Original Article

WM&R

Waste Management & Research
2022, Vol. 40(7) 1027–1038

DOI: 10.1177/0734242X211052856
journals.sagepub.com/home/wmr
SAGE

A construction and demolition waste management model applied to social housing to trigger post-pandemic economic recovery in Mexico

Pilar Mercader-Moyano[1], Patricia Edith Camporeale[2] and Jesús López-López[3]

Abstract

Buildings consume 40% of raw material and primary energy and generate 35% of industrial waste worldwide, making this sector play a main role in raw material depletion, energy consumption and carbon emissions which provoke great environmental impact and worsen Global Warming. Latin American countries including Mexico have the world's highest urbanisation rate (84%) but lack effective construction and demolition waste (CDW) management to thrive in regenerative sustainability, climate change mitigation and post-pandemic economic recovery. This work applies the Spanish current model to quantify on-site 61 Mexican social housing CDW with surveys to workers and supervisors as an additional source of data. The results of the case study show that social housing consumes 1.24 t.m^{-2} of raw materials and produces 0.083 t.m^{-2} of CDW. Cement-based, ceramic and mixed CDW represent 83.44% of total CDW. When considering inert soil as a recyclable resource, 78% of the remaining CDW ends in landfills and only 22% of it goes to recycling plants. The implementation of this methodology will deliver sustainable CDW management in Mexico, by minimising CDW production, promoting related legislation and allowing replacement of current construction materials for eco-efficient ones. Furthermore, these data can broaden the Spanish coefficients of the construction resources that become CDW to build an internationally sourced database.

Keywords

Social housing CDW quantification, CDW environmental impact assessment, post-pandemic recovery through a circular economy, CDW transformation coefficients, CDW onsite measurement

Received 3rd June 2021, accepted 22nd September 2021 by Associate Editor Nemanja Stanisavljevic.

Introduction

Buildings consume 40% of natural resources and primary energy worldwide (López-Mesa et al., 2009) while accounts for 35% of industrial waste (Hendriks, 2000) and 36% of greenhouse gas (GHG) emissions showing a growing tendency (OECD, 2019). Only in the European Union (EU), this sector represents 10% of gross domestic product (GDP), consumes 50% of natural resources, and 40% of primary energy, generating 35% of construction and demolition waste (CDW) and 30% of building carbon footprint. CDW represents the largest flow in terms of mass: 1/3 of 3 billion tonnes annually. Although it seems to be economically circular since it avoids landfill and incineration, CDW recycling mainly orients to backfilling for road subsoil, reducing its potential towards a circular CWD management (European Commission, 2018). In the United States, the environmental protection agency (EPA) reports that 22% of 600 million tonnes of CDW produced in 2020 were recycled: 52% for aggregate products, 24% for landfills, less than 2% for soil remediation and composting, and less than 1% for fuel (U.S. Environmental Protection Agency, 2020). Mexico produces more than 6 million tonnes year^{-1} (Cámara Mexicana de la Industria de la Construcción, 2016) without considering CDW from informal construction activities and earthquakes that mainly end in landfills, of which only some have acquired international standards to regard them as authorised places.

While developed countries have implemented CDW management plans based on standards like ISO 14001 (ISO, 2015) which is voluntary and, LEED certification (LEED v4.1| U.S. Green Building Council, 2021), BREEAM (BREEAM – Sustainability Assessment Method, 2016) and EU Directives (European

[1]Departamento de Construcciones Arquitectónicas I, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Seville, Spain
[2]Facultad de Arquitectura y Urbanismo, Universidad Nacional de La Plata, La Plata, Argentina
[3]Facultad de Arquitectura, Diseño y Urbanismo Centro Universitario, Universidad Autónoma de Tamaulipas, Tampico, Mexico

Corresponding author:
Pilar Mercader-Moyano, Departamento de Construcciones Arquitectónicas I, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, 2, De la Reina Mercedes Ave., Seville 41004, Spain.
Email: pmm@us.es

Commission, 2018), Mexico is beginning to implement CDW management plans (GODF, 2015; Procuraduría Federal de Protección al Ambiente, 2014).

But the COVID-19 pandemic provoked a sanitary crisis that made GDP fall 1.67% to 2009 level worldwide (OECD, 2020; World Bank, 2020). Raw material and oil prices fall have become barriers to the transition to the circular economy because of idle assets, supply chain disruption, uncertain availability and price volatility. Consequently, the path to decarbonized cities, energy poverty reduction and socioeconomic sustainability proposed by the EU Circular Economy Action Plan (European Commission, 2019), the 'Renovation Wave' and the 'Green Deal' (European Commission, 2020b) show strong affinity to EU strategic priorities for economic recovery. New business models may activate local resources, reduce import dependence, and diversify supplies to increase resilience, along with the creation of green jobs. In addition, circular economy contributes to achieve carbon neutrality with nearly a half of current emissions reduction (300 million tonnes) by 2050. Furthermore, the EU Social and Economic Committee identifies the building sector plays an important role to promote economic recovery because of the intensive labour use in the construction industry, mainly in local companies (Zahradnik et al., 2020). The circular economy promotes the seven Rs: redesign, reduce, reuse, repair, renovate, recover and recycle, making EU to compel the second-use materials standardisation and its dissemination among stakeholders to reduce CDW production and acquire a better and higher recycling quality (European Commission, 2020b). The European Commission has issued 54 measures to apply along the construction material lifecycle in five prior sectors that comprehend construction and demolition like the CDW Protocol and Guidelines (European Commission, 2018), Level(s) assessment framework (European Commission, 2020), one-use plastic ban, critical raw material reuse/recycling, eco-design, spare parts eco-labelling, lifecycle end of waste treatment and packaging reuse/recycling (European Environment Agency, 2020). Spain updated CDW management to achieve a sustainable, decarbonized, resource-efficient, and competitive economy through the Spanish Strategy on Circular Economy 2030 (Jefatura de Gobierno, 2011; Ministerio de Agricultura, Alimentación y Medio Ambiente, 2015a, 2015b; Ministerio de la Presidencia, 2008). Five of their six goals are directly or indirectly related to CDW management: 15% CDW reduction, 30% of raw material and CO_{2e} emissions reduction to less than 10 million annual tonnes by 2030.

The situation is quite different in Latin America and the Caribbean with the highest urbanisation rate worldwide (84%), where 32% of the inhabitant lives in cities that are greater than 1-million people and host 40% of the global urban population. In Mexico, municipal solid waste (MSW) that includes CDW daily collection leaves aside 35,000 tonnes from 40 million marginal and rural people (United Nations Environment Programme, 2018), while 60% (145,000 tonnes daily) ends in landfills being most of them only 'supervised landfills'. Mexico City has got only two authorised landfills, so the City Government has launched the Zero Waste Plan to reduce the 8600 tonnes sent to landfills to 2000 tonnes by 2024 (CDMX, 2019; Ríos, 2019). CDW accounts for 6.7% of GDP without including CDW due to natural disasters (earthquakes) and employs 5.6 million people (Araiza-Aguilar et al., 2019). Mexico is the second regional economy and the 15th in the global ranking, but it had a poverty rate of 48.8% in 2018 (61.1 million people) that will increase to 66.9% after the pandemic. It will become the 4th poorest regional country with 8.6% GDP fall (Comisión Económica para América Latina y el Caribe, 2020; Consejo Nacional de Evaluación de la Política de Desarrollo Social (CONEVAL), 2018). Hence, Mexican cities will become even more vulnerable to infectious disease outbreaks due to low-income residential density (Ghosh et al., 2020; Matthew and McDonald, 2006). Moreover, CDW quantification is the first step for CDW management policies to motivate the adoption of emergent technologies, on-site audits, government supervision, economic incentives, interaction with stakeholders, coordination between operative departments and directions towards a circular economy (Aslam et al., 2020).

This research reviews different CDW quantification methodologies (Supplemental material Appendix A, Table A1) that include material flow analysis (Bakchan et al., 2019; Cochran and Townsend, 2010; Ding and Xiao, 2014; Lu et al., 2015; Miatto et al., 2019; Zaman & Lehmann, 2013), direct and indirect on-site and off-site CDW quantification (Barón, J. et al., 2017; Carpio et al., 2016; de Guzmán Báez et al., 2012; Jaillon et al., 2009; Kleemann et al., 2017; Li et al., 2013; Li et al., 2016;Mercader-Moyano and Ramírez-de-Arellano-Agudo, 2013; Parisi Kern et al., 2015; Ram & Kalidindi, 2017; Wu et al., 2019), CDW track load counts to treatment plants or landfills (Blaisi, 2019; Cha et al., 2020; Kartam et al., 2004; Villoria Sáez et al., 2018), surveys to workers, recyclers and government officials to follow CDW from origin to end, life cycle assessment (LCA) (Wu et al., 2016; Yuan, 2017) and building information modelling (BIM) applied to buildings and executive project plans consulting, among others (Ajayi et al., 2015; Jalaei et al., 2019; Jiménez Rivero et al., 2016; Luciano et al., 2018; Akinade et al., 2018; Cheng & Ma, 2013; S. Liu et al., 2015; H. Liu et al., 2019; Won and Cheng, 2017; H. Wu et al., 2019; Mercader Moyano et al., 2019; Ge et al., 2017; Guerra et al., 2019; Bakchan et al., 2019; C. Z. Li et al., 2020; Tanikawa & Hashimoto, 2009; Park et al., 2014).

In Mexico, CDW quantification follows a methodology that considers the construction material purchases with a CDW production coefficient of $0.3\,m^3\,m^{-2}$ and another coefficient to convert volume to weight of $1.5\,tonne\,m^{-3}$, referred to research from the United States and Europe. The composition of CDW consisted in the observation and measurement of truckloads sent to a landfill in Mexico Federal District (Secretaría de Medio Ambiente y Recursos Naturales, 2010). In compliance with the environmental goals proposed by the Development National Plan (2013–2018), SEMARNAT and the Mexican Chamber of Construction Industry delivered a National Plan for CDW management to implement the Mexican Standard NOM-161-SEMARNAT-2011. The CDW quantification focused on the tasks that produced the highest volumes of CDW while giving general recommendations about the CDW

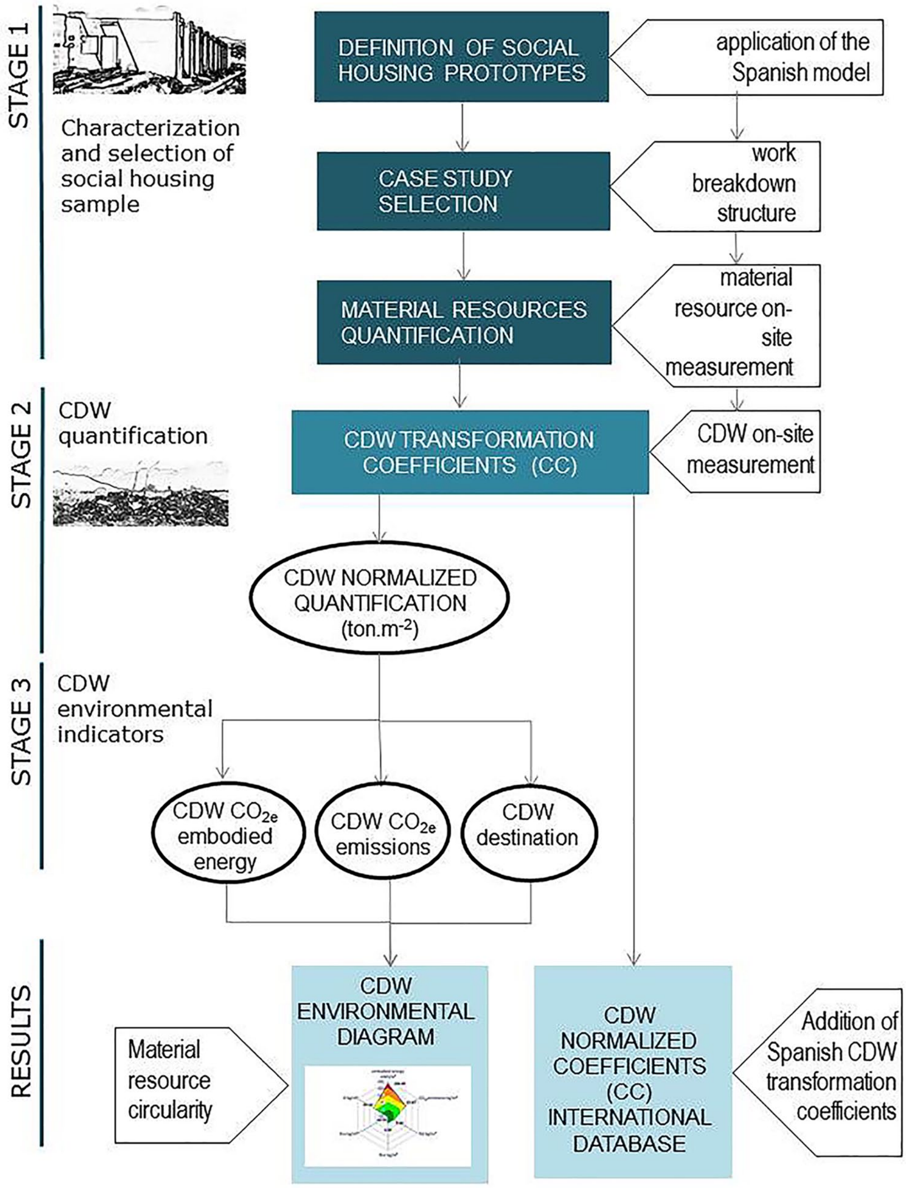

Figure 1. Methodological framework and stages.

measurement and on-site selection. This report estimated that 6.08 million tonnes generated in 2011 would reach 9.2 million tonnes in 2018, with a rise of 3.5% of the construction industry activity. CDW composition consisted of 39% of soil excavation, 25% of concrete, 24% of mixed CDW and 12% of other types (Cámara Mexicana de la Industria de la Construcción, 2016; Procuraduría Federal de Protección al Ambiente, 2014). However, the lack of effectiveness of this CDW quantification model shows the need to obtain real coefficients from CDW production and management, which would favour its circular economy, increasing Mexican GDP and offering an exit to the post-COVID crisis.

This paper aims to apply on-site CDW quantification by the weighted transfers of measurement and user surveys by auditing 61 single-family Mexican social housing over 5 years with the addition of its environmental impact: embodied energy (EE) and carbon emissions (CEs) and, CDW destination: landfill, onsite, and offsite reuse and recycle.

Materials and methods

The methodology consists of three stages. In the first one, the definition of the housing conventional construction model (CCM) requires stabilising the typology features, selecting a representative sample and quantifying the material resources consumed in the construction process. In the second stage, the CDW quantification requires the calculation of the transformation coefficients from the on-site measurement and surveys. In the third one, CDW EE and CO_{2e} emissions combined with CDW destination provide the data to build environmental indicators (Figure 1).

The weighted transfer of measurement (WTM) identifies and quantifies CDW from the consumed material resources of the social housing CCM. Thus, this work delivers CDW transformation coefficients and environmental impact indicators to favour the transition from a linear economy model to a circular one by

Figure 2. Social housing under construction.

reintroducing CDW as reused, recycled and by-products to close the material flows. This methodology had been previously applied and successfully implemented in Spain, giving rise to municipal regulations associated with the Andalusian Construction Costs Database (Mercader-Moyano and Ramírez-de-Arellano-Agudo, 2013). Since current coefficients used in Mexico have failed to succeed because they were based on foreign models, this work will be the first step to help CDW management policies and municipal regulations to predict CDW production and promote reuse and recycling to minimise raw materials and energy consumption and CEs.

Stage 1

The methodological steps define the prototype of the social housing CCM, select the sample of the predominant typology and quantify the material resources from their basic material components (BMCs) in Mexico.

Definition of the Mexican CCM. Mexican CCM has a built area between 42 and 76 m^2. However, the Building Code states a lower size for them that includes a kitchen-dining room, one or two bedrooms, one bathroom, one parking space, and basic services (Alderete Herrera, 2010; Gobierno Federal de México, 2016). Building materials and systems changed along with the evolution of the social housing in Mexico, hence this work limits up to 10-year-old housing to avoid referring to extinguished construction processes and materials. The CCM consists of a load-bearing structure of reinforced concrete foundation slab and wall-embedded pillars, concrete block walls, roofs of reinforced concrete vault blocks and prefabricated beams, cement-based outer finishes, plaster inner finishes, ceramic floors, single-pane glazing with aluminium frame and wooden doors with aluminium frame (López-López, 2019). In the '70s and '80s, several companies began to build one/two-storey social housing neighbourhoods with rigid schemes that do not respond to the changing needs along their life cycle (Sánchez-Corral, 2013).

Sample selection. The sample locates in Saltillo City, the capital district of Coahuila State, in Northern Mexico, next to the US frontier. Despite its large volume of social housing neighbourhoods, the city government lacks the necessary data to determine CDW management policies (Hyman et al., 2015). In 2015, Coahuila State population accounted for more than 2,950,000 people. In Saltillo City, around 807,000 people were distributed 90% in urban areas, and 10% in rural areas, with a poverty rate of 61.1% (CONEVAL, 2020). Its strategic location, administrative importance, and industrial development make this city a relevant data source in the social housing sector to approach CDW production in the construction industry.

Even when the social housing CCM changed traditional materials like adobe or quincha for modern ones like reinforced concrete, the construction techniques that local developers use are still artisan, as surveys to supervisors and workers reveal (Figure 2). During the last decade, the microcrystalline cellulose (MCC) morphology, construction systems and materials have been standardised by the different companies in Saltillo by building nearly identical prototypes. The three main companies situated in SE Coahuila: DAVISA, RUBA and SERVE, produce the prototypes between 46 m^2 and 52.13 m^2 that are the basis for this investigation.

CCM material resource quantification. The material take-off (MTO) provides the BMCs list from the Housing Institute of Coahuila State Government, local building companies and Saltillo housing developers. Due to different criteria among the Mexican States, this research adopts the average between 58 m^2 (from Coahuila State mortgages) and 42 m^2 (from CONAVI prescriptions) that accounts for 49.4 m^2 with 90% confidence interval and 10% error from the mortgages delivered in Saltillo along

2016 (López-López, 2019) (Supplemental material Appendix B. Table B.1).

The first step consists of a social housing historic and evolution approach to find the referential places in Saltillo City for the sample selection. The second step consists of the 61 social housing audits to identify and quantify the material resource consumption involving direct observation and surveys to workers and supervisors.

Following the model developed by Arellano (Ramírez de Arellano Agudo, 2002), the work breakdown structure (WBS) codifies the CCM construction tasks. These data come from the executive project documentation and technical specification sheets. The bill of quantities (BOQs) provides the BMC consumption; each task code consists of one letter (X), and the addition of a sequence of two letters and three numbers in the case that there is more than one type (XYZ00n) while BMCs show a three-letter code (TUV) (Supplemental material Table B.2). The quantification of BMCs consumed in the sample construction uses kg m^{-2} units (Supplemental material Table B.3).

Stage 2

In this stage, the CDW quantification lets calculate the transformation coefficients.

CDW characterization and classification. The on-site observation revealed four stages of CDW production: product delivery (deficient quality, download breaks and unproperly atmospheric conditions), storage (expired storage time, material breaks and package waste), construction works (internal transport breaks, mortar/concrete remains, material trimmings, badly executed works demolition, incorrect manoeuvre losses, machinery lubricant replacement and excavation soil not backfilled on site) and demolition.

After analysing different sources like the Mexico City Government CDW Standard (GODF, 2015), Mexican Federal Environmental Secretary Report (Medina Ross and Secretaría de Medio Ambiente y Recursos Naturales, 2001), and EU Waste Catalogue (Official Journal of the European Communities. & Commission Decision 2001/118/EC of wastes, 2001) to address CDW materials and their codification, it is decided to build an own classification and codification, according to Mexican regulations and following the systematic classification of the Andalusian Construction Costs Database (ACCD) as it has already shown its effectiveness since it was implemented (Barón et al., 2017). This codification allows identifying CDW from BCMs consumed in the construction process since they refer to the task, the type, and material resource where CDW comes from (Table 1).

BCMs transformation into CDW. The transformation coefficient (CR) measures the proportional part of a BCM that becomes CDW. This methodology called WTM, as mentioned in section 'Materials and methods', is based on the on-site

Table 1. WBS Codification: tasks, task types, BCMs and CDW.

Task		Task type					BCM				CDW								
Code	Description	Code	Description	Specifications	Quantity	Unit	Code	Description	Quantity	Unit	Code	Type	Quantity	Unit	CR	CC	CT	Quantity	Unit
X		XYZ00n					TUV				XYZ00n-TUV	BCM							
											XYZ00n-WWW	Pack							

Ref. CR, CC and CT = transformation coefficients, X = task alphabetical code.
XYZ00n = task type alphanumeric code, TUV = BCM alphabetical code, YZ00n-TUV = CDW alphanumeric code from BCM, XYZ00n-WWW = CDW alphanumeric code from BCM package.

Figure 3. CDW packages stored in the construction site.
Note: Steel, copper, plaster, cement-based coating and cement adhesive are grouped to facilitate the graphic reading just because they account for 1.04%.

CDW quantification from the selected 61 houses construction sites (Figure 3). This methodology also provided the basis for the EU 2030 Climate & Energy Framework (European Commission, 2016).

CDW not only includes BCMs but other materials as well. Package (plastic, board, paper, tins and others) becomes CDW even though it is not a constituent part of the building. Some material resources undergo physical or chemical changes from their initial state after their installation or use and may vary their properties like ceramic CDW, which increases its volume and changes its use. Likewise, formworks, struts and scaffolds end their life cycle after a certain number of uses and become CDW.

For the reasons explained above, it is necessary to apply indirect measurement methods to determine the CDW quantities from the material resources, following the mathematic model WTM (Mercader-Moyano and Ramírez-de-Arellano-Agudo, 2013) (equation (1)).

$$Q_t = \sum_{i}^{N} Q_i \times CR_i \times CC_i \times CT_1 \quad (1)$$

where Q_t is the CDW total quantity (tonne), N is the material resource/package index, Q_i is the quantity of material resource (tonne), CR_i is the transformation coefficient of the material resource that becomes CDW, CC_i is the CDW transformation coefficient from BCM unit to CDW unit and CT_i is the transformation coefficient from BCM measurement criterion to CDW criterion.

CR is directly measured at the construction place, while CC converts the material resource units to CDW units. Finally, CT converts the material resource measurement criterion to the CDW measurement criterion.

When applying equation (1) to this research, CC and CT coefficients are equal to 1 because CR is expressed in tonnes. Package CR coefficient is always equal to 1.

CDW normalised quantification. When comparing CDW quantification from different typologies or locations, it is necessary to normalise the quantification according to the corresponding built area (equation (2)).

$$Q_{tn} = \frac{Q_t}{built\,area} \quad (2)$$

where Q_{tn} is the normalised CDW weight per area (tonne m^{-2}), Q_t is the CDW total weight (tonne) and built area is the built area of the building/s (m^2).

Stage 3

In this stage, the methodological steps let build CDW environmental indicators

CDW characterization according to its destination. In Mexico, CDW may have four destinations: on-site reuse, on-site recycling, off-site recycling and landfill. Therefore, CDW types are characterised and quantified according to their destination. The Environmental Secretary of Mexico Federal District developed these indicators in 2013 and updated them in 2015 (GODF, 2015). This Standard compels the addition of reused or recycled materials to the executive project of a building if the second-use material is available within a 20-km distance from the building site (equation (3))

$$T = RU + RC_o + RC_a + D \quad (3)$$

where T is the CDW total quantity (tonne m^{-2}), RU is the CDW on-site reuse (tonne m^{-2}), RC_o is the CDW on-site recycled (tonne m^{-2}), RC_a is the CDW recycled in treatment plant (tonne m^{-2}), and D is the CDW sent to landfill (tonne m^{-2})

CDW environmental impact indicators. After CDW characterisation and quantification according to its destination, the next step is to calculate two environmental impact indicators according to CDW type: EE and CO_{2e} emissions, whose sources are the BEDEC database and Arguello Mendez et al. research because Mexico lacks of its own environmental impact database (Argüello Méndez and Cuchí Burgos, 2008; ITEC Instituto de la construcción de Catalunia, n.d.).

CDW environmental performance. Finally, a radial graphic synthesises the CDW environmental indicators from the executive project to assess the CDW environmental performance. It

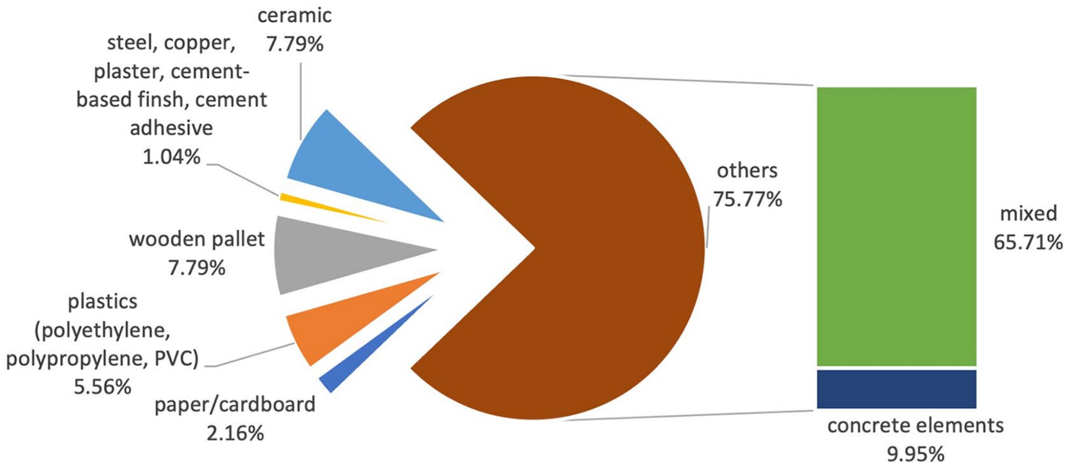

Figure 4. CDW percentages of the CCM.

intends to serve as a basis for CDW labelling from a circular economy framework. Furthermore, these indicators provide the CDW quantity and destination to orient CDW management public policies about the location, size, and type of treatment plants for reuse and recycle and landfills.

Results and discussion

The proposed methodology allows measuring the CCM material resources (Supplemental material Table B.3) and CDW produced at each stage of the building construction to obtain one CR coefficient for each BCM (Supplemental material Table B.4). The implementation of a 'hard' method of material tally during storage, installations or construction process and the CDW bucket and truck loads reckon complemented with a 'soft' method of on-site surveys provide reliable data on real cases. The application of the coefficients (CR, CT and CC) accounts for the total normalised weight of the case study: 0.083 tonne m^{-2}, without considering excavation soil (Supplemental material Table B.5) (Figure 4). CDW painting (6.02E−2) does not appear because it constitutes hazardous waste.

The obtained 38 CR coefficients may be added to the database developed in the CDW quantification methodology that has served as a basis for this research (Mercader-Moyano and Ramírez-de-Arellano-Agudo, 2013). Furthermore, this research not only validates its application to any other country but updates and complements the database with the addition of a multidimensional environmental impact label. It synthesises CDW environmental impact and destination for each executive project in a radial graphic to be a precedent for CDW environmental assessment labelling.

A Sankey diagram synthesises the material flows from their arrival to the construction site as far as their destination as CDW (Figure 5).

Concrete and cement-based materials account for the majority of the CCM resources provoking the largest amount of CDW; foundations, load bearing structure and walls. After adding mortars, they totalise 75.77% of CDW.

It can be observed that the CCM construction process is far from closing the material flow cycle. The CCM consumes 1.24 tonne m^{-2} and produces 0.083 tonne m^{-2} CDW, of which only a small amount is reintroduced as cement or lime packages. New construction materials only use raw materials, Mexican regulations compel neither manufacturers to add recycled steel or recycled inert aggregates nor constructors to use recycled materials if they are farther than 20 km from the construction site.

Notwithstanding, Mexican Federal District (F.D.) officials compel developers to provide a CDW management plan coordinated with transport service, in case that its amount overpasses 7 m^3, including authorised on-site storage places, and recycling plants, or landfills. Nevertheless, the National CDW Management Plan estimated that only 20% of CDW from public and private constructions ended in authorised places, 77% in backfills, landfills, soil remediation and road subsoils, and only 3% in recycling plants (Cámara Mexicana de la Industria de la Construcción, 2016; CDMX, 2019; Gobierno de México, 2015; GODF, 2015; Secretaría del Medio Ambiente, 2018, 2021).

This work may help organise on-site CDW storage places since the design stage calculating the CDW amount produced by task: foundations (19.78%), masonry (64.69%), roof (8.70%), finishes (6.39%) and sanitary, drainage, electric and glazing systems (0.44%), separating them according to destination: on-site re-use or recycling, recycling plant or landfill. Since CDW quantification lets know the environmental impact derived from the BCMs employed in the CCM, designers may substitute current construction materials for eco-efficient ones.

Polyethylene packaging constitutes a special case among other plastics because it accounts for more than a half of the CDW EE while polypropylene and PVC account for minimal quantities. Besides, it represents 71% of CDW CO_{2e} emissions and only 5% is recycled offsite. Mixed CDW constitutes

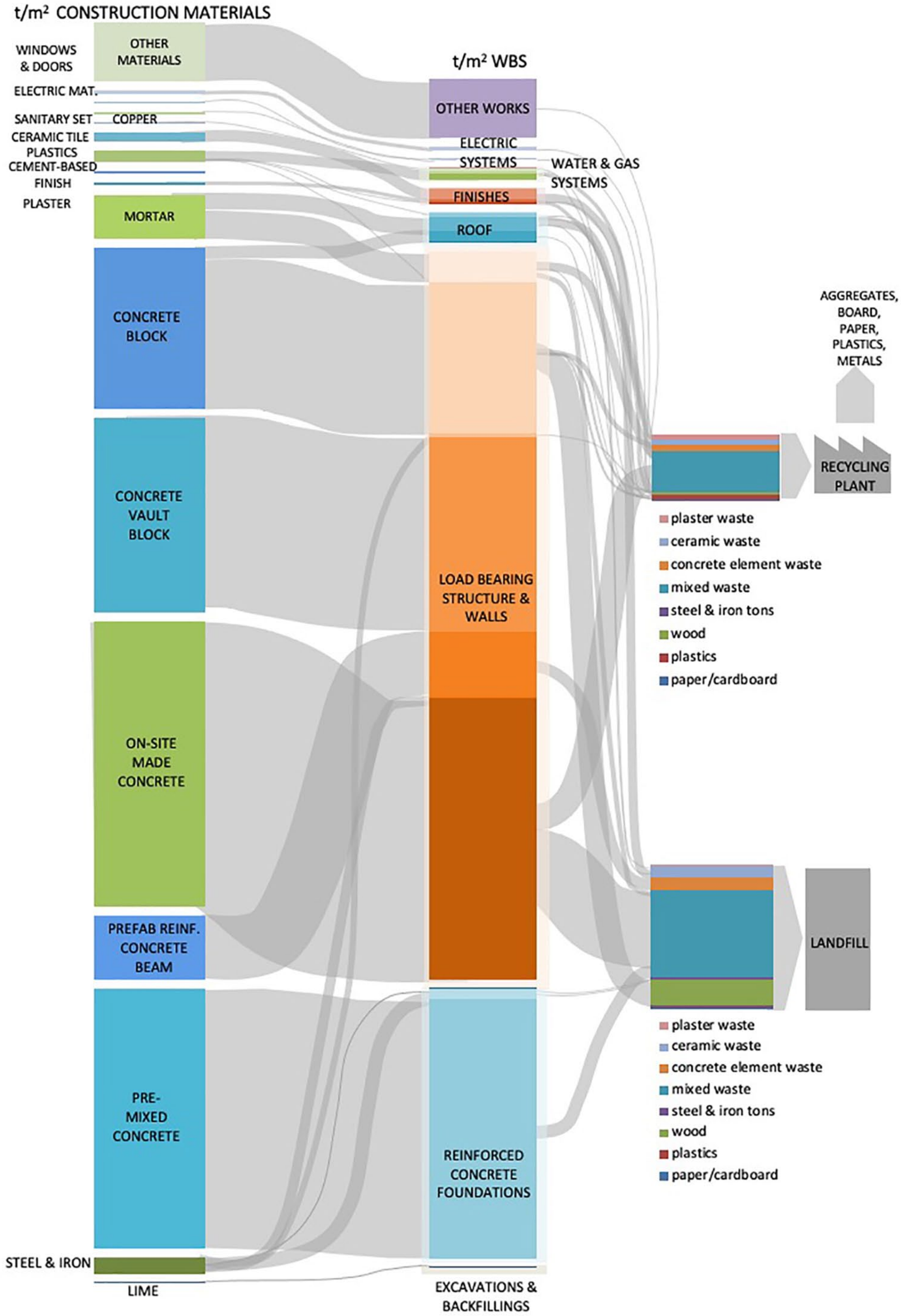

Figure 5. Sankey diagram: CCM construction materials and CDW.

43.60 kg m^{-2} of the total amount of CDW (65.1 kg m^{-2}) sent to landfills (Supplemental material Table B.5). Supplemental material Table B.6 shows CDW by type.

A radial diagram synthesises these data to characterise the executive project by its environmental indicators. They quantify CDW according to its destination: reused (RU), on-site recycle (RCo), off-site recycle (RCa), and landfill (D). RU, RCo, and RCa show values equal to 0, or negative if CDW is recycled. Instead, *D* is always positive because it accounts for CDW which ends its lifecycle in a landfill. CDW EE and CEs appear on the two other axes. As it happens with building energy labelling, colours indicate CDW environmental indicators performance that mean greater inefficiency from green to red. CDW sent to landfill (D) accounts for 69.20 kg m^{-2} while reused off-site CDW (RCa) comprehends 27.19 kg m^{-2} of inert soil and only 19.92 kg m^{-2} of other CDW (Figure 6).

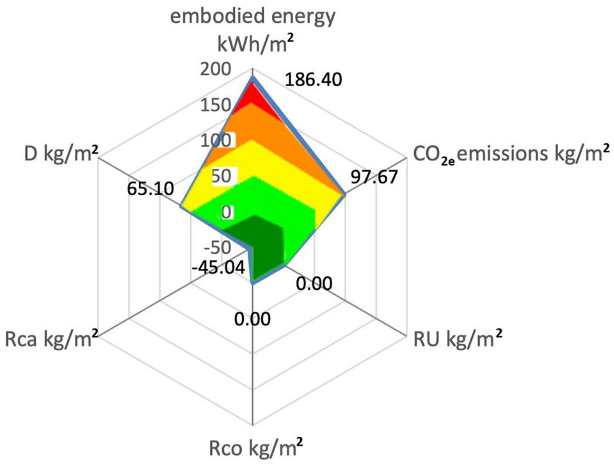

Figure 6. CDW environmental indicators of the CCM.

Results show that mixed CDW (mortar, on-site made concrete and concrete elements) accounts for the largest volume and weight. This waste could be grinded on-site to be used as inert aggregate for subsoils (Concretos Reciclados, n.d.) or to make on-site blocks (Yajnes et al., 2017). Nonetheless, many authors propose to use it as inert aggregate in prefabricated blocks (Luciano et al., 2021; Pacheco-Torgal, 2014; Rakhshan et al., 2020). These experimental materials represent a solution to make concrete blocks, but they still lack the required certification, dissemination and acceptance from users, developers and stakeholders (Molar-Orozco et al., 2020; Roux Gutierrez et al., 2015).

Iron and steel waste can be recycled to reduce its environmental impact and recover EE and CE from its production process. However, recycling cement-based products partially reduce their EI and CE because of low aggregate value by-products.

As this work has pointed out, Mexico still lacks mandatory CDW quantification and environmental impact assessment, so the proposed methodology is determinant to implement federal and state legislation for CDW recovery to reintroduce them in the productive chain and minimise those with low aggregated value that end in infrastructure work subsoil but mostly in landfills. These latter constitute air, water and earth polluters and infection foci because of different kinds of gases that increase global warming, and the proliferation of flora and fauna that rise public health costs (Gobierno de México, 2015).

Conclusion

This work proposes a methodology for CDW quantification and environmental characterization that not only considers CDW weight and volume but its physical or chemical transformation and the changes in its measurement criteria. It validates its results by contrasting CDW quantification at the executive project stage with the CDW amounts effectively measured on-site along the construction process. It is possible to apply the new coefficients to the Mexican CCM to foresee CDW types and quantities, and to plan its storage on-site, and CDW destination for reuse or recycle. This methodology may serve as a basis for the implementation of local and national regulations.

On the contrary, the lack of control of Mexican mandatory regulations makes that the most of CDW ends in illegal places, increasing environmental risks (Turcott Cervantes et al., 2021). These barriers require an integrated public policy plan to shift from a linear economic model towards a circular one that involves all the players, generates green jobs, environmental benefits and motorises the weak economy after the COVID19 pandemic. Notwithstanding, the authors find some limitations in this research: one is the dependence on staff collaboration for surveys, another one is the CDW real end because of the many illegal landfills. They may be solved with a kind of incentive to improve staff collaboration, and by strict monitoring to assure the data accuracy.

A future research line may expand the CR coefficient database with other building typologies, adding the CDW economic valorisation to implement business models to involve local resources, reduce import dependence on supplies, make the construction industry more resilient, and create new jobs. The estimation of CDW management costs from the executive project stage in social housing public procurement through a BIM model (Mercader-Moyano et al., 2019) would make mandatory a CDW management plan.

One of the CC and pandemic consequences will be the worsening of the already existing poverty and inequality in countries like Mexico (López-Feldman, 2014). A proper CDW management as part of a circular economy model reduces the increment of GHG emissions, contributes to climate change (CC) mitigation and improve public health by the eradication of open-air garbage dumps. Reuse and recycling may produce second-use materials that close the material flow loop and diminish the depletion of raw materials. Construction and operation of new facilities create employment, and workers training improves quality labour, especially in local communities favouring social inclusion and diminishing poverty.

The fall of raw material prices, the disruption of supply chains and the reduced investment that worsens liquidity might threaten the advances towards a circular model. However, the COVID-19 recovery would foster resilience, sustainability and inclusion if labour and capital resources underpin the circular economy transition agenda like recycling infrastructure instead of remaining idle in a low aggregate demand economy. This model improves the capital assets productivity, efficient production of materials and waste reduction expanding the resource base of the economy.

If the recycling process could be improved in quality and quantity, Mexico could gain new resources, independence from imports, new jobs and help meeting its CC goals. Better CDW waste management and recycling technologies, and design for recyclability may maintain the material value longer in the economic cycle (Klevnäs and Kulldorff, 2020; Tennakoon et al., 2021).

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship and/or publication of this article: This paper is funded by 'PROARID GREEN S.L'. for financial support via the research contract (68/83) ref.: 4115/0632. This research was also developed due to the financial support of the University of Seville (VI PPIT-US; 2.2.3. 2018 grants) for the research stay of Jesús López-López at University of Seville in Spain.

ORCID iD

Pilar Mercader-Moyano https://orcid.org/0000-0003-2180-4887

Supplemental material

Supplemental material for this article is available online.

References

Ajayi SO, Oyedele LO, Ceranic B, et al. (2015) Life cycle environmental performance of material specification: A BIM-enhanced comparative assessment. *International Journal of Sustainable Building Technology and Urban Development* 6: 14–24.

Akinade OO, Oyedele LO, Ajayi SO, et al. (2018) Designing out construction waste using BIM technology: Stakeholders' expectations for industry deployment. *Journal of Cleaner Production* 180: 375–385.

Alderete Herrera JCA (2010) VIVIENDA DE INTERÉS SOCIAL. *Universidad Veracruzana. Repositorio Institucional*, 5.

Aslam MS, Huang B and Cui L (2020) Review of construction and demolition waste management in China and USA. *Journal of Environmental Management* 264: 110445. https://doi.org/10.1016/j.jenvman.2020.110445

Araiza-Aguilar JA, Gutiérrez-Palacios C, Rojas-Valencia MN, et al. (2019) Selection of sites for the treatment and the final disposal of construction and demolition waste, using two approaches: An analysis for Mexico City. *Sustainability* 11: 4077.

Argüello Méndez TDR and Cuchí Burgos A (2008) Analysis of the environmental impact associated with the materials of construction used in the low cost houses of the program 10 x10 With Roof-Chiapas of the CYTED. *Informes de La Construcción* 60: 25–34.

Bakchan A, Faust KM and Leite F (2019) Seven-dimensional automated construction waste quantification and management framework: Integration with project and site planning. *Resources, Conservation and Recycling* 146: 462–474.

Barón J, Conde J, Osuna M, et al. (2017) *Consejería de Fomento y Vivienda / Vivienda y Rehabilitación / Base de Costes de la Construcción de Andalucía (BCCA) 29 abril 2016. Banco de precios*. Available at: https://www.juntadeandalucia.es/organismos/fomentoinfraestructurasyordenaciondelterritorio/areas/vivienda-rehabilitacion/planes-instrumentos/paginas/bcca-abr-2016.html

Blaisi NI (2019) Construction and demolition waste management in Saudi Arabia: Current practice and roadmap for sustainable management. *Journal of Cleaner Production* 221: 167–175.

BREEAM – Sustainability Assessment Method (2016) August 24. Available at: https://www.breeam.com/

Cámara Mexicana de la Industria de la Construcción. (2016) *Plan de Manejo de Residuos de la Construcción y la Demolición*. Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT). Available at: https://www.gob.mx/cms/uploads/attachment/file/190015/Plan_de_Manejo_de_Residuos_de_la_Construccion_y_la_Demolicion_de_la_CMIC.pdf

Carpio M, Roldán-Fontana J, Pacheco-Torres R, et al. (2016) Construction waste estimation depending on urban planning options in the design stage of residential buildings. *Construction and Building Materials* 113: 561–570. https://doi.org/10.1016/j.conbuildmat.2016.03.061

CDMX (2019) *Ahorrará Gobierno de la Ciudad de México para 2024, 8 mil 500 mdp con estrategia 'Basura Cero'*. CDMX. Available at: https://www.jefaturadegobierno.cdmx.gob.mx/comunicacion/nota/ahorrara-gobierno-de-la-ciudad-de-mexico-para-2024-8-mil-500-mdp-con-estrategia-basura-cero

Cha G-W, Moon HJ, Kim Y-C, et al. (2020) Evaluating recycling potential of demolition waste considering building structure types: A study in South Korea. *Journal of Cleaner Production* 256: 120385. https://doi.org/10.1016/j.jclepro.2020.120385

Cheng JCP and Ma LYH (2013) A BIM-based system for demolition and renovation waste estimation and planning. *Waste Management* 33: 1539–1551.

Cochran KM and Townsend TG (2010) Estimating construction and demolition debris generation using a materials flow analysis approach. *Waste Management* 30: 2247–2254.

Comisión Económica para América Latina y el Caribe (2020) *Contracción de la actividad económica de la región se profundiza a causa de la pandemia: Caerá -9,1% en 2020* [Text]. CEPAL. Available at: https://www.cepal.org/es/comunicados/contraccion-la-actividad-economica-la-region-se-profundiza-causa-la-pandemia-caera-91

Concretos Reciclados (n.d.) Available at: http://www.concretosreciclados.com.mx/#3

Consejo Nacional de Evaluación de la Política de Desarrollo Social (CONEVAL) (2020) *Informe de pobreza y evaluación 2018.* Coahuila. Available at: https://www.coneval.org.mx/coordinacion/entidades/Coahuila/Paginas/principal.aspx

de Guzmán Báez A, Villoria Sáez P, del Río Merino M, et al. (2012) Methodology for quantification of waste generated in Spanish railway construction works. *Waste Management* 32: 920–924. https://doi.org/10.1016/j.wasman.2012.01.007

Ding T and Xiao J (2014) Estimation of building-related construction and demolition waste in Shanghai. *Waste Management* 34: 2327–2334.

European Commission (2016) Marco sobre clima y energía *para 2030* [Text], 23 November. Acción Por El Clima – European Commission. Available at: https://ec.europa.eu/clima/policies/strategies/2030_es

European Commission (2018) *EU Construction and Demolition Waste Protocol and Guidelines*. Available at: https://ec.europa.eu/growth/content/eu-construction-and-demolition-waste-protocol-0_en

European Commission (2019) *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Comittee of the Regions on the implementation of the Circular Economy Action Plan*. European Commission. Available at: https://ec.europa.eu/commission/sites/beta-political/files/report_implementation_circular_economy_action_plan.pdf

European Commission (2020a) *Level(s) the European Framework for Sustainable Buildings*, October. Available at: https://ec.europa.eu/environment/topics/circular-economy/levels_en

European Commission (2020b) *A New Circular Economy Action Plan for a Cleaner and More Competitive Europe*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52019DC0190

European Environment Agency (2020) *Construction and Demolition Waste: Challenges and Opportunities in a Circular Economy*. Available at: https://www.eea.europa.eu/themes/waste/waste-management/construction-and-demolition-waste-challenges

Ge XJ, Livesey P, Wang J, et al. (2017) Deconstruction waste management through 3d reconstruction and bim: A case study. *Visualization in Engineering* 5: 13.

Ghosh A, Nundy S, Ghosh S, et al. (2020) Study of COVID-19 pandemic in London (UK) from urban context. *Cities* 106: 102928. https://doi.org/10.1016/j.cities.2020.102928

Gobierno de México (2015) *Informe de la Situación del Medio Ambiente en México*. Available at: https://apps1.semarnat.gob.mx:8443/dgeia/informe15/tema/cap7.html

Gobierno Federal de México (2016) *Código de Edificación de Vivienda 2010*. Comisión Nacional de Vivienda (CONAVI). Available at: https://www.cmic.org.mx/comisiones/Sectoriales/vivienda/2016/BIBLIOTECA/CEV%20PDF.pdf

GODF (2015) *Norma Ambiental para el Distrito Federal NADF-007-RNAT-2013, que establece la clasificación y especificaciones de manejo* *para residuos de la construcción y demolición, en el Distrito Federal; actualizada el 26 de febrero de 2015. Gaceta Oficial del Distrito Federal*. Secretaría de Medio Ambiente. Available at: https://www.cmic.org.mx/comisiones/Sectoriales/medioambiente/PROY-NADF-007-RNAT-2013/Gaceta_DF_NADF-007-RNAT-2013.pdf

Guerra BC, Bakchan A, Leite F, et al. (2019) BIM-based automated construction waste estimation algorithms: The case of concrete and drywall waste streams. *Waste Management* 87: 825–832.

Hendriks CF (ed.) (2000) *Sustainable Raw Materials: Construction and Demolition Waste*. Cedex: RILEM Publication.

Hyman M, Turner B, Carpintero A, et al. (2015) *Guidelines for National Waste Management Strategies: Moving from Challenges to Opportunities*. Available at: https://cwm.unitar.org/national-profiles/publications/cw/wm/UNEP_UNITAR_NWMS_English.pdf

ISO (2015) *ISO 14001:2015(en), Environmental Management Systems – Requirements with Guidance for Use*. Available at: https://www.iso.org/obp/ui/#iso:std:iso:14001:ed-3:v1:en

ITEC Instituto de la construcción de Catalunia (n.d.) Información ambiental de productos y sistemas. Available at: https://itec.es/metabase/productos-sostenibles/0/0/0/

Jaillon L, Poon CS and Chiang YH (2009) Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong. *Waste Management* 29: 309–320

Jalaei F and Jrade A (2015) Integrating building information modeling (BIM) and LEED system at the conceptual design stage of sustainable buildings. *Sustainable Cities and Society* 18: 95–107.

Jefatura de Gobierno (2011) Ley 22/2011 Residuos y Suelos Contaminados. Gobierno de España. Available at: https://www.boe.es/eli/es/l/2011/07/28/22/con

Jiménez Rivero A, Sathre R and García Navarro J (2016) Life cycle energy and material flow implications of gypsum plasterboard recycling in the European Union. *Resources, Conservation and Recycling* 108: 171–181.

Kartam N, Al-Mutairi N, Al-Ghusain I, et al. (2004) Environmental management of construction and demolition waste in Kuwait. *Waste Management* 24: 1049–1059.

Kleemann F, Lehner H, Szczypińska A, et al. (2017) Using change detection data to assess amount and composition of demolition waste from buildings in Vienna. *Resources, Conservation and Recycling* 123: 37–46.

Klevnäs P and Kulldorff A (2020) The circular economy and covid-19 recovery how pursuing a circular future for Europe fits with recovery from the economic crisis. *Material Economics*. https://materialeconomics.com/publications/publication/circular-recovery

LEED v4.1| U.S. Green Building Council (2021) Available at: https://www.usgbc.org/leed/v41?creative=340432208133&keyword=leed%20certification&matchtype=b&network=g&device=c&gclid=CjwKCAjwsNiIBhBdEiwAJK4khiPEokm9zsmKDwOvFcrKAmG_IL7nilCWW_05EsakHcjzSiQ5-tzppBoCI-IQAvD_BwE

Li CZ, Zhao Y, Xiao B, et al. (2020) Research trend of the application of information technologies in construction and demolition waste management. *Journal of Cleaner Production* 263: 121458.

Li J, Ding Z, Mi X, et al. (2013) A model for estimating construction waste generation index for building project in China. *Resources, Conservation and Recycling* 74: 20–26.

Li Y, Zhang X, Ding G, et al. (2016) Developing a quantitative construction waste estimation model for building construction projects. *Resources, Conservation and Recycling* 106: 9–20.

Liu H, Sydora C, Altaf MS, et al. (2019) Towards sustainable construction: BIM-enabled design and planning of roof sheathing installation for prefabricated buildings. *Journal of Cleaner Production* 235: 1189–1201.

Liu Z, Osmani M, Demian P, et al. (2015) A BIM-aided construction waste minimisation framework. *Automation in Construction* 59: 1–23.

López-Feldman A (2014) *Cambio climático, distribución del ingreso y la pobreza. El caso de México (Estudios Del Cambio Climático En América Latina)*. Comisión Económica para América Latina y el Caribe (CEPAL). Available at: https://repositorio.cepal.org/bitstream/handle/11362/36777/1/S2013710_es.pdf

López-López J (2019) *Caracterización de los residuos de la construcción de la vivienda en México. Un modelo teórico*. Universidad de Sevilla. Available at: https://idus.us.es/handle/11441/89386

López-Mesa B, Pitarch Á, Tomás A, et al. (2009) Comparison of environmental impacts of building structures with in situ cast floors and with precast concrete floors. *Building and Environment* 44: 699–712.

Lu W, Chen X, Peng Y, et al. (2015) Benchmarking construction waste management performance using big data. *Resources, Conservation and Recycling* 105: 49–58.

Luciano A, Cutaia L, Cioffi F, et al. (2021) Demolition and construction recycling unified management: The DECORUM platform for improvement of resource efficiency in the construction sector. *Environmental Science and Pollution Research* 28: 24558–24569.

Matthew RA and McDonald B (2006) Cities under Siege: Urban Planning and the Threat of Infectious Disease. *Journal of the American Planning Association* 72(1): 109–117. https://doi.org/10.1080/01944360608976728

Medina Ross J & Secretaría de Medio Ambiente y Recursos Naturales (2001) *Minimización y manejo ambiental de los residuos sólidos*. Secretaría de Medio Ambiente y Recursos Naturales. Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiBqvTZ0cLxAhUXrJUCHTWdDo4QFjAAegQICBAD&url=http%3A%2F%2Fwww.ingenieroambiental.com%2F4014%2Fminimiza6.pdf&usg=AOvVaw3ltvZNbolnRQZ-jk16jw-o

Mercader-Moyano M, del P, Camporeale PE, et al. (2019) Evaluación de impacto ambiental mediante la introducción de indicadores a un modelo BIM de vivienda social. *Revista Hábitat Sustentable* 9: 78–93.

Mercader-Moyano P and Ramírez-de-Arellano-Agudo A (2013) Selective classification and quantification model of C&D waste from material resources consumed in residential building construction. *Waste Management & Research: The Journal for a Sustainable Circular Economy* 31: 458–474.

Miatto A, Schandl H, Forlin L, et al. (2019) A spatial analysis of material stock accumulation and demolition waste potential of buildings: A case study of Padua. *Resources, Conservation and Recycling* 142: 245–256.

Ministerio de Agricultura, Alimentación y Medio Ambiente. (2015a). Real Decreto 180/2015 Traslado de residuos en el interior del territorio del Estado. Gobierno de España. https://www.boe.es/eli/es/rd/2015/03/13/180

Ministerio de Agricultura, Alimentación y Medio Ambiente. (2015b). Plan Estatal Marco de Gestión de Residuos (PEMAR) 2016-2022. Gobierno de España. https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/planes-y-estrategias/Planes-y-Programas.aspx

Ministerio de la Presidencia. (2008). Real Decreto 105/2008. La producción y gestión de los residuos de construcción y demolición. Gobierno de España. https://www.boe.es/buscar/act.php?id=BOE-A-2008-2486

Molar-Orozco ME, Velázquez-Lozano J and Vázquez-Jiménez MG (2020) Comportamiento térmico de tres prototipos en Saltillo, Coahuila (bloques de tierra, concreto y tapa de huevo). *Revista Hábitat Sustentable* 10: 22–31.

OECD (2019) *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*. OECD. Available at: https://doi.org/10.1787/9789264307452-en

OECD (2020) *OECD Economic Outlook, Volume 2020 Issue 1, OECD Publishing, Paris*. Available at: https://doi.org/10.1787/0d1d1e2e-en

Official Journal of the European Communities. Commission Decision 2001/118/EC of wastes (2001) *European Waste Catalogue*.

Pacheco-Torgal F (2014) Eco-efficient construction and building materials research under the EU Framework Programme Horizon 2020. *Construction and Building Materials* 51: 151–162.

Parisi Kern A, Ferreira Dias M, Piva Kulakowski M, et al. (2015) Waste generated in high-rise buildings construction: A quantification model based on statistical multiple regression. *Waste Management* 39: 35–44.

Park JW, Cha GW, Hong WH, et al. (2014) *A Study on the Establishment of Demolition Waste DB System by BIM-based Building Materials*. Applied Mechanics and Materials; Trans Tech Publications Ltd. Available at: https://doi.org/10.4028/www.scientific.net/AMM.522-524.806

Procuraduría Federal de Protección al Ambiente (2014) *Norma Oficial Mexicana NOM-161-SEMARNAT-2011*. Gobierno de Mexico. Available at: http://dof.gob.mx/nota_detalle.php?codigo=5286505&fecha=01/02/2013

Rakhshan K, Morel J-C, Alaka H, et al. (2020) Components reuse in the building sector – A systematic review. *Waste Management & Research: The Journal for a Sustainable Circular Economy* 38: 347–370.

Ramírez de Arellano Agudo A (2002) Retirada selectiva de residuos: Modelo de presupuestación. Colegio Oficial de Aparejadores y Arquitectos Técnicos de Sevilla.

Ram V and Kalidindi SN (2017) Estimation of construction and demolition waste using waste generation rates in Chennai, India. *Waste Management & Research: The Journal for a Sustainable Circular Economy* 35: 610–617.

Ríos O (2019) *Instituto de ecologia*. Instituto de Ecología UNAM. Available at: http://www.ecologia.unam.mx/web/index.php?option=com_content&view=article&id=193

Roux Gutierrez RS, García Izaguirre VM and Espuna Mujica JA (2015) Los materiales alternativos estabilizados y su impacto ambiental. *Nova scientia* 7: 243–266.

Sánchez-Corral J (2013) *La vivienda 'social' en México pasado, presente, futuro?* Sistema Nacional de Creadores de Arte- JSE. Available at: http://conurbamx.com/home/la-vivienda-social-en-mexico/

Secretaría de Medio Ambiente y Recursos Naturales (2010) *Estudio de análisis, evaluación y definición de estrategias de solución de la corriente de residuos generada por las actividades de construcción en México*. Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). Available at: http://www.semarnat.gob.mx/gobmx/biblioteca/index.html

Secretaría del medio ambiente (2018) *Norma ambiental para el D.F. NADF-024-AMBT-2013, que establece los criterios y especificaciones técnicas bajo las cuales se deberá realizar la separación, clasificación, recolección selectiva y almacenamiento de los residuos del Distrito Federal*. Gaceta oficial del Distrito Federal. Available at: https://coprocesamiento.org/wp-content/uploads/2019/05/NADF-024-AMBT-2013.pdf

Secretaría del Medio Ambiente (2021) *En marcha, Basura Cero en la Ciudad de México*. Secretaría del Medio Ambiente. Available at: https://sedema.cdmx.gob.mx/comunicacion/nota/en-marcha-basura-cero-en-la-ciudad-de-mexico

Tanikawa H and Hashimoto S (2009) Urban stock over time: Spatial material stock analysis using 4d-GIS. *Building Research & Information* 37: 483–502. https://doi.org/10.1080/09613210903169394

Turcott Cervantes DE, Romero EO, del Consuelo Hernández Berriel M, et al. (2021) Assessment of some governance aspects in waste management systems: A case study in Mexican municipalities. *Journal of Cleaner Production* 278: 123320.

United Nations Environment Programme (2018) Waste Management Outlook for Latin America and the Caribbean. Latin America and the Caribbean Office. Available at: https://www.unenvironment.org/ietc/resources/publication/waste-management-outlook-latin-america-and-caribbean

U.S. Environmental Protection Agency (2020) *Advancing Sustainable Materials Management: 2018 Fact Sheet. Assessing Trends in Materials Generation and Management in the United States*. Available at: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/advancing-sustainable-materials-management

Villoria Sáez P, Santa Cruz Astorqui J, del Río Merino M, et al. (2018) Estimation of construction and demolition waste in building energy efficiency retrofitting works of the vertical envelope. *Journal of Cleaner Production* 172: 2978–2985. https://doi.org/10.1016/j.jclepro.2017.11.113

Won J and Cheng JCP (2017) Identifying potential opportunities of building information modeling for construction and demolition waste management and minimization. *Automation in Construction* 79: 3–18.

World Bank (2020) *Global Economic Prospects, June 2020*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1553-9

Wu H, Duan H, Zheng L, et al. (2016) Demolition waste generation and recycling potentials in a rapidly developing flagship megacity of South China: Prospective scenarios and implications. *Construction and Building Materials* 113: 1007–1016.

Wu H, Zuo J, Zillante G, et al. (2019a) Status quo and future directions of construction and demolition waste research: A critical review. *Journal of Cleaner Production* 240: 118163. https://doi.org/10.1016/j.jclepro.2019.118163

Wu Z, Yu ATW and Poon CS (2019b) An off-site snapshot methodology for estimating building construction waste composition – A case study of Hong Kong. *Environmental Impact Assessment Review* 77: 128–135.

Yajnes M, Caruso S, Kozak D, et al. (2017) Gestión de residuos y producción de bloques con material reciclado in situ en una obra de escala intermedia en la ciudad de Buenos Aires, Argentina. In: *3er Congreso Internacional de Construcción Sostenible y Soluciones Eco-Eficientes*, pp.1035–1059. Available at: https://idus.us.es/handle/11441/80933?

Yuan H (2017) Barriers and countermeasures for managing construction and demolition waste: A case of Shenzhen in China. *Journal of Cleaner Production* 157: 84–93.

Zahradnik P, Palmieri S, and Dirx J (2020) Resolución sobre las propuestas del CESE para la reconstrucción y la recuperación tras la crisis de la COVID-19. Diario Oficial de la Unión Europea. https://www.boe.es/doue/2020/311/Z00001-00018.pdf

Zaman AU and Lehmann S (2013) The zero waste index: A performance measurement tool for waste management systems in a 'zero waste city'. *Journal of Cleaner Production* 50: 123–132.