, 04015003.

19 Huysman, S., Debaveye, S., Schaubroeck, T., Meester, S.D., Ardente, F., Mathieux, F.,
20 Dewulf, J., 2015. The recyclability benefit rate of closed-loop and open-loop systems: A case
21 study on plastic recycling in Flanders. *Resources, Conservation and Recycling* 101, 53-60.

22 Iacovidou, E., Millward-Hopkins, J., Busch, J., Purnell, P., Velis, C.A., Hahladakis, J.N.,
23 Zwirner, O., Brown, A., 2017. A pathway to circular economy: Developing a conceptual
24 framework for complex value assessment of resources recovered from waste. *Journal of
25 Cleaner Production* 168, 1279-1288.

1 Iacovidou, E., Purnell, P., 2016. Mining the physical infrastructure: Opportunities, barriers
2 and interventions in promoting structural components reuse. *Science of The Total*
3 *Environment* 557-558, 791-807.

4 Kader, S.A., 2016. Trash to treasure: Recycling construction waste in Qatar. Available at:
5 www.qatarconstructionnews.com/trash-treasure-recycling-construction-waste-qatar. QCN,
6 <http://www.qatarconstructionnews.com>.

7 Kajanus, M., Leskinen, P., Kurttila, M., Kangas, J., 2012. Making use of MCDS methods in
8 SWOT analysis—Lessons learnt in strategic natural resources management. *Forest Policy*
9 *and Economics* 20, 1-9.

10 Kasai, Y., 2004. Recent trends in recycling of concrete waste and use of recycled aggregate
11 concrete in Japan. , in: Liu TC, Meyer C (Eds.), *Recycling concrete and other materials for*
12 *sustainable development*. American Concrete Institute, pp. 11–33.

13 Katz, A., 2003. Properties of concrete made with recycled aggregate from partially hydrated
14 old concrete. *Cement and Concrete Research* 33, 703-711.

15 Kim, H.K., Lee, H.K., 2011. Use of power plant bottom ash as fine and coarse aggregates in
16 high-strength concrete. *Construction and Building Materials* 25, 1115-1122.

17 Kim, S.B., Yi, N.H., Kim, H.Y., Kim, J.-H.J., Song, Y.-C., 2010. Material and structural
18 performance evaluation of recycled PET fiber reinforced concrete. *Cement and Concrete*
19 *Composites* 32, 232-240.

20 Kisku, N., Joshi, H., Ansari, M., Panda, S.K., Nayak, S., Dutta, S.C., 2017. A critical review
21 and assessment for usage of recycled aggregate as sustainable construction material.
22 *Construction and Building Materials* 131, 721-740.

23 Kou, S.-C., Poon, C.-S., 2008. Mechanical properties of 5-year-old concrete prepared with
24 recycled aggregates obtained from three different sources. *Magazine of Concrete Research*
25 60, 57-64.

1 Kou, S.-C., Poon, C.-S., 2013. Long-term mechanical and durability properties of recycled
2 aggregate concrete prepared with the incorporation of fly ash. *Cement and Concrete*
3 *Composites* 37, 12-19.

4 Kou, S.C., Poon, C.S., 2012. Enhancing the durability properties of concrete prepared with
5 coarse recycled aggregate. *Construction and Building Materials* 35, 69-76.

6 Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A.,
7 Schandl, H., Haberl, H., 2017. Global socioeconomic material stocks rise 23-fold over the
8 20th century and require half of annual resource use. *Proceedings of the National Academy*
9 *of Sciences* 114, 1880-1885.

10 Kucukvar, M., Egilmez, G., Tatari, O., 2014. Evaluating environmental impacts of alternative
11 construction waste management approaches using supply-chain-linked life-cycle analysis.
12 *Waste Management & Research* 32, 500-508.

13 Kumbhar, S., Gupta, A., Desai, D., 2013. Recycling and Reuse of Construction and
14 Demolition Waste for Sustainable Development OIDA International Journal of Sustainable
15 Development 6, 83-92.

16 Levy, S.M., Helene, P., 2004. Durability of recycled aggregates concrete: a safe way to
17 sustainable development. *Cement and Concrete Research* 34, 1975-1980.

18 Limantono, H., Ekaputri, J.J., Susanto, T.E., 2016. Effect of Silica Fume and Glass Powder
19 on High-Strength Paste. *Key Engineering Materials* 673, 37-46.

20 Limbachiya, M.C., Leelawat, T., Dhir, R.K., 2000. Use of recycled concrete aggregate in
21 high-strength concrete. *Materials and Structures* 33, 574.

22 Llatas, C., 2013. 3 - Methods for estimating construction and demolition (C&D) waste, in:
23 Pacheco-Torgal, F., Tam, V.W.Y., Labrincha, J.A., Ding, Y., de Brito, J. (Eds.), *Handbook of*
24 *Recycled Concrete and Demolition Waste*. Woodhead Publishing, pp. 25-52.

1 Lotfy, A., Al-Fayez, M., 2015. Performance evaluation of structural concrete using controlled
2 quality coarse and fine recycled concrete aggregate. *Cement and Concrete Composites* 61,
3 36-43.

4 Lu, W., Yuan, H., 2010. Exploring critical success factors for waste management in
5 construction projects of China. *Resources, Conservation and Recycling* 55, 201-208.

6 Malešev, M., Radonjanin, V., Marinković, S., 2010. Recycled Concrete as Aggregate for
7 Structural Concrete Production. *Sustainability* 2, 1204.

8 Martín-Morales, M., Zamorano, M., Ruiz-Moyano, A., Valverde-Espinosa, I., 2011.
9 Characterization of recycled aggregates construction and demolition waste for concrete
10 production following the Spanish Structural Concrete Code EHE-08. *Construction and*
11 *Building Materials* 25, 742-748.

12 Marzouk, M., Azab, S., 2014. Environmental and economic impact assessment of
13 construction and demolition waste disposal using system dynamics. *Resources, Conservation*
14 *and Recycling* 82, 41-49.

15 Mas, B., Cladera, A., Olmo, T.d., Pitarch, F., 2012. Influence of the amount of mixed
16 recycled aggregates on the properties of concrete for non-structural use. *Construction and*
17 *Building Materials* 27, 612-622.

18 Matias, D., Brito, J.d., Rosa, A., Pedro, D., 2014. Durability of Concrete with Recycled
19 Coarse Aggregates: Influence of Superplasticizers. *Journal of Materials in Civil Engineering*
20 26, 06014011.

21 McNeil, K., Kang, T.H.-K., 2013. Recycled Concrete Aggregates: A Review. *International*
22 *Journal of Concrete Structures and Materials* 7, 61-69.

23 MDPS, 2017. Environment Statistics In the State of Qatar, 2015. Available at:
24 <https://www.mdps.gov.qa/en/statistics/Statistical%20Releases/Environmental/Environmental>
25 [Statistics/Environment_QSA_EN_2015.pdf](https://www.mdps.gov.qa/en/statistics/Statistical%20Releases/Environmental/Environmental)

1 Medina, C., Sánchez de Rojas, M.I., Frías, M., 2013. Freeze-thaw durability of recycled
2 concrete containing ceramic aggregate. *Journal of Cleaner Production* 40, 151-160.

3 Meyer, C., 2009. The greening of the concrete industry. *Cement and Concrete Composites*
4 31, 601-605.

5 Mittal, V.K., Sangwan, K.S., 2014. Prioritizing Barriers to Green Manufacturing:
6 Environmental, Social and Economic Perspectives. *Procedia CIRP* 17, 559-564.

7 Mohamed, F., Musharavati, F., 2016. Green Building Rating Systems: A Comparison of
8 LEED and GSAS Systems on Construction & Demolition Waste Management Performance
9 in Qatar. Qatar University, Qatar.

10 Mousa, M.I., Mahdy, M.G., Abdel-Reheem, A.H., Yehia, A.Z., 2015. Self-curing concrete
11 types; water retention and durability. *Alexandria Engineering Journal* 54, 565-575.

12 Mukharjee, B.B., Barai, S.V., 2014. Influence of Nano-Silica on the properties of recycled
13 aggregate concrete. *Construction and Building Materials* 55, 29-37.

14 Nagataki, S., Gokce, A., Saeki, T., Hisada, M., 2004. Assessment of recycling process
15 induced damage sensitivity of recycled concrete aggregates. *Cement and Concrete Research*
16 34, 965-971.

17 Nunes, K.R.A., Mahler, C.F., Valle, R., Neves, C., 2007. Evaluation of investments in
18 recycling centres for construction and demolition wastes in Brazilian municipalities. *Waste*
19 *Management* 27, 1531-1540.

20 Oner, A., Akyuz, S., Yildiz, R., 2005. An experimental study on strength development of
21 concrete containing fly ash and optimum usage of fly ash in concrete. *Cement and Concrete*
22 *Research* 35, 1165-1171.

23 Ortiz, O., Pasqualino, J.C., Castells, F., 2010. Environmental performance of construction
24 waste: Comparing three scenarios from a case study in Catalonia, Spain. *Waste Management*
25 30, 646-654.

1 Özkan, Ö., Yüksel, I., Muratoğlu, Ö., 2007. Strength properties of concrete incorporating coal
2 bottom ash and granulated blast furnace slag. *Waste Management* 27, 161-167.

3 Padmini, A.K., Ramamurthy, K., Mathews, M.S., 2009. Influence of parent concrete on the
4 properties of recycled aggregate concrete. *Construction and Building Materials* 23, 829-836.

5 Pardo Martínez, C.I., Piña, W.A., 2017. Solid waste management in Bogotá: the role of
6 recycling associations as investigated through SWOT analysis. *Environment, Development
7 and Sustainability* 19, 1067-1086.

8 Park, S.B., Jang, Y.I., Lee, J., Lee, B.J., 2009. An experimental study on the hazard
9 assessment and mechanical properties of porous concrete utilizing coal bottom ash coarse
10 aggregate in Korea. *Journal of Hazardous Materials* 166, 348-355.

11 Peng, C., 2016. Calculation of a building's life cycle carbon emissions based on Ecotect and
12 building information modeling. *Journal of Cleaner Production* 112, 453-465.

13 Pereira, P., Evangelista, L., de Brito, J., 2012. The effect of superplasticizers on the
14 mechanical performance of concrete made with fine recycled concrete aggregates. *Cement
15 and Concrete Composites* 34, 1044-1052.

16 Purnell, P., Dunster, A., 2009. Recycling of concrete, in: Goodship, V. (Ed.), *Management,
17 recycling and reuse of waste composites*. Elsevier.

18 QCS, 2014. Qatar Construction Standards. Available at:
19 <https://amtcqatarwp.files.wordpress.com/2015/04/section-1-general.pdf>.

20 QDVC, 2016. QDVC Sustainable Development Policy on Environment. Available at:
21 <http://qdvc.com/index.php/en/sustainable-development/environment>.

22 Rafi, M., Qadir, A., Ali, S., Siddiqui, S., 2014. Performance of Hot Mix Asphalt Mixtures
23 Made of Recycled Aggregates. *Journal of Testing and Evaluation* 42, 357-367.

24 Rafi, M.M., 2018. Study of Bond Properties of Steel Rebars with Recycled Aggregate
25 concrete. *Experimental Testing. Strength of Materials* 50, 937-950.

1 Rafi, M.M., 2019. Study of Bond Properties of Steel Rebars with Recycled Aggregate
2 Concrete. *Analytical Modeling. Strength of Materials* 51, 166-174.

3 Rafi, M.M., Qadir, A., Siddiqui, S.H., 2011. Experimental testing of hot mix asphalt mixture
4 made of recycled aggregates. *Waste Management & Research* 29, 1316-1326.

5 Rahal, K., 2007. Mechanical properties of concrete with recycled coarse aggregate. *Building
6 and Environment* 42, 407-415.

7 Ranta, V., Aarikka-Stenroos, L., Ritala, P., Mäkinen, S.J., 2018. Exploring institutional
8 drivers and barriers of the circular economy: A cross-regional comparison of China, the US,
9 and Europe. *Resources, Conservation and Recycling* 135, 70-82.

10 Reid, J.M., Hassan, K.E.-G., Al-Kuwari, M.b.S., 2016. Improving the management of
11 construction waste in Qatar, *Waste and Resource Management*, pp. 21-29.

12 Richardson, A., Coventry, K., Edmondson, V., Dias, E., 2016. Crumb rubber used in concrete
13 to provide freeze–thaw protection (optimal particle size). *Journal of Cleaner Production* 112,
14 599-606.

15 Ritzén, S., Sandström, G.Ö., 2017. Barriers to the Circular Economy – Integration of
16 Perspectives and Domains. *Procedia CIRP* 64, 7-12.

17 Rodríguez, G., Medina, C., Alegre, F.J., Asensio, E., Sánchez de Rojas, M.I., 2015.
18 Assessment of Construction and Demolition Waste plant management in Spain: in pursuit of
19 sustainability and eco-efficiency. *Journal of Cleaner Production* 90, 16-24.

20 Rosado, L.P., Vitale, P., Penteadó, C.S.G., Arena, U., 2017. Life cycle assessment of natural
21 and mixed recycled aggregate production in Brazil. *Journal of Cleaner Production* 151, 634-
22 642.

23 Ryu, J.S., 2002. An experimental study on the effect of recycled aggregate on concrete
24 properties. *Magazine of Concrete Research* 54, 7-12.

1 Sagoe-Crentsil, K.K., Brown, T., Taylor, A.H., 2001. Performance of concrete made with
2 commercially produced coarse recycled concrete aggregate. *Cement and Concrete Research*
3 31, 707-712.

4 Sani, D., Moriconi, G., Fava, G., Corinaldesi, V., 2005. Leaching and mechanical behaviour
5 of concrete manufactured with recycled aggregates. *Waste Management* 25, 177-182.

6 Schrör, H., 2011. Generation and Treatment of Waste in Europe. Available at:
7 [http://www.gaiialibrary.org/system/files/Eurostat%20statistics%20waste%20generation%20an](http://www.gaiialibrary.org/system/files/Eurostat%20statistics%20waste%20generation%20and%20treatment%20in%202008.pdf)
8 [d%20treatment%20in%202008.pdf](http://www.gaiialibrary.org/system/files/Eurostat%20statistics%20waste%20generation%20and%20treatment%20in%202008.pdf), in: Eurostat (Ed.), *Statistics in focus*.

9 Shahba, S., Arjmandi, R., Monavari, M., Ghodusi, J., 2017. Application of multi-attribute
10 decision-making methods in SWOT analysis of mine waste management (case study: Sirjan's
11 Golgohar iron mine, Iran). *Resources Policy* 51, 67-76.

12 Silva, R.V., de Brito, J., Dhir, R.K., 2017. Availability and processing of recycled aggregates
13 within the construction and demolition supply chain: A review. *Journal of Cleaner Production*
14 143, 598-614.

15 Silva, R.V., Neves, R., de Brito, J., Dhir, R.K., 2015. Carbonation behaviour of recycled
16 aggregate concrete. *Cement and Concrete Composites* 62, 22-32.

17 Sim, J., Park, C., 2011. Compressive strength and resistance to chloride ion penetration and
18 carbonation of recycled aggregate concrete with varying amount of fly ash and fine recycled
19 aggregate. *Waste Management* 31, 2352-2360.

20 Somna, R., Jaturapitakkul, C., Amde, A.M., 2012. Effect of ground fly ash and ground
21 bagasse ash on the durability of recycled aggregate concrete. *Cement and Concrete*
22 *Composites* 34, 848-854.

23 Son, K.S., Hajirasouliha, I., Pilakoutas, K., 2011. Strength and deformability of waste tyre
24 rubber-filled reinforced concrete columns. *Construction and Building Materials* 25, 218-226.

1 Tam, V.W.Y., Gao, X.F., Tam, C.M., 2005. Microstructural analysis of recycled aggregate
2 concrete produced from two-stage mixing approach. *Cement and Concrete Research* 35,
3 1195-1203.

4 Tam, V.W.Y., Tam, C.M., 2007. Assessment of durability of recycled aggregate concrete
5 produced by two-stage mixing approach. *Journal of Materials Science* 42, 3592-3602.

6 Tam, V.W.Y., Tam, C.M., 2008. Diversifying two-stage mixing approach (TSMA) for
7 recycled aggregate concrete: TSMA and TSMA^{sc}. *Construction and Building Materials* 22,
8 2068-2077.

9 Thiery, M., Dangla, P., Belin, P., Habert, G., Roussel, N., 2013. Carbonation kinetics of a bed
10 of recycled concrete aggregates: A laboratory study on model materials. *Cement and*
11 *Concrete Research* 46, 50-65.

12 Thomas, C., Setién, J., Polanco, J.A., Alaejos, P., Sánchez de Juan, M., 2013. Durability of
13 recycled aggregate concrete. *Construction and Building Materials* 40, 1054-1065.

14 Topçu, İ.B., Şengel, S., 2004. Properties of concretes produced with waste concrete
15 aggregate. *Cement and Concrete Research* 34, 1307-1312.

16 Tuyan, M., Mardani-Aghabaglou, A., Ramyar, K., 2014. Freeze–thaw resistance, mechanical
17 and transport properties of self-consolidating concrete incorporating coarse recycled concrete
18 aggregate. *Materials & Design* 53, 983-991.

19 Üрге-Vorsatz, D., Novikova, A., 2008. Potentials and costs of carbon dioxide mitigation in
20 the world's buildings. *Energy Policy* 36, 642-661.

21 Vázquez, E., Barra, M., Aponte, D., Jiménez, C., Valls, S., 2014. Improvement of the
22 durability of concrete with recycled aggregates in chloride exposed environment.
23 *Construction and Building Materials* 67, 61-67.

24 Velenturf, A., Purnell, P., 2017. Resource Recovery from Waste: Restoring the Balance
25 between Resource Scarcity and Waste Overload. *Sustainability* 9, 1603.

1 Vieira, D.R., Calmon, J.L., Coelho, F.Z., 2016. Life cycle assessment (LCA) applied to the
2 manufacturing of common and ecological concrete: A review. *Construction and Building*
3 *Materials* 124, 656-666.

4 Vilches, A., Garcia-Martinez, A., Sanchez-Montañes, B., 2017. Life cycle assessment (LCA)
5 of building refurbishment: A literature review. *Energy and Buildings* 135, 286-301.

6 Villagrán-Zaccardi, Y.A., Zega, C.J., Maio, Á.A.D., 2008. Chloride Penetration and Binding
7 in Recycled Concrete. *Journal of Materials in Civil Engineering* 20, 449-455.

8 Vinay Kumar, B.M., Ananthan, H., Balaji, K.V.A., 2017. Experimental studies on utilization
9 of recycled coarse and fine aggregates in high performance concrete mixes. *Alexandria*
10 *Engineering Journal*.

11 Weil, M., Jeske, U., Schebek, L., 2006. Closed-loop recycling of construction and demolition
12 waste in Germany in view of stricter environmental threshold values. *Waste Management &*
13 *Research* 24, 197-206.

14 WRAP, 2004. Improving specifications for use of recycled and secondary aggregates in
15 construction. Available at:
16 [http://www.wrap.org.uk/sites/files/wrap/BRE%20Improving%20specification%20WRAP%20](http://www.wrap.org.uk/sites/files/wrap/BRE%20Improving%20specification%20WRAP%20T.pdf)
17 [T.pdf](http://www.wrap.org.uk/sites/files/wrap/BRE%20Improving%20specification%20WRAP%20T.pdf).

18 Xiao, J., Lei, B., Zhang, C., 2012. On carbonation behavior of recycled aggregate concrete.
19 *Science China Technological Sciences* 55, 2609-2616.

20 Yuan, H., 2013. A SWOT analysis of successful construction waste management. *Journal of*
21 *Cleaner Production* 39, 1-8.

22 Yuan, H., 2017. Barriers and countermeasures for managing construction and demolition
23 waste: A case of Shenzhen in China. *Journal of Cleaner Production* 157, 84-93.

- 1 Yuan, H., Chini, A.R., Lu, Y., Shen, L., 2012. A dynamic model for assessing the effects of
2 management strategies on the reduction of construction and demolition waste. *Waste*
3 *Management* 32, 521-531.
- 4 Zega, C.J., Di Maio, Á.A., 2011. Use of recycled fine aggregate in concretes with durable
5 requirements. *Waste Management* 31, 2336-2340.
- 6 Zhao, W., Leefink, R.B., Rotter, V.S., 2010. Evaluation of the economic feasibility for the
7 recycling of construction and demolition waste in China—The case of Chongqing.
8 *Resources, Conservation and Recycling* 54, 377-389.
- 9 Zhu, Y.-G., Kou, S.-C., Poon, C.-S., Dai, J.-G., Li, Q.-Y., 2013. Influence of silane-based
10 water repellent on the durability properties of recycled aggregate concrete. *Cement and*
11 *Concrete Composites* 35, 32-38.

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