An Environmental Construction and Demolition Waste Management Model to Trigger Post-pandemic Economic Recovery Towards a Circular Economy: The Mexican and Spanish Cases

Pilar Mercader-Moyano, Jesús López-López, and Patricia Edith Camporeale

Abstract The Architecture, Engineering and Construction (AEC) industry consume 40% of raw material generating 35% of industrial waste worldwide. In the EU, it consumes 50% of raw material and generates 35% of industrial waste; while in the USA, 22% of 600 million tons of Construction and Demolition Waste (CDW) were recycled into new products: 52% as aggregates but 24% ended in landfills, in 2020. A transition to a circular economy may trigger post-COVID-19 economic recovery. Thus, the EU promotes it through the EU Green Deal, Renovation Wave and Circular Economy Action Plan. This work applies the Spanish CDW "weighted transfer of measurement" current model to broaden its construction material database and to add environmental indicators. Latin America has the world's highest urbanization rate (84%) but lacks effective CDW management to thrive in Regenerative Sustainability, Climate Change mitigation and post-pandemic economic recovery. This research quantifies onsite 61 Mexican social housing CDW, comparing both countries' results. Mexico consumes 1.24 ton m^{-2} of raw materials and produces 0.083 ton m^{-2} CDW with a 16% recycling rate, while Spain consumes 1.90 ton m^{-2} and produces 0.08 ton m^{-2} with a 75% recycling rate. Cement-based, ceramic and mixed CDW represent 83.44% for Mexico and 95.61% for Spain. The implementation of this methodology will deliver sustainable CDW management in Mexico, minimizing CDW production, by the replacement of current construction materials for eco-efficient ones and the promotion of related legislation. Moreover, this updated

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transformation coefficient database widens the Spanish model to an international scale.

Keywords Building sector circular economy · CDW environmental footprint assessment · CDW quantification · Post-pandemic economic recovery · CDW executive project indicators

1 Introduction

Buildings consume 40% of natural resources and primary energy worldwide (López-Mesa et al. 2009) while the AEC industry generates 35% of the industrial waste (Hendriks 2000) and 36% of Greenhouse Gas (GHG) Emissions. Only in the EU, the AEC industry represents 10% of GDP, consumes 50% of natural resources and 40% of primary energy and generate 35% of CDW. The carbon footprint accounts for 30% of the total but if construction materials had a more efficient use they could decrease 80% (Da Costa-Gómez 2020; Mercader Moyano 2010).

In the EU, CDW represents the largest flow in terms of mass: 1/3 of 3 billion tons annually, being this quantity relatively stable. This sector seems to be economically circular as it avoids landfills and incineration. However, CDW recycling mainly orients to backfilling with a low grade of recovery like recycled aggregates used in road subsoil, reducing its potential towards circular CWD management (European Commission 2018). Spain is the 7° EU country in the CDW production ranking: 138 million tons generated during 2018 with a 75% recycling rate (Eurostat 2020a) while the European average was 90% (Eurostat 2020b).

However, CDW is not suitable for reuse or recycling because of old construction techniques that prevent high purity raw material recovery during demolition or refurbishment. It could be possible to prevent CDW augment and achieve a better recycling process if prices became competitive, second-use materials were reliable and material data from existing buildings were available. Notwithstanding, the decades between the construction period and CDW management at the demolition or refurbishment stages constitute another barrier (European Environment Agency 2020).

COVID-19, declared a pandemic by the World Health Organization (WHO), provoked a sanitary crisis triggering the economy to the lowest activity level since 2009: GDP fell 1.674% worldwide (OECD 2020; World Bank 2020). Raw material and oil prices fall have become a barrier to these initiatives: idle assets, disruptions in supply chains, uncertainty in availability and price volatility add other barriers to the circular transition (Fig. 1).

However, the circular economy path to achieve decarbonized cities, energy poverty reduction and socioeconomic sustainability like the EU Circular Economy Action Plan (European Commission 2019), the "Renovation Wave" and the "Green Deal" (European Commission 2020a) show strong affinity to EU strategic priorities to economic recovery. These new business models activate local resources, reduce import dependence, diversify supplies to increase resilience and make create

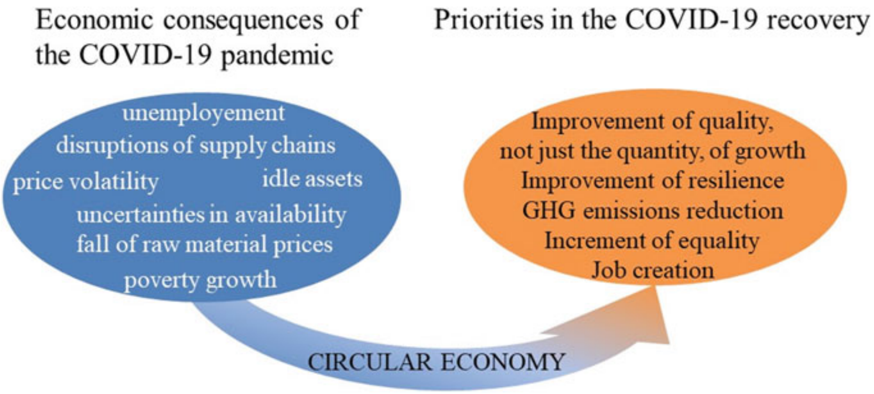


Fig. 1 The shift from the linear to the circular economy trigger post-pandemic recovery. *Source* The authors

650,000–700,000 jobs by 2030. The reduction of cost mobility and food benefits low-income households, promoting equality. In addition, circular economy contributes to achieving carbon neutrality with a nearly 300 million tons annual reduction (almost 50%) by 2050.

Furthermore, the EU Social and Economic Committee identifies the building sector as the main actor to promote European recovery after the COVID19 crisis because of the intensive use of labour in the AEC industry, mainly in the hands of local companies (Zahradnik et al. 2020). In Spain, the building energy retrofit plan manages a € 300 million budget provided by the National Fund for Energy Efficiency and EU Funds for the Spanish COVID economic recovery. That will generate around 48,000 jobs annually in the next nine years (Gobierno de España 2020); these funds will help the most vulnerable groups make the necessary housing retrofit including active or passive HVAC-SDHW systems. As a matter of fact, the circular economy promotes the 7 Rs: redesign, reduce, reuse, repair, renovate, recover and recycle (European Commission 2020b), making EU compel the standardization of second-use materials and its dissemination among stakeholders to reduce CDW production and acquire a better and higher recycling quality (European Commission 2020a). European Commission has issued 54 measures to apply along the construction material lifecycle in five prior sectors that comprehend construction and demolition. Some of them are the CDW Protocol and Guidelines (European Commission 2018) that improves the reliance on recycled products, Level(s) that provides an assessment and reporting framework to promote a lifecycle approach for residential and office buildings, one-use plastic ban, critical raw material reuse/recycling, eco-design, eco-labelling to favour spare parts availability for repair, waste treatment at the end of the lifecycle and packaging reuse/recycling (European Commission 2020c).

Nevertheless, after the 2008 crisis when Spanish regulations promoted building retrofit, they did not care about CDW plastic insulation material management. Consequently, in 2010, 10% of CDW (860 million tons) came from plastic materials apart from those typically associated, whose environmental footprint remains disregarded (Villoria Sáez et al. 2018) and provoked the failure to achieve the 70% CDW recycling rate (European Commission 2008; Ministerio de la Presidencia 2008). Since EU Directives guide EU members' regulations, Spain updated CDW management through the Spanish Strategy on Circular Economy 2030 (Jefatura de Gobierno 2011; Ministerio de Agricultura, Alimentación y Medio Ambiente 2015a, b; Ministerio de la Presidencia 2008). Furthermore, Spain intends to achieve a sustainable, decarbonized, resource-efficient and competitive economy consisting of six goals for 2030: five of them are directly or indirectly related to CDW management: 15% CDW reduction, 30% of raw materials, as well as CO_2e emissions reduction to less than 10 million annual tons because of the construction material reuse.

The situation is quite different In Latin America and the Caribbean; this region presents the highest urbanization rate worldwide (84%), where 32% of the total population lives in cities of more than 1 million people that accounts for 40% of the global urban population. Municipal solid waste (MSW) including CDW collection leaves aside 7% of marginal and rural people (40 million) that produce 35,000 tons daily (United Nations Environment Programme 2018). Moreover, 60% of MSW (145,000 tons daily) ends in landfills, some of which have acquired international standards as authorized places being most of them only "supervised landfills". In the case of Mexico City, which has got only two authorized landfills, the city government has launched the Zero Waste Plan to reduce the 8600 tons sent to landfills to 2000 tons by 2024, from a current amount of 16,000 daily tons (CDMX 2019; Ríos 2019). In Mexico, CDW accounts for 6.7% of GDP, generated approximately 5.6 million jobs (Cámara Mexicana de la Industria de la Construcción 2016) without including CDW due to natural disasters (earthquakes) (Araiza-Aguilar et al. 2019). Mexico, which is the second regional economy and the 15th globally, had a poverty rate of 48.8% in 2018 (61.1 million people) that will increase to 66.9%, becoming the 4th poorest regional country with a GDP fall of 8.6% (Comisión Económica para América Latina y el Caribe 2020; Consejo Nacional de Evaluación de la Política de Desarrollo Social 2018). As a consequence, high residential density and large population make cities most vulnerable to infectious disease outbreaks (Ghosh et al. 2020; Matthew and McDonald 2006), especially in the case of Mexico cities as mentioned above.

CDW quantification is the first step for CDW management policies to promote circular economy as a trigger for economic recovery. Many CDW quantification methodologies depend on local goals and scenarios, which could vary according to population augment, legislation, planning and the AEC industry (Jin et al. 2019; Wu et al. 2014). CDW quantity and quality depend on construction systems and materials, building typologies, age and demolition techniques (Menegaki and Damigos 2018). Additionally, CDW management plans are mandatory in many countries, requiring CDW selection, collection and transport to treatment plants or landfills, controlled by audits (Kabirifar et al. 2020). The increment of the AEC industry activity in developed and developing countries motivates the comparison of CDW management in different scenarios such as the EU, USA and China, recommending the adoption of emergent technologies, onsite 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 (Table 2 in Appendix 1) that include material flow analysis, direct and indirect onsite and offsite CDW quantification, CDW track load counts to treatment plants or landfills, surveys to workers, recyclers and government officials to follow CDW from origin to end and executive project plans consulting among others.

For instance, Mercader et al. quantify CDW from 10 social housing blocks, following the work breakdown structure of the Andalusian Construction Cost Database (BCCA) and the Royal Decree 105/2008 about CDW management in Spain (Barón et al. 2017; Mercader-Moyano and Ramírez-de-Arellano-Agudo 2013; Ministerio de la Presidencia 2008). This methodology quantifies CDW as the portion of the resource material that become waste during the construction process by transformation coefficients that, unlike others, calculate CDW weight and volume, allowing to measure, for instance, soil swelling.

On the other hand, some authors use municipal statistical data based on demolition permissions combined with GIS data about building area, volume, age and typology (Kleemann et al. 2017). Building Information Modelling is a platform where CDW quantification methodologies proliferate, providing several data sources for CDW production and involving stakeholders, designers and decision-makers to plan from design and procurement documentation to construction and demolition stages (Akinade et al. 2018; Cheng and Ma 2013; Liu et al. 2019; Won and Cheng 2017; Xu et al. 2019). Mercader Moyano et al. develop a quantification method for construction materials and CDW measuring their embodied energy and carbon emissions from cradle to the end of the construction stage and calculating indicators based on the BCCA work breakdown structure (Mercader Moyano et al. 2019). Many other authors develop CDW quantification methods using BIM tools (Bakchan et al. 2019; Ge et al. 2017; Guerra et al. 2019) and GIS data (Li et al. 2020; Miatto et al. 2019; Park et al. 2014; Tanikawa and Hashimoto 2009). Other authors link BIM with life cycle assessment (LCA) for CDW quantification (Jalaei et al. 2019). Likewise, LCA has provided a versatile tool to assess CDW from a circular economy framework (Jiménez Rivero et al. 2016; Luciano et al. 2018).

In Mexico, CDW quantification follows a methodology that considers the construction material purchases with a CDW production coefficient $= 0.3\ \text{m}^3\ \text{m}^{-2}$ and another one to convert volume to weight $= 1.5$ ton m^{-3}, referred to research from the USA and Europe. The composition of CDW consisted in the observation and measure of truckloads sent to a landfill in Mexico Federal District (Secretaría de Medio Ambiente y Recursos Naturales 2010). In the commitment of 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 measurement and onsite selection. This report estimated that 6.08 million tons generated in

2011 would reach 9.2 million tons in 2018, with a rise of 3.5% of the AEC industry activity. CDW composition consists 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 the CDW circular economy, increasing Mexican GDP and offering an exit to the post-COVID crisis from the AEC industry.

This paper aims to develop a CDW management methodology through the transformation coefficient calculation of each construction material that becomes CDW, followed by its environmental footprint to quantify them from the design stage. This methodology, applied to social housing in Mexico, was developed and successfully implemented by the authors, giving rise to municipal regulations associated with the Andalusian Construction Costs Database and BIM software in Spain. Since current coefficients used in Mexico have failed to succeed because they base on foreign models, this methodology adapted to the Mexican scenario delivers data from onsite CDW quantification and user surveys after auditing 61 single-family housing over five years. This work will be the first step to help CDW management policies and municipal regulations to predict CDW production and promote reusing and-or recycling to minimize raw materials consumption. Furthermore, the environmental footprint addition to the original Spanish methodology accomplishes the EU Circular Economy Action Plan requirements (European Commission 2020b).

2 Objective and Methodology

The methodology consists of three stages that satisfy the objectives of the main scope that was mentioned above. In the first stage, the definition of the housing conventional construction model (CCM) requires establishing the typology features, select a representative sample and quantify the material resources consumed in the construction process. In the second stage, the CDW quantification requires its identification and characterization and the calculation of the transformation coefficients from the onsite measurement and surveys. In the third stage, CDW embodied energy (EE) and CO2e emissions combined with CDW destination characterize the CDW to assess its environmental footprint (Fig. 2).

This methodology applies the Spanish CDW methodology, which uses the weighted transfer of measurement (WTM) to identify and quantify CDW generated from the consumed material resources of the social housing CCM studied over ten years and developed by Mercader-Moyano and Ramírez-de-Arellano-Agudo (2013). It has also provided the basis for new CDW municipal regulations in Andalusia and Madrid (Ramírez de Arellano Agudo 2014). In this way, this work adds new CDW transformation coefficients and environmental footprint assessment to favour the transition from a linear economy model to a circular one. Consequently, CDW can be reintroduced into the economic cycle as reused, recycled and by-products.

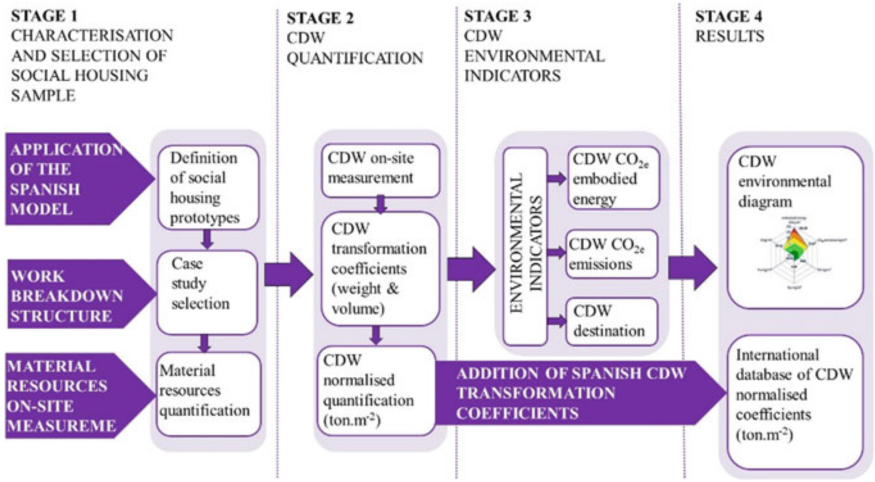


Fig. 2 Methodological framework and stages. *Source* The authors

3 Materials and Methods

The methodology is divided into three stages.

3.1 *First Stage: Characterization and Selection of Social Housing Sample*

Mexican social housing presents a built area between 42 and 76 m^2. On the other hand, the Building Code (CONAVI) states a lower size for them that includes a kitchen-dining room, one or two bedrooms, one bathroom, one parking space and basic services, considering that one family can satisfy all their needs there (Alderete Herrera 2010; Gobierno Federal de México 2016). Building materials and systems changed along with the evolution of the social housing in Mexico, so this work comprehends cases that are not more than 10-years-old to avoid referring to extinguished processes and materials. The CCM consists of reinforced concrete foundation slab and pillars, concrete block walls, reinforced concrete vault blocks and prefabricated beams, outer cement-based finish, inner plaster finish, ceramic floors, single-pane glazing with aluminium frame and wooden doors with aluminium frame (López-López 2019). In the ‘70s and ‘80s, several companies begin to build social housing neighbourhoods for low-income populations in urban outskirts; they comprehend one/two-story houses with a rigid scheme that do not respond to the household changing needs along their life cycle (Sánchez-Corral 2013).

The sample locates in Saltillo City, the capital district of Coahuila State, in Northern Mexico, next to the USA 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, 27% of which (around 807,000 people) were distributed 90% in urban areas and 10% in rural areas, with a poverty rate of 61.1% (Consejo Nacional de Evaluación de la Política de Desarrollo Social (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 AEC industry (Fig. 3).

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 onsite surveys to supervisors and workers have shown (Figs. 4 and 5). During the last decade, the MCC morphology, construction systems and materials have been standardized by the different building companies in Saltillo, building nearly identical prototypes. The three main companies situated in SE Coahuila: DAVISA, RUBA and SERVER, produce the prototypes between 46 and 52.13 m^2 that are the basis for this investigation.

The BMCs list utilizes a material take-off (MTO) whose data sources are 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)

Fig. 3 Saltillo City location in Coahuila State, Mexico. *Source* Modified from López-López (2019)

Fig. 4 Social housing under construction. *Source* The authors

Fig. 5 Inner plaster finish and reinforced concrete vault block concrete slab. *Source* The authors

and 42 m^2 (from CONAVI prescriptions) that accounts for 49.4 m^2 with 90% confidence interval and 10% error in regard to the mortgages delivered in Saltillo during 2016 (López-López 2019) (Table 3 in Appendix 2).

The first step consists of a social housing historic and evolution approach to find the referential places in Saltillo City. After selecting the sample, 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.

When 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 (BOQ) 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

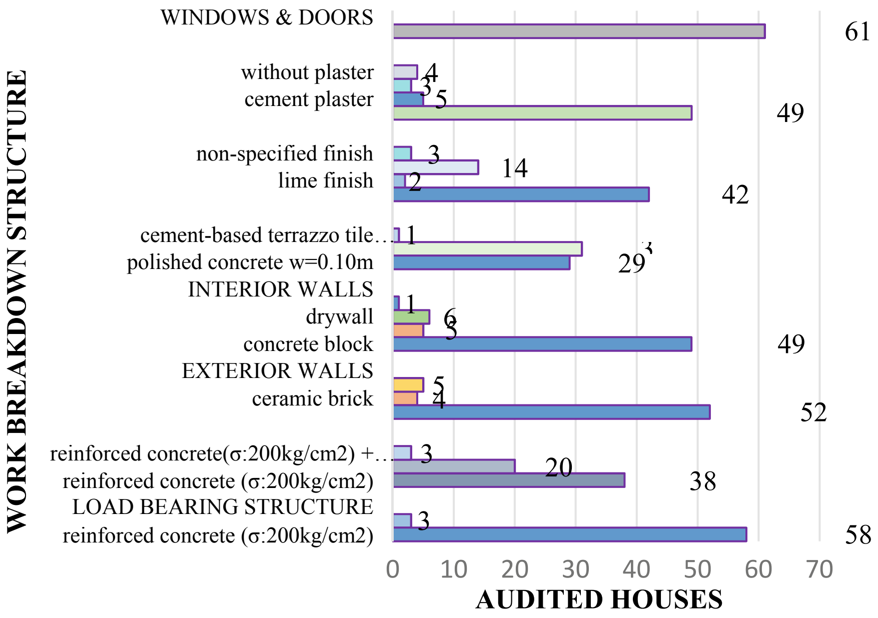


Fig. 6 CCM material resource consumption of the 61-house sample. *Source* The authors

3-letter code (TUV) (Table 4). The quantification of BMCs consumed in the sample construction uses kg m^{-2} units (Fig. 6; Table 5).

3.2 *CDW Quantification*

In this stage, the methodological steps let the CDW quantification through the transformation coefficients. From the onsite observation, it is possible to detect four steps of CDW production:

- Product delivery: deficient quality, download breaks, unproperly atmospheric conditions
- Storage: expired storage time, material breaks, package waste
- Construction tasks: internal transport breaks, mortar/concrete remains, material trimmings, badly executed works demolition, incorrect manoeuvre losses, machinery lubricant replacement, excavation soil not backfilled onsite
- Demolition waste.

After analysing different sources to address CDW materials and their codification like the Mexico City Government (GODF 2015), Mexican Federal Environmental Secretary (Medina Ross et al. 2001) and EU Waste Catalogue (Official Journal of the European Communities and Commission Decision 2001/118/EC of wastes 2001), 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).

The transformation coefficient (CR) measures the proportional part of a BCM that becomes waste. This methodology called WTM, as mentioned in Sect. 2, is based on the onsite CDW quantification from the selected 61 houses construction sites (Fig. 7). This methodology successfully applied in Spain, provided the basis not only for the Spanish CDW management regulations but the EU 2030 Climate and Energy Framework as well (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.

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

$$Q_{\mathrm{t}} = \sum_{i}^{N} Q_i \times \mathrm{CR}_i \times \mathrm{CC}_i \times \mathrm{CT}_1 \tag{1}$$

where

Q_{t}	CDW total quantity (ton)
N	material resource/package index
Q_i	quantity of material resource (ton)
CR_i	transformation coefficient of the material resource that becomes CDW
CC_i	CDW transformation coefficient from BCM unit to CDW unit
CT_i	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 Eq. 1 to this research, CC and CT coefficients are equal to 1 because CR is in tons. Packages CR is always equal to 1.

To compare CDW quantification of different typologies or locations, it is necessary to normalize them according to the corresponding built area (Eq. 2)

$$Q_{\mathrm{tn}} = \frac{Q_{\mathrm{t}}}{\text{built area}} \tag{2}$$

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
where
X = task alphabetical code
XYZ00n = task type alphanumeric code
TUV = BCM alphabetical code
XYZ00n-TUV = CDW alphanumeric code from BCM
XYZ00n-WWW = CDW alphanumeric code from BCM package
Source The authors

Fig. 7 CDW packages stored in the construction site. *Source* The authors

where

Q_{tn}	normalized CDW weight per area (ton m^{-2})
Q_t	CDW total weight (ton)
built area	built area of the building/s (m^2).

3.3 *CDW Environmental Indicators*

In Mexico, CDW may have four destinations: onsite reuse, onsite recycling, treatment plant for recycling and landfill. Therefore, CDW types are characterized and quantified according to their disposal to build four new CDW management indicators. Environmental Secretary of Mexico Federal District developed them 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 radius of less than 20 km from the building site (Eq. 3).

$$T = \mathrm{RU} + \mathrm{RC_o} + \mathrm{RC_a} + D \tag{3}$$

where

T	CDW total quantity (ton m^{-2})
RU	CDW onsite reuse (ton m^{-2})
$\mathrm{RC_o}$	CDW onsite recycled (ton m^{-2})
$\mathrm{RC_a}$	CDW recycled in treatment plant (ton m^{-2})
D	CDW sent to landfill (ton m^{-2}).

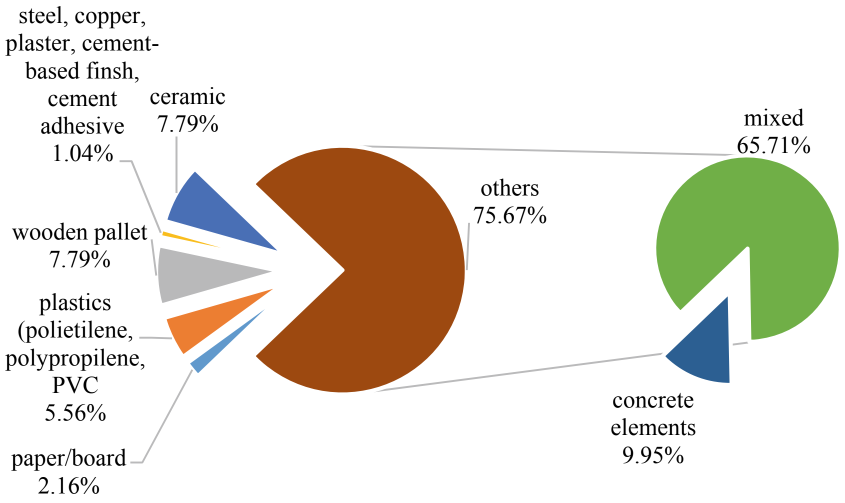
After CDW characterization and quantification according to its destination, the next step is to calculate two environmental footprint indicators according to CDW type: embodied energy and CO_{2e} emissions, whose sources are the BEDEC database and Arguello Mendez et al. research (Argüello Méndez and Cuchí Burgos 2008;

ITEC Instituto de la construcción de Catalunia n.d.) because Mexico lacks its own environmental footprint database.

Finally, a radial graphic synthesizes the CDW environmental indicators quantifying the environmental performance of an executive project. It intends to serve as a basis for an environment assessment labelling from a circular economy perspective. Furthermore, these indicators provide the quantity and destination of CDW to orient CDW management public policies to determine the need, location, size and type of treatment plants for reuse and recycle and landfills.

4 Results and Discussion

The proposed methodology allows measuring the CCM material resources (Table 5) and CDW produced at each stage of the building construction to obtain one CR coefficient for each BCM (Table 6). The implementation of a "hard" method like material tally during storage, installation, or construction process and the reckon of CDW bucket loads and truckloads complemented with a "soft" method of onsite surveys to workers and supervisors provide reliable data on real cases. The application of the coefficients (CR, CT and CC) accounts for the total normalized weight of the case study: 0.083 ton m^{-2}, without considering excavation soil (Table 7; Fig. 8). CDW painting (6.02E−2) does not appear because it constitutes hazardous waste.



Note: Steel, copper, plaster, cement-based coating, and cement adhesive are grouped to facilitate the graphic reading just because they account for 1.04%.

Fig. 8 CDW percentages of the CCM. *Source* The authors

A Sankey diagram synthesizes the material flows from their arrival to the construction site as far as their destination as CDW (Fig. 9).

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 totalize 75.77% of CDW.

It can be observed that the CCM construction process is far from closing the material flow loop. The CCM consumes 1.24 ton m^{-2} and produces 0.083 ton 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 constructors to provide a CDW management plan coordinated with CDW transport service, in case that CDW overpasses 7 m^3. The plan must include the authorized onsite 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 authorized places, 77% in backfills, landfills, soil remediation and road subsoils and only 3% in recycling plants (Ambiente n.d.; Cámara Mexicana de la Industria de la Construcción 2016; CDMX 2019; Gobierno de México 2015; GODF 2015; Secretaría del medio ambiente 2018).

The CDW management plan proposed in this research would serve to organize the construction site leaving enough room at different times for CDW storage and inner transport during the construction, taking into account that foundations produce 19.78%, masonry, 64.69%, roof, 8.70% and finishes, 6.39% of total CDW while sanitary, drainage, electric and glazing systems account for 0.44% of the total CDW. It would also allow onsite CDW separation according to the destination: onsite reuse, recycling, recycling plant or landfill. In addition, CDW quantification let know the environmental footprint derived from the material resources employed in the CCM since the design stage. Hence, designers may substitute current construction materials for others with a lower environmental footprint.

Figure 10 shows the different CDW types per CCM square meter. Polyethylene packaging constitutes a special case among other plastics because it accounts for more than half of the CDW embodied energy while polypropylene and PVC account for minimal quantities (Fig. 11). Besides, it represents 71% of CDW CO_{2e} emissions (Fig. 12) and only 5% is recycled offsite (Fig. 13). Figure 14 shows the different CDW types sent to landfills (Table 7).

Then, a radial diagram synthesizes these data to characterize the executive project in regard to environmental indicators. They quantify CDW according to its destination: reused (RU), onsite recycle (RCo), offsite 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 embodied energy and carbon emissions appear on the two other axes. As it happens with building energy labelling, colours indicate CDW environmental indicators performance that means greater inefficiency from green to red. CDW sent to

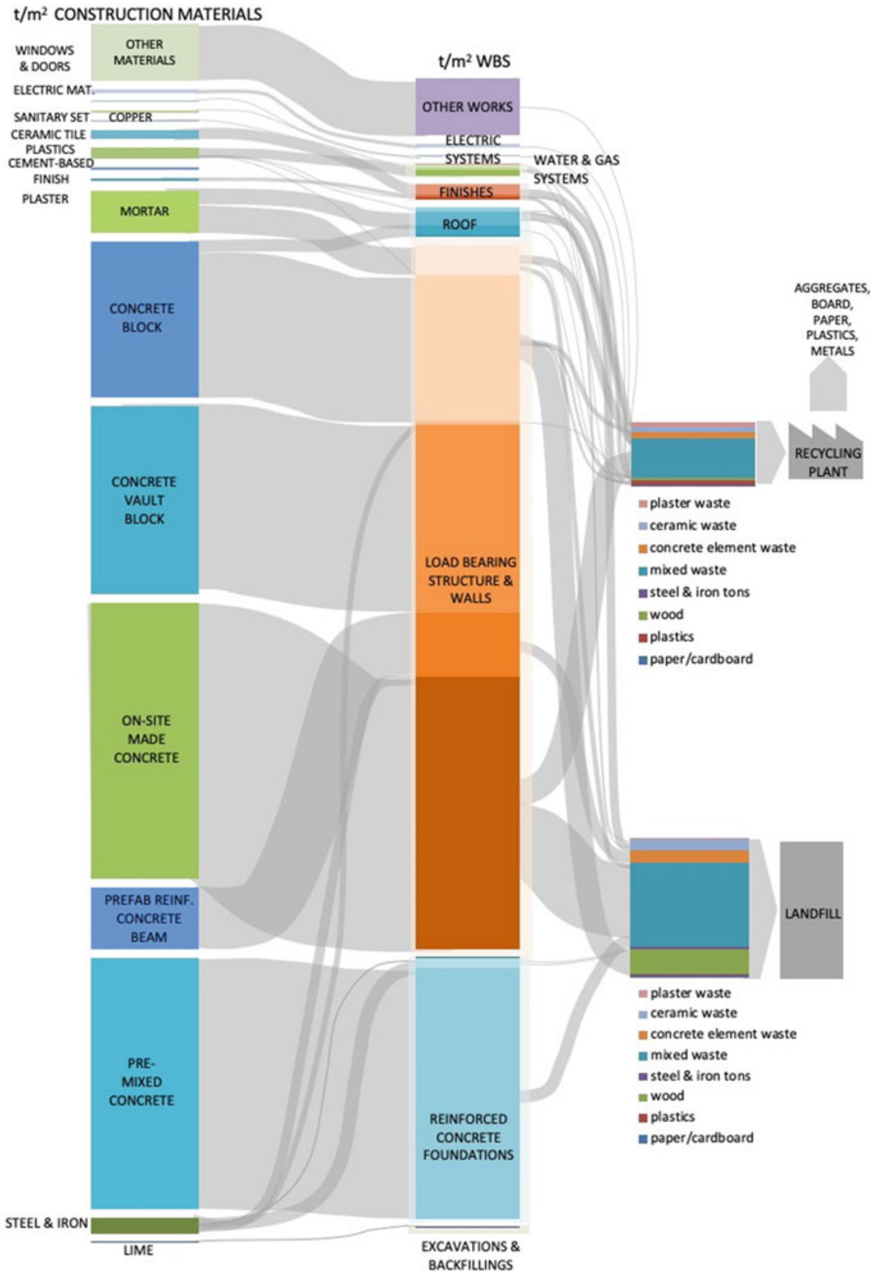


Fig. 9 Sankey diagram: CCM construction materials and CDW. *Source* The authors

Fig. 10 CDW weight (ton m^{-2})

Fig. 11 CDW EE (kWh m^{-2})

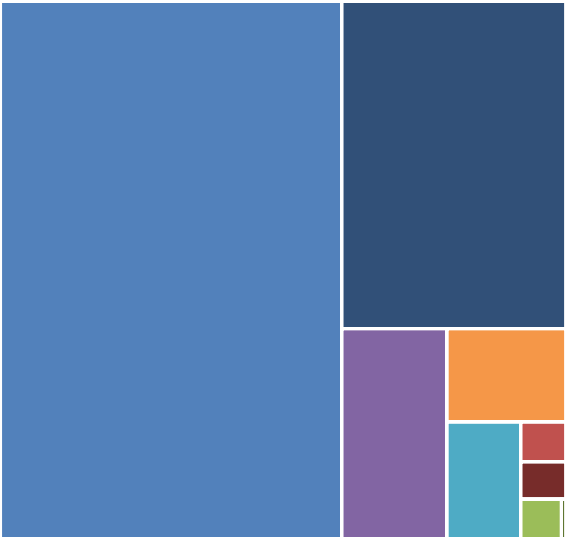
landfill (D) accounts for 69.20 kg m^{-2} while reused offsite CDW (RCa) comprehends 27.19 kg m^{-2} inert soil and only 19.92 kg m^{-2} other CDW (Fig. 15).

The proposed model validates its methodology when compared with Spanish social housing CCM that consumes 1.9 ton m^{-2} and produces 0.08 ton m^{-2} of CDW (Mercader-Moyano and Ramírez-de-Arellano-Agudo 2013). Both models omit inert soil as CDW. In the Mexican case, 6.71% of material resources become CDW, while it accounts for 4.21% in the Spanish case, deducing a more efficient CDW management for this last one. Nevertheless, mixed CDW accounts for 6.27E−2 ton m^{-2} (75.76% CDW) in the Mexican CCM and 6.80E−2 ton m^{-2} (85.13% CDW) in the Spanish CCM. After adding mixed CWD with ceramic, the total amount rises to 83.44% in the Mexican case and 95.61% in the Spanish case (Fig. 16; Table 8).

Results show that mixed CDW (mortar, onsite made concrete and concrete elements) accounts for the largest volume and weight. This waste could be grinded

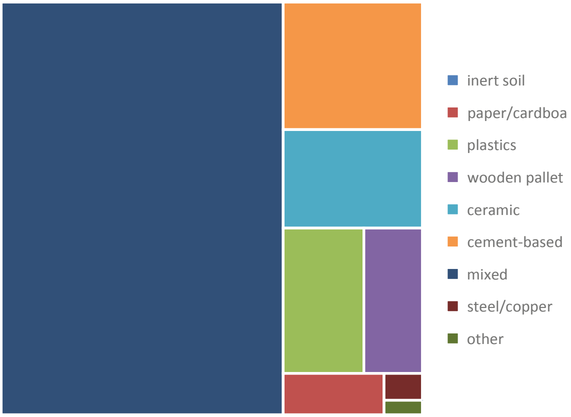
Fig. 12 CDW CO_{2e} (ton m^{-2})

Fig. 13 Recycled CDW (ton m^{-2})



onsite to use as inert aggregate for subsoils ("Concretos Reciclados" n.d.) or to make onsite blocks as it happened in an exceptional case reported in Buenos Aires (Yajnes et al. 2017). Nonetheless, many authors propose to use it as inert aggregate in prefabricated blocks (Luciano et al. 2020; 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, as it happens with blocks with added cardboard or just adobe bricks (Molar-Orozco et al. 2020; Roux Gutierrez et al. 2015).

Fig. 14 CDW to landfill (ton m^{-2}). *Source* The authors



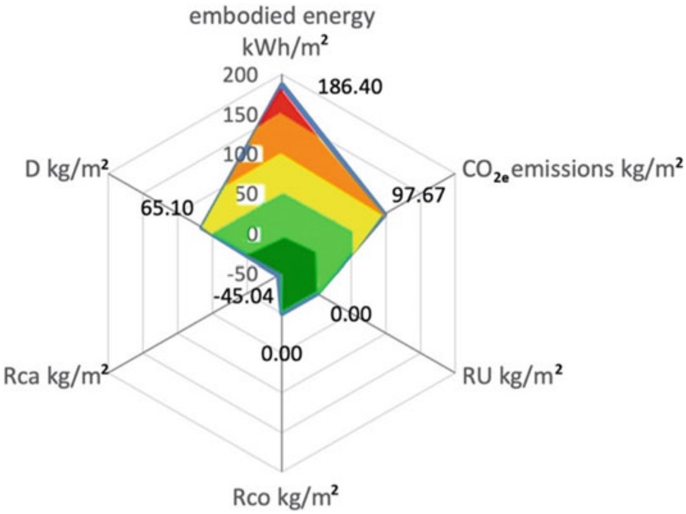


Fig. 15 CDW environmental indicators of the CCM. *Source* The authors

As it is observed, steel can be recycled reducing its environmental footprint, recovering part of their EE and the carbon emissions from its production process. However, recycling cement-based products partially reduce the EI and carbon emissions of cement production because their by-products present low aggregate value.

As this work has pointed out, Mexico still lacks mandatory CDW quantification and environmental footprint assessment, so the proposed methodology is determinant to implement federal and state legislation for CDW recovery to reintroduce them in the productive chain, minimizing those with low aggregated value that end in infrastructure work subsoil but mostly in landfills. These latter constitute pollution and infection focus exposing vulnerable populations that live in the surroundings.

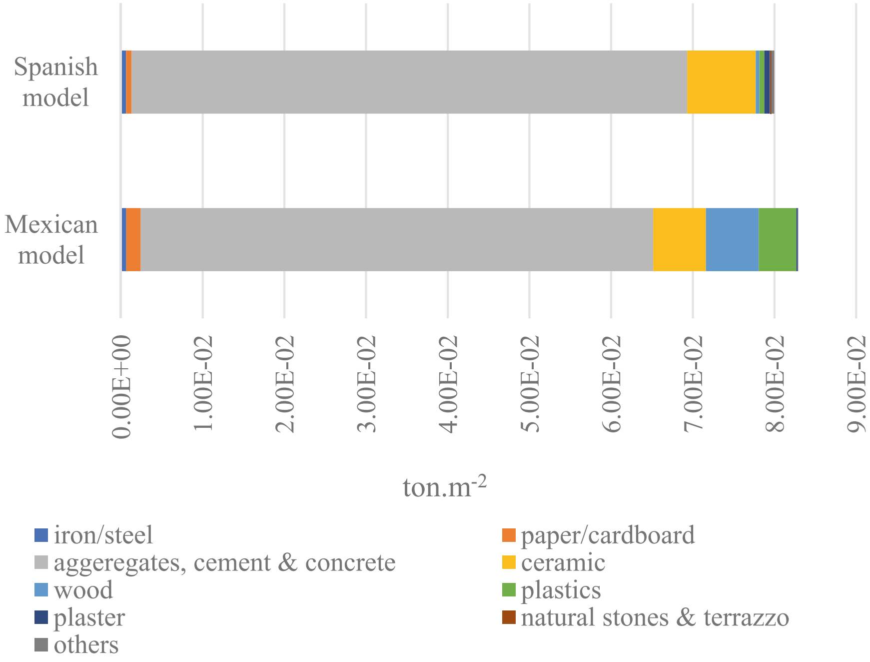


Fig. 16 CDW per type: Mexican and Spanish CCM. *Source* The authors

Moreover, landfills augment the incidence of breathing illnesses, increasing risk groups comorbidity in the case of the COVID19 pandemic, without leaving aside that 66.9% of the Mexican population will be poor in 2021 as mentioned in the Introduction (Comisión Económica para América Latina y el Caribe 2020).

Likewise, landfills emit biogases, including GHG with a high proportion of methane (CH_4) and carbon dioxide (CO_2), small amounts of nitrogen (N_2), hydrogen sulphide (H_2S), hydrogen (H_2) and oxygen (O_2) and trace amounts of carbon monoxide (CO), ammonia (NH_3), aromatic and cyclic hydrocarbons and volatile organic compounds (VOC). Environmental issues caused by these gases comprehend from nauseating odours to Global Warming contribution. Moreover, some of them as NH_4, CO, VOC and CO_2 have a direct harmful effect on human health. Furthermore, refrigerant and foaming gases and aerosols like chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC), hydrofluorocarbons (HFC) and halons provoke atmospheric ozone (O3) depletion. Besides, landfill leachate may pollute soils and superficial/subterranean adjacent water bodies, causing toxicity, eutrophication and acidification issues. Landfills also cause the proliferation of fauna that transmit illnesses or act as their vector like flies, mosquitoes, fleas, rats, birds and others that provoke diarrhoea, typhus, paludism, giardiasis, dengue fever, bubonic plague, leptospirosis and toxoplasmosis among others, rising public health costs (Gobierno de México 2015).

5 Conclusions

This work proposes a methodology for CDW quantification and environmental characterization applied to 61 social housing in Saltillo City, Coahuila, Mexico. This methodology considers not only CDW weight and volume but CDW physical or chemical transformation and the changes in their measurements criteria. It validates its results by contrasting CDW quantification at the executive project stage with the CDW amounts effectively measured onsite along the construction process.

The obtained 38 CR coefficients are 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). After being contrasted with the Spanish CR coefficients, it is possible to apply the new ones to the Mexican CCM to foresee CDW types and quantities and to plan its storage onsite and CDW destination for reuse or recycle. This methodology may serve as a basis for the implementation of local and national regulations.

Regarding the Spanish methodology, this research not only validates its application to any other country but updates and complements it with the addition of a multidimensional environmental footprint indicator. The design of this indicator synthesizes CDW environmental footprint and destination for each executive project in a radial graphic. Moreover, it may be a precedent for CDW environmental assessment labelling.

On the other hand, Mexico lacks enough CDW selection plants and authorized landfills favouring unauthorized places. Additionally, the lack of control of mandatory regulations makes that a high proportion of CDW ends in the mentioned illegal places, increasing environmental risks (Turcott Cervantes et al. 2021). These barriers require an integrated plan that covers the needed policies to shift from a linear economic model of extraction, use and discard towards a circular one of transformation of waste into a resource, involving all those AEC industry actors, generating green jobs, environmental benefits and motorizing 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 CDW destination verification because of the many illegal landfills where CDW may end. To solve the first one, a kind of incentive could improve the collaboration and for the second one, strict monitoring could assure the result accuracy.

These updates and additions prepare this new method to fulfil the new exigencies and objectives of the EU Circular Economy Action Plan that Spain had not accomplished by 2020 (European Commission 2020b).

Possible future lines of research will orient to the addition of CR coefficients to the CDW normalized database for social housing, by extending the work to other building typologies over the whole Mexican territory.

Other research lines could be the CDW economic valorisation to implement business models that make its transformation viable after the pandemic economic crisis. Circular business models involve local resources, reduce import dependence on supplies making the AEC industry more resilient and as they are labour intensive, they can create new jobs: EU estimations calculate around 600,000/700,000 net jobs by 2030.

Other lines of research may be the real estimation costs of CDW management developed from the executive project stage to include them in social housing public procurements through a BIM model as proposed by Mercader-Moyano et al. (2019). The addition of a CDW management plan and a fee to the municipal permission would compel the promoter to commit to these new regulations.

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 delivers undoubtful benefits to the environment reducing the increment of GHG emissions, contributing to Climate Change (CC) mitigation while eradicating open-air garbage dumps to limit environmental pollution. In the EU, the circular transition could reduce 300 million tons per year by 2050. Reuse and recycling may produce second-use materials that close the material flow loop and diminish the depletion of raw materials. Also, CDW management may deliver social benefits like sanitary conditions and public health improvement, construction and operation of new facilities create employment and workers training improves quality labour, especially in local communities favouring social inclusion and diminishing poverty.

Nevertheless, 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. Notwithstanding, 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.

In the EU, approximately 15% of construction materials become waste during the construction phase showing a 50% overuse of steel and concrete materials. Likewise, aluminium recycling market could augment from EUR 3 billion to EUR 12 billion with a recycling rate increment by 2050. About 180/190 million tons of steel, plastics and aluminium lose their original value of EUR 140/150 billion when they reach their end of life preserving only 41% each year through volume or price losses. If the recycling process could be improved in quality and quantity, the EU could gain new resources, independence from imports, new jobs and help meet 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).

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doctoral research developed by the author entitled “Characterization of CDW in Mexico. A theoretical model”, in co-supervision between the University of Seville and the Autonomous University of Tamaulipas.

Appendix 1

See Table 2.

Appendix 2

See Tables 3, 4, 5, 6, 7 and 8.

Table 2 Comparison of CDW quantification methods

Author	Country	Study case	CDW quantification methodology	Conclusions
Villoria Sáez et al. (2018)	Spain	Residential façade renovation in Jerez and Madrid cities	Visits to construction sites for direct and indirect measurement	Focused on the reduction of concrete, ceramic, metal and wood CDW
Blaisi (2019)	Saudi Arabia	CDW in the Eastern Province, Saudi Arabia	Truck loads measurement from construction sites to landfills	Lack of institutional collaboration, CDW management policies, coordination among the different actors, incentives, mandatory laws for CDW collectors, landfills and recycling plants
Kartam et al. (2004)	Kuwait	Kuwait's recycling plants	CDW minimization	CDW recycling plants: advantages and disadvantages
Cha et al. (2020)	South Korea	1034 residential buildings	CDW rate measurement before demolition to calculate carbon emissions and potential recyclability according to economic and environmental values	Plastic waste has the highest recycling rate followed by wood, aggregates and metals

(continued)

Table 2 (continued)

Author	Country	Study case	CDW quantification methodology	Conclusions
Wu et al. (2016)	China	Shenzhen city	Deep surveys to recyclers and officials to gather data on CDW in construction and demolition sites from CDW production to final disposition. Extrapolation and CDW production methods, material flows and possible CDW use	CDW production is increasing in Shenzhen city so higher recycling rates may augment CDW economic potential
Yuan (2017)			Data collection through publications, government regulations, surveys and group discussions with public authorities and industry actors	Lack of coordination among the government departments, reliable data, construction project supervision and slow increment of recycling plants
Li et al. (2013)		New residential building at Shenzhen city	CDW production index based on built area, bill of quantities and material waste rate	Coefficient table for CDW generation for AEC industry
Jaillon et al. (2009)		Hong Kong	Potential CDW reduction by implementation of prefabricated systems	
Wu et al. (2019)			Critical comparison of CDW quantification methods in different scenarios	Detailed pros and cons of them
Li et al. (2016)		High-rise building in Tangshan	CDW quantification from the work breakdown structure and bill of quantities	CDW calculation at design phase to help developers minimize CDW

(continued)

Table 2 (continued)

Author	Country	Study case	CDW quantification methodology	Conclusions
Kleemann et al. (2017)	Austria	Vienna	Statistical analysis based on demolition permissions combined with GIS data: construction year, typology, area, volume to calculate gross demolition volume and transform them into different material rates: kg/m^3	Underestimation of CDW quantities because of statistical data that distort the following management
Barón et al. (2017)	Spain	20 housing blocks at design stage in Andalusia	CDW management costs added to the Andalusian construction cost database following the European waste catalogue	CDW codification, measurement and valorisation criteria
Mercader-Moyano and Ramírez-de-Arellano-Agudo (2013)	Spain	10 social housing blocks in Seville	aplicación de coeficientes de transformación a los materiales que, a diferencia del resto de las metodologías analizadas, permiten medir los residuos en peso y volumen	Flexible method to be applied to other countries
Ram and Kalidindi (2017)	India	Demolition of 45 buildings	CDW quantification rates according to typology and demolition area	CDW accurate estimation to implement management policies
de Guzmán Báez et al. (2012)	Spain	Railway works	CDW predictive model by work site selection, bill of quantities and CDW onsite quantification	CDW quantification in weight and volume units

(continued)

Table 2 (continued)

Author	Country	Study case	CDW quantification methodology	Conclusions
Carpio et al. (2016)		Housing blocks in Granada city	CDW quantification in different urban planning scenarios	CDW quantity depends on different typologies from the urbanization stage
Parisi Kern et al. (2015)	Brazil	16 high-rise housing buildings with different design floors	Floor plan influence on CDW quantification using multiple regression	Need to identify and consider all the variables that were considered in the design and affect the CDW production
Ajayi et al. (2015)	UK	Theoretical model	BIM and LCA	CDW quantity reduction through design executive project stages considering building material standard measures and implementing construction methods that minimize waste from broken pieces, excess and other causes
Jalaei et al. (2019)	Canada	12-story residential building in Montreal		BIM/LCA joint to reduce CDW and environmental footprint
Jiménez Rivero et al. (2016)	Spain	Recycling of gypsum board in the EU-27	Gypsum board LCA	Gypsum board recycling reduces certain aspects of environmental footprint while increases others depending on possible scenarios

(continued)

Table 2 (continued)

Author	Country	Study case	CDW quantification methodology	Conclusions
Luciano et al. (2018)	Italy	Public works	BIM and LCA: construction materials and CDW quantification	DECORUM integrates production phases with efficient resource use and CDW
Akinade et al. (2018)	UK	Surveys to AEC industry manufacturers	BIM	The factors that affect this sector are BIM-based collaboration for CDW management, CDW-based design, building LCA, innovative technologies for CDW management
Cheng and Ma (2013)	China	47-story residential building	BIM applied to construction, demolition and renovation waste (CDRW)	BIM-CDRW integration to calculate transport and disposition rate
Liu et al. (2015)	UK	100 surveys to architect firms	BIM framework for CDW minimization from design stage	Possible extension to other AEC sectors
Liu et al. (2019)	China	2 single-family houses	BIM optimization of roof sheathing	Efficient use of construction material through automated cut

(continued)

Table 2 (continued)

Author	Country	Study case	CDW quantification methodology	Conclusions
Won and Cheng (2017)	Several countries	Several study cases	BIM methodology analysis	Identification of limitations according to building construction processes, technologies, limitations identification, policies and BIM applied to CDW management
Wu et al. (2019)	Several countries	Several study cases	Assessment of CDW quantification methodologies: CDW rate, onsite visits LCA	Selection of the correct CDW methodology according to contextual scenario
Mercader Moyano et al. (2019)	Spain	Social housing blocks	Transformation coefficients applied to CDW embodied energy and carbon emissions embedded in BIM according to work breakdown structure of the Andalusian construction costs database	Normalized quantification method applicable to different cities and countries
Ge et al. (2017)	Australia	Building in university campus	BIM applied to DW	CDW management strategies differ from construction ones; reuse and recycling rates improvement and demolition and logistic cost reduction
Guerra et al. (2019)	EEUU	4000 m^2 building in university campus	CDW management through BIM bill of quantities	This methodology improves efficiency in CDW management

(continued)

Table 2 (continued)

Author	Country	Study case	CDW quantification methodology	Conclusions
Bakchan et al. (2019)	EEUU	40,135 m^2 pilot building in university campus	CDW calculated in BIM and contrasted with a pilot case	Difference of 5.3% between estimated and measured CDW
Zaman and Lehmann (2013)	Australia, EEUU and Sweden	Adelaide, San Francisco and Stockholm	"Zero Waste Index" measure the material recovery capacity within CDW flows quantifying raw material, energy and carbon emission savings	This tool assesses CDW management and material substitution through management systems applied to different cities
Li et al. (2020)	Several countries	Several study cases	BIM, GIS	Digital tools prevalence over traditional ones for CDW management
Tanikawa and Hashimoto (2009)	UK-Japan	Urban areas in Salford, UK and Wakayama, Japan	4D GIS	Building stock renovation at urban scale includes underground infrastructure within CDW
Park et al. (2014)	South Korea	Public procurement case	CDW quantification of 7 from 52 construction materials in BIM	Aplicación de la herramienta para licitaciones públicas
Miatto et al. (2019)	Italy	Padova (1902/2007)	CDW material flow through map and aerial photographs analysis of building renovation promoted by public policies on energy efficiency and asbestos removal	GIS-based data of building stock to encourage public policies on CDW management

(continued)

Table 2 (continued)

Author	Country	Study case	CDW quantification methodology	Conclusions
Lu et al. (2015)	China	5764 buildings in Hong Kong	Big Data: CDW production rate	Results are reliable only as benchmarks
Cochran and Townsend (2010)	EEUU	EEUU	CDW material flow quantification	Methodology with potential application to other countries
Ding and Xiao (2014)	China	Shanghai	CDW material flow quantification by weight/area	Concrete, bricks and blocks constitute more than 80% CDW. 50% of them could be recycled
Bakchan et al. (2019)	Lebanon	CDW quantification of 28 construction sites in Beirut	CDW material flow quantification	CDW amounts 38–43 kg/m^2, masonry and concrete accounts for 60% of them

Table 3 Building elements composition of the 61 audited social housing

Task	Construction system	Number of dwellings	Total
Load bearing structure	Reinforced concrete (σ: 200 kg/cm^2)	58	61
	Reinforced concrete (σ: 200 kg/cm^2) + steel/wood	3	
Roofs	Reinforced concrete (σ: 200 kg/cm^2)	38	61
	Lightened reinforced concrete with EPS blocks	20	
	Reinforced concrete (σ: 200 kg/cm^2) + steel/wood	3	
External walls	Concrete block	52	61
	Ceramic brick	4	
	Concrete block + brick	5	
Internal walls	Concrete block	49	61
	Ceramic brick	5	
	Drywall	6	
	Concrete block + drywall	1	
Floors	Polished cement 0.10 m	29	61
	Vitrified tile	31	
	Cement-based terrazzo 0.30 × 0.30 × 0.025	1	
External coatings	Cement-based	42	61
	Lime	2	
	Premixed	14	
	Non-specified	3	
Internal coatings	Plaster	49	61
	Cement-based	5	
	Non-specified	3	
	No coating	4	
Windows/doors	Inner wooden doors + Al frame		61
	Steel cover door + wooden frame		61
	Kitchen steel door + steel frame		61
	Single-glazed Al windows		61

Table 4 Codes according to CCM social housing tasks and material resources

Task	Task type		Material resources		
	Code	Description	Family	Code	Description
A. Excavations and backfillings	ADS	Plot clearing	N. Raw material	NTI	Inert soil
	ALT	Plot cleaning		NTO	Organic soil
	ALD	Plot clearing and cleaning		NAA	Sand/gravel
	ANC	Plot levelling and compaction		NPN	Natural stone
	ANV	Plot levelling		NCL	Lime
	ACT	Plot compaction	H. Cement-based	HHC	Cement
	ATR	Plot demarcation		HHO	Onsite made concrete
	AEC	Foundation excavation		HHP	Premixed concrete
	AEP	Well excavation		HMM	Mortar
	AEN	Levelling excavation		HBC	Concrete block
	ARE	Backfilling		HPA	Artificial stone
	ARN	Levelling landfilling		HMP	Cement-based terrazzo
	AWW	Other works		HRI	Exterior coating
B. Foundations	BMM	Stone masonry secured with cement mortar		HAI	Adhesive
	BCC	Cyclopean concrete: 40% stone min. $\Phi 10''$		HEI	Joint filler
	BZA	Reinforced concrete basement		HVI	Prefabricated reinforced concrete beam
	BZC	Reinforced concrete continuous basement		HBO	Concrete slab block
	BLC	Reinforced concrete plate slab	M. Metals	MHC	Steel
	BDC	Foundation beam		MAA	Aluminium
	BME	Levelling wall		MAB	Bronze
	BMC	Containment wall		MBC	Copper
	BTL	League beam		MBL	Brass

(continued)

Table 4 (continued)

Task	Task type		Material resources		
	Code	Description	Family	Code	Description
	BCE	Especial foundation		MHH	Iron
	BWW	Other works		MCC	Annealed wire
C. Masonry	CKH	Reinforced concrete pillars		MPP	Lead
	CKA	Reinforced concrete column		MRR	Mixed waste
	CCE	Reinforced concrete top ring beam		MOO	Insulation material
	CVI	Reinforced concrete beam	Y. Gypsum-based	YYY	Gypsum
	CCM	Reinforced concrete slab	L. Cellulose	LMD	Wood
	CAB	Reinforced concrete slab with ceramic brick vault		LMP	Industrialized wood
	CVC	Reinforced concrete slab with concrete block vault		LPC	Paper/cardboard
	CVP	Reinforced concrete slab with EPS block vault		LTM	Wooden pallet
	CBA	Bare concrete block wall	P. Industrialized metals	PHV	Reinforcing steel bar
	CLA	Bare ceramic brick wall		PHR	Electric wire
	CCA	Bare reinforced concrete wall		PME	Steel bar mesh
	CMB	Concrete block wall		PCL	Nail
	CMP	Stone wall		PKC	Reinforced steel bar column
	CML	Ceramic brick wall	C. Ceramic	CPC	Ceramic floor
	CMC	Reinforced concrete wall		CAZ	Tile
	CMW	Other walls		CMC	Walls
	CPC	Cement mortar	A. Clay-based	ACT	Roof tile

(continued)

Table 4 (continued)

Task	Task type		Material resources		
	Code	Description	Family	Code	Description
	CFC	Lean concrete subfloor		ALD	Brick
	CFA	Reinforced concrete subfloor		ABB	Adobe brick
	CBC	Concrete floor		ABA	Lightened brick
	CRP	Concrete moulding	S. Synthetic	SMP	Plastics
	CRS	Drainage chamber		SMS	Synthetics
	CWW	Other works		SPV	PVC
D. Roof	DIM	Waterproof coating	T. Painting	TBA	Water-based
	DPB	Concrete block parapet		TSE	Sealer
	DPL	Ceramic brick parapet			
	DCH	Concrete chamber			
	DBT	Water tank base			
	DCP	Rainwater basin			
	DBP	Rainwater drain pipe			
	DPP	Tilted subfloor			
	DWW	Other works			
E. Coatings	EAP	Cement-based plaster			
	EAI	Industrialized cement-based plaster			
	EYS	Gypsum plaster			
	ELC	Ceramic tile coating			
	EPC	Ceramic tile floor			
	EPB	Mud floor			
	EPF	Polished cement floor			
	EZB	Mud baseboard			
	EZC	Ceramic baseboard			
	ETX	One-layer textured coating			
	EPV	Vinylic painting			

(continued)

Table 4 (continued)

Task	Task type		Material resources		
	Code	Description	Family	Code	Description
	EWW	Other coatings			
F. Water, sewer and gas systems	F1H	Water provision			
	F2S	Sewer			
	F3G	Gas			
	F5W	Others			
G. Electric, lighting and communication systems	G1E	Electric			
	G2I	Lighting			
	G3T	Communication			
	G4D	Automation			
	G5W	Others			
H. Windows, doors	H1A	Aluminium			
	H2M	Wood			
	H3A	Steel			
	H4C	Hinges, latches, locks			
	H5P	Plastic			
	H6W	Others			
I. Outside works	I1J	Gardening and landscape			
	I2I	Outer lighting			
	I30	Complementary works			
	I4L	Final cleaning			
	I5W	Other works			

Table 5 Material resources quantification of social housing

Task		Task type					Material resources					
Code	Description	Code	Description	Specifications	Q	u	Code	Description	Deliver. quant.	Net quant.	Orig. unit	Normal quant. kg/m^2
A	Soil excavation-prelimin. works	ATR001	Demarcation		1	pl	NCL	Lime	5.00E−03	5.00E−03	t	1.01E−01
B	Foundation	BLC001	Reinforced concrete foundation slab	Premixed-concrete Holcim ($\sigma' c = 200$ kg/cm^2), coarse aggr. max. Φ 3/4″, slump test: 0.12 cm, steel bar, double mesh Φ3.8″ (0.20 × 0.20 m), superimposed in both directions, tied with annealed wire (BWG 16)	49.40	m^2	HHP200	Premixed concrete	6	5.93	m^3	2.88E+02
							PHV3-8	Steel bar	595	561	kg	1.14E+01
							PHVC-16	Annealed wire	4	3.84	kg	7.77E−02
C	Masonry	CKH001	Reinforced concrete pillar	Onsite made concrete ($\sigma' c =$ 150 kg/cm^2), coarse aggr. max. Φ 3/4″, casted in concrete block wall (6″ width), 1 steel bar Φ 3,8″ fixed to foundation slab (L-shape), 0.40 m length, separated 1.20 m each	102.45	m	HHO150	Onsite concrete	1.91	1.75	m^3	8.50E+01
							PHV3-8	Steel bar	66.84	64.83	kg	1.14E+01
		CCE001	Top ring beam	Concrete ($\sigma' c = 150$ kg/cm^2) 0.15 × 0.20 m, prefabricated steel frame ARMEX DeAcero™, 0.12 × 0.18 m	12.75	m	HHO150	Onsite made concrete	0.42	0.38	m^3	1.86E+01
							PKC12	Prefab. frame ARMEX 0.12 × 0.18 m	13	12.75	m	4.23E−01
		CVC001	Reinforced concrete slab with concrete block vault	Onsite made concrete 0.15 high compression layer 0.04 m high steel mesh DeAcero™ 66-1010	49.40	m^2	HVI	Prefab. reinforced concrete beam	66	65.87	m	7.20E+01
							HBO	Concrete block	268.57	263.30	Block	2.16E+02
							PME	Steel mesh	50	49.40	m^2	5.00E+00

(continued)

Table 5 (continued)

Task		Task type					Material resources					
Code	Description	Code	Description	Specifications	Q	u	Code	Description	Deliver. quant.	Net quant.	Orig. unit	Normal quant. kg/m^2
							HHO150	Onsite made concrete	2.16	1.98	m^3	9.60E+01
		CMB001	Concrete block wall	Concrete block 0.15 × 0.20 × 0.40 m laid with cement mortar 1:5	102.56	m^2	HBC15	Concrete block 0.15 × 0.20 × 0.40 m	1400	1370	Block	1.66E+02
							HMM1-5	Onsite made mortar (1:5)		0.92	m^3	3.35E+01
		CBC001	Concrete floor auxiliary yard	$\sigma'c = 150$ kg/cm^2, 0.08 m width polished	5.16	m^2	HHO150	Onsite made concrete		0.41	m^3	6.00E+01
		CBC002	Concrete floor parking space	$\sigma'c = 150$ kg/cm^2, 0.08 m width textured	15.44	m^2	HHO150	Onsite made concrete		1.24	m^3	6.00E+01
		CBC003	Concrete shoulder	$\sigma'c = 150$ kg/cm^2, 0.08 m width, squared textured 0.65 × 1.20 m	7.80	m^2	HHO150	Onsite made concrete		0.62	m^3	3.03E+01
		CRS	Sewer chamber	$\sigma'c = 75$ kg/cm^2, floor width = 0.08 m polished, concrete walls 1.10 × 0.20 × 0.40 m onsite made, reinforced concrete cover $\sigma'c =$ 100 kg/cm^2 steel mesh 66-1010	3	u	HBC15	Concrete block 0.15 × 0.20 × 0.40 m	9	8.01	Block	9.73E−01
							HMM1-5	Onsite made mortar (1:5)		4.03E−04	m^3	1.47E−02
							HHO75	Onsite made concrete		0.04	m^3	1.71E+00
							HHO100	Onsite made concrete cover		0.02	m^3	1.07E+00
							PME	Steel mesh 66-1010		0.44	m^2	4.45E−02
D	Roof	DIM001	Insulation/waterproof coating	Elastomeric acrylic coating Thermotek™ Max 7, type 7ª, cold aqueous emulsion, reinforced with simple membrane Thermotek™	59.30	m^2	PBA	Insulating/waterproof painting × 200 l	62.56	59.30	l	1.68E+00
							SMS	Simple membrane Thermotek × roll = 109.25 m	62.56	59.30	m^2	4.20E+00

(continued)

Table 5 (continued)

Task		Task type					Material resources					
Code	Description	Code	Description	Specifications	Q	u	Code	Description	Deliver. quant.	Net quant.	Orig. unit	Normal quant. kg/m^2
		DPB001	Concrete block parapet	Onsite made with mortar 1:5 and on top mortar chamfer (0.05 a 0.01 m)	33	m	HBC15	Concrete block 0.15 × 0.20 × 0.40 m	82.10	80.49	Block	9.78E+00
							HMM1-5	Onsite made mortar 1:5		0.05	m^3	1.97E+00
		DCH001	Concrete chamfer	Mortar 1:5, 45°	32	m	HMM1-5	Onsite made mortar 1:5		0.36	m^3	1.31E+01
		DBT001	Storage water tank base	h:2 concrete block rows laid with mortar 1:5 and onsite made reinforced concrete plate $w = 0.08$ m steel mesh 66-1010 DeAcero™ plastered with stucco Cemix™	1	u	HBC15	Concrete block	10.90	10.69	Block	1.30E+00
							HMM1-5	Onsite made mortar 1:5		0.01	m^3	2.61E−01
							HHO100	Onsite made concrete		0.08	m^3	3.89E+00
							PME	Steel mesh 66-1010	1.003	1.00	m^2	1.01E−01
							HMMP	Stucco Cemix	17.23	16.3	kg	3.30E−01
		DCP	Rainfall drainage pipe	PVC pipe Φ2″	2	u	SPV	PVC pipe Φ2″	6.00	5.90	m	4.78E−01
E	Coatings	EAI001	Premixed mortar coating	Exterior block coating Aderblock CEMIX™ $w =$ 0.005 m max. on primary sealer 5-1 CEMIX™	69.80	m^2	HMMP	Stucco Cemix	0.07	0.07	t	1.41E+00
							HRI	Primary sealer	24.43	23.27	kg	4.71E−01
		EYS001	Gypsum coating	Width = 0.015 m	151.25	m^2	YYY	Gypsum		0.61	kg	1.22E−02
		EYS002	Ceiling gypsum plastering	$w = 0.015$ m	42.70	m^2	YYY	Gypsum		170.80	kg	3.46E+00
		ELC001	Interior ceramic coating	White enamelled ceramic Tile grade 1A model Alcalá Vitromex™	7.62	m^2	CMC	Ceramic	8.08	7.62	m^2	1.39E+00
							HAI	Adhesive Cemix™	2.96	2.82	kg	5.71E−02
		ELC002	Ceramic tile coating on façades	Ceramic tiles DalGres, Slate Brown 1ª, Daltile™ 0.605 × 0.605 m laid with floor adhesive Pegamix Constructor Cemix™	4.80	m^2	CMC	Ceramic tile	5.09	4.80	m^2	8.74E−01
							HAI	Adhesive Cemix™	1.87	1.78	kg	3.60E−02

(continued)

Table 5 (continued)

Task		Task type					Material resources					
Code	Description	Code	Description	Specifications	Q	u	Code	Description	Deliver. quant.	Net quant.	Orig. unit	Normal quant. kg/m^2
		EPC001	Ceramic tile interior floor	Ceramic tiles DalGres, Slate Brown 1ª, Daltile™ 0.605 × 0.605 m laid with floor adhesive Pegamix Constructor Cemix™	41.95	m^2	CMC	Ceramic tile	44.47	41.95	m^2	7.64E+00
							HAI	Adhesive Cemix™	16.31	15.54	kg	3.15E−01
		EZC001	Ceramic tile baseboard	Ceramic tiles DalGres, Slate Brown 1ª, Daltile™ 0.605 × 0.605 m laid with floor adhesive Pegamix Constructor Cemix™	43.75	m	CMC	Ceramic tile	5.57	5.25	m^2	9.56E−01
							HAI	Adhesive Cemix™	0.10	1.94	kg	3.94E−02
F	Water, sewer and gas systems	F1H001	Water pipes	Thermally fused PP pipe Random/PP-R (NMX-E-226/2-CNCP-2007) Tuboplus, Rotoplas™, Φ3/4″-1/2″ within foundation slab and walls	45.00	m	SMP	PP pipe thermally fused	45.90	45.00	m	7.29E+00
		F1H002	Shower set	2 ceramic lock mixing faucets, shower with sprinkler, 2 PVD brushed nickel-plated stopcocks, model Builders Glacier Bay™	1	u						6.07E−02
		F1H003	Bath set	Bath set HD Cosmos II RD 4 pieces WC white with rounded storage tank 4.8 l with frontal handle, basin and washstand Orion™	1	u						9.78E−01
		F1H004	Laundry set	Granite worktop with laundry basin 65 × 50 cm	1	u						1.12E+00
		F2S001	Sewer piping	PVC pipe (NMX-E-215/1-1994-SCFI) Futura Rexolit™ or simil, Φ2″-4″ embedded in foundation slab and walls	20	u	SPV	PVC pipe Φ2″	20.40	20.00	m	3.24E+00

(continued)

Table 5 (continued)

Task		Task type					Material resources					
Code	Description	Code	Description	Specifications	Q	u	Code	Description	Deliver. quant.	Net quant.	Orig. unit	Normal quant. kg/m^2
		F3G001	Gas piping	Copper pipe L-shaped (NMX-W-018-SCFI-2016) Nacobre™ or simil. Φ 1/2″ welded with tin/antimony (95/5) embedded in foundation slab and walls	14.50	m	MBC	Copper pipe	14.79	14.50	m	7.81E−02
G	Electric, lighting, communication systems	G1E001	Grid connection		1	u						2.02E−02
		G1E002	Main control table	3 100A keys Schneider Electric™	1	u						1.01E−02
		G1E003	Wiring	Wire calibre 12 y 14 (NOM-001-SEDE-2012) Condumex™ or simil. Corrugated plastic tube Φ 1/2″-3/4″ embedded in slab foundation and walls	35.60	m	MBC	Electric wire	36.67	35.60	m	1.44E−02
							SMP	Corrugated plastic tube	36.67	35.60	m	1.44E−01
		G1E004	Cieling socket	embedded resin octagonal box 4″ × 4″ Bticino™	5	u						1.37E−02
		G1E005	Socket	embedded resin box 2″ × 4″ for 3 modules Bticino™ for double contact with ivory plate Levinton™	11	u						8.20E−03

(continued)

Table 5 (continued)

Task		Task type					Material resources					
Code	Description	Code	Description	Specifications	Q	u	Code	Description	Deliver. quant.	Net quant.	Orig. unit	Normal quant. kg/m^2
		G1E006	Switches	Embedded resin box 2″ × 4″ for 3 modules Bticino™ for double contact with ivory plate Levinton™	6	u						8.20E−03
		G3T	Phone, fibre and tv coaxial cable sockets	Embedded resin box 2″ × 4″ for 3 modules Bticino™ for double contact with ivory plate Levinton™	5	u						1.64E−02
H	Windows, doors	H1A001	Al bedroom window	Anodized natural Al 1.20 × 1.50 XO lower fixed single pane 4 mm h: 0.30	3	u						8.38E−01
		H1A002	Al bathroom window	Anodized natural Al 1.20 × 1.50 XO lower fixed single pane 4 mm h: 0.30	2	u						2.31E−01
		H1A003	Al small window	Anodized natural Al 1.20 × 1.00 XO single pane 4 mm	1	u						2.15E−01
		H1A004	Al bathroom fixed window	Anodized natural Al 1.20 × 0.30 XO single pane 4 mm	1	u						1.15E−01
		H1A005	Kitchen door	White steel door Masonite™ 0.80 × 2.13	1	u						4.05E−01
		H2M001	Interior wooden door	Flush door (caobilla) 0.80 × 2.13 m transparent varnished, Al frame	2	u						8.28E−01
		H2M002	Bathroom door	Flush door (caobilla) 0.60 × 2.13 m transparent varnished, Al frame	1	u						3.10E−01
		H3A001	Main access door	Wooden frame, steel covered wooden door, 2 matte white panels, curve lintel single pane 3 mm	1	u						6.21E−01
Total												1.23E+03

Table 6 CDW transformation coefficients of material resources (CR)

Material resource	Waste origin	Produced waste	CR
Lime	Material loss	Lime	0.01
Lime	Paper	Paper/cardboard	1.00
Premixed concrete	Material loss	Concrete	0.07
Onsite made concrete	Material loss	Concrete	0.09
Onsite made concrete	Paper	Paper/cardboard	1.00
Concrete block vault	Material loss	Concrete	0.02
Concrete block vault	Wooden pallet	Wood	1.00
Concrete block vault	Plastic cover	Plastic	1.00
Concrete block 0.15 × 0.20 × 0.40 m	Material loss	Concrete	0.02
Concrete block 0.15 × 0.20 × 0.40 m	Wooden pallet	Wood	1.00
Concrete block 0.15 × 0.20 × 0.40 m	Plastic cover	Plastic	1.00
1:5 onsite made mortar	Material loss	Mixed	0.09
1:5 onsite made mortar	Paper	Paper/cardboard	1.00
Stucco	Material loss	Mixed	0.06
Stucco	Paper	Paper/cardboard	1.00
Cement-based adhesive	Material loss	Mixed	0.05
Cement-based adhesive	Paper	Paper/cardboard	1.00
Primary sealer	Material loss	Painting	0.05
Primary sealer	Tin	Steel/iron	1.00
Steel bar	Material loss	Steel/iron	0.03
Steel wire	Material loss	Steel/iron	0.01
Prefabricated steel column 0.12 × 0.18 × 3 m	Material loss	Steel/iron	0.08
Steel mesh	Material loss	Steel/iron	0.01
Steel mesh	Plastic cover	Plastic	1.00
Waterproof and insulating coating	Material loss	Painting	0.05
Waterproof and insulating coating	Metallic tin	Steel/iron	1.00
Polyester membrane roll	Material loss	Plastic	0.06
Polyester membrane roll	Plastic cover	Plastic	1.00
PVC tube Φ2″	Material loss	Plastic	0.02
Gypsum	Material loss	Gypsum	0.06
Gypsum	Paper	Paper/cardboard	1.00
Ceramic tile	Material loss	Ceramic	0.06
Ceramic tile	Cardboard	Paper/cardboard	1.00
Thermally fused PP water pipe	Material loss	Plastic	0.02
Plastic corrugated tube	Material loss	Plastic	0.03
Copper pipe 1/2″	Material loss	Copper	0.02

(continued)

Table 6 (continued)

Material resource	Waste origin	Produced waste	CR
Electric wire	Material loss	Copper	0.03
Electric wire	Cardboard	Paper/cardboard	1.00
Windows and doors	Plastic cover	Plastic	0.05

Table 7 Conventional construction model: CDW ton/m^2 and environmental indicators

CDW	Weight kg/m^2	Energy kWh/m^2	CO$_{2e}$ emissions kg/m^2	Reused CDW (RU) kg/m^2	Onsite recycled CDW (RCo) kg/m^2	Offsite recycled CDW (RCa) kg/m^2	CDW to landfill (D) kg/m^2
Inert soil	2.72E+01	7.55E−01	8.16E−01	0.00E+00	0.00E+00	2.72E+01	0.00E+00
Paper/cardboard	1.79E+00	1.62E−01	2.60E+00	0.00E+00	0.00E+00	2.63E−01	1.53E+00
Plastics	4.61E+00	9.60E−01	6.94E+01	0.00E+00	0.00E+00	2.30E−01	4.38E+00
Wooden pallet	6.46E+00	5.38E+00	4.07E+00	0.00E+00	0.00E+00	3.23E+00	3.23E+00
Ceramic	6.44E−01	2.33E−01	1.80E+00	0.00E+00	0.00E+00	1.29E+00	5.16E+00
Cement-based	6.92E+01	6.44E+00	1.84E+01	0.00E+00	0.00E+00	1.66E+00	6.63E+00
Mixed	1.74E−01	3.03E+00	4.41E−01	0.00E+00	0.00E+00	1.09E+01	4.36E+01
Steel/copper	5.47E−02	7.72E+00	1.81E−01	0.00E+00	0.00E+00	2.52E−01	3.94E−01
Others	8.29E−04	3.48E−01	1.37E−02	0.00E+00	0.00E+00	3.47E−02	1.99E−01
Total	1.10E+02	18.64E+01	9.77E+01	0.00E+00	0.00E+00	4.50E+01	6.51E+01

Table 8 Comparison between Mexican and Spanish CDW quantification models

Code Mexican model	Material resource	Weight ton/m^2	Waste type ton/m^2									Total
			Iron/steel	Paper/cardboard	Aggreg., cement and concrete	Ceramic	Wood	Plastics	Gypsum	Natural stones and terrazzo	Others	
CMC	Ceramic tile	1.09E−02		3.09E−04		6.46E−03						6.76E−03
F1H002	Shower set	6.07E−02		7.09E−06								7.09E−06
HAI	Adhesive Cemix	4.47E−04		3.26E−06								3.60E−06
HBC15	Concrete block 0.15 × 0.20 × 0.40 m	1.78E−01			5.71E−03		5.49E−03	3.84E−03				1.50E−02
HBO	Concrete block vault	2.16E−01			2.54E−03		9.71E−04					3.51E−03
HHO100	Onsite made concrete	4.96E−03		1.32E−06	4.51E−04							4.52E−04
HHO150	Onsite made concrete	3.10E−01		9.60E−05	2.92E−02							2.93E−02
HHO75	Onsite made concrete	1.71E−03		1.50E−07	1.56E−04							1.56E−04
HHP200	Premixed concrete	2.88E−01			2.13E−02							2.13E−02
HMM1-5	Onsite mortar 1:5	4.89E−02		2.38E−05	3.34E−03							3.36E−03
HMMP	Stucco Cemix™	1.74E−03		1.32E−03								1.32E−03
HRI	Primary sealer	4.71E−04						2.77E−05				2.77E−05
HVI	Prefab. reinforced concrete beam	7.20E−02										0.00E+00
MBC	Copper pipe	7.81E−05									2.64E−07	2.64E−07
MBC	Electric wire	1.44E−05		7.09E−06							6.49E−07	7.73E−06
NCL	Lime	1.01E−04		1.82E−07								1.82E−07
PBA	Insulating/waterproof painting × 200 l	1.68E−03	1.02E−04									1.02E−04

(continued)

Table 8 (continued)

Code Mexican model	Material resource	Weight ton/m^2	Waste type ton/m^2									Total
			Iron/steel	Paper/cardboard	Aggreg., cement and concrete	Ceramic	Wood	Plastics	Gypsum	Natural stones and terrazzo	Others	
PHV3-8	Steel bar	1.27E−02	5.06E−04									5.06E−04
PHVC-16	Steel wire	7.77E−05	7.00E−07									7.00E−07
PKC12	Prefab. steel framework ARMEX™ 0.12 × 0.18 m	4.23E−04	3.22E−05									3.22E−05
PME	Steel mesh	5.15E−03	3.09E−06					3.43E−04				3.46E−04
SMP	Thermally fused PP pipe	1.53E−02						3.64E−06				3.64E−06
SMP	Plastic corrugated tube	1.44E−04						4.32E−06				4.32E−06
SMS	Polyester membrane Thermotek™ × roll 109.25 m	4.20E−03						1.96E−04				1.96E−04
SPV	PVC pipe Φ2″	3.72E−03						2.69E−06				2.69E−06
W	Others	3.56E−03						1.90E−04			6.11E−05	2.51E−04
YYY	Gypsum	3.47E−03		2.17E−05					1.74E−04			1.95E−04
Mexican model		1.24E+00	6.44E−04	1.79E−03	6.27E−02	6.46E−03	6.46E−03	4.61E−03	1.74E−04		6.11E−05	8.30E−02
Spanish model		1.90E+00	6.20E−04	6.80E−04	6.80E−02	8.40E−03	4.40E−04	6.20E−04	6.80E−04	1.60E−04	3.80E−04	8.00E−02

References

Ajayi SO, Oyedele LO, Ceranic B, Gallanagh M, Kadiri KO (2015) Life cycle environmental performance of material specification: a BIM-enhanced comparative assessment. Int J Sustain Build Technol Urban Dev 6(1):14–24. https://doi.org/10.1080/2093761X.2015.1006708

Akinade OO, Oyedele LO, Ajayi SO, Bilal M, Alaka HA, Owolabi HA, Arawomo OO (2018) Designing out construction waste using BIM technology: stakeholders' expectations for industry deployment. J Clean Prod 180:375–385. https://doi.org/10.1016/j.jclepro.2018.01.022

Alderete Herrera JCA (2010) Vivienda de interés social. Universidad Veracruzana. Repositorio Institucional 5

Ambiente SM (n.d.) En marcha, Basura Cero en la Ciudad de México [WWW document]. Secretaría del Medio Ambiente. https://sedema.cdmx.gob.mx/comunicacion/nota/en-marcha-basura-cero-en-la-ciudad-de-mexico. Accessed 4.22.21

Araiza-Aguilar JA, Gutiérrez-Palacios C, Rojas-Valencia MN, Nájera-Aguilar HA, Gutiérrez-Hernández RF, Aguilar-Vera RA (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. https://doi.org/10.3390/su11154077

Argüello Méndez TR, Cuchí Burgos A (2008) Análisis del impacto ambiental asociado a los materiales de construcción empleados en las viviendas de bajo coste del programa 10×10 Con Techo-Chiapas del CYTED. Informes de la Construcción 60:25–34

Aslam MS, Huang B, Cui L (2020) Review of construction and demolition waste management in China and USA. J Environ Manag 264:110445. http://doi.org/10.1016/j.jenvman.2020.110445

Bakchan A, Faust KM, Leite F (2019) Seven-dimensional automated construction waste quantification and management framework: integration with project and site planning. Resour Conserv Recycl 146:462–474. http://doi.org/10.1016/j.resconrec.2019.02.020

Barón J, Conde J, Osuna M, Ramírez A, Solís J (2017) Consejería de Fomento y Vivienda/Vivienda y Rehabilitación/Base de Costes de la Construcción de Andalucía (BCCA), 29 abril 2016. Banco de precios

Blaisi NI (2019) Construction and demolition waste management in Saudi Arabia: current practice and roadmap for sustainable management. J Cleaner Prod 221:167–175. https://doi.org/10.1016/j.jclepro.2019.02.264

Cámara Mexicana de la Industria de la Construcción (2016) Plan de Manejo de Residuos de la Construcción y la Demolición

Carpio M, Roldán-Fontana J, Pacheco-Torres R, Ordóñez J (2016) Construction waste estimation depending on urban planning options in the design stage of residential buildings. Constr Build Mater 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" [WWW document]. CDMX. 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. Accessed 4.22.21

Cha G-W, Moon HJ, Kim Y-C, Hong W-H, Jeon G-Y, Yoon YR, Hwang C, Hwang J-H (2020) Evaluating recycling potential of demolition waste considering building structure types: a study in South Korea. J Cleaner Prod 256:120385. https://doi.org/10.1016/j.jclepro.2020.120385

Cheng JCP, Ma LYH (2013) A BIM-based system for demolition and renovation waste estimation and planning. Waste Manage 33:1539–1551. https://doi.org/10.1016/j.wasman.2013.01.001

Cochran KM, Townsend TG (2010) Estimating construction and demolition debris generation using a materials flow analysis approach. Waste Manage 30(11):2247–2254. https://doi.org/10.1016/j.wasman.2010.04.008

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 [WWW document]. https://www.cepal.org/es/comunicados/contraccion-la-actividad-economica-la-region-se-profundiza-causa-la-pandemia-caera-91. Accessed 9.30.20

Concretos Reciclados [WWW document] (n.d.). http://www.concretosreciclados.com.mx/#3. Accessed 12.20.20

Consejo Nacional de Evaluación de la Política de Desarrollo Social (2018) Pobreza en México | CONEVAL [WWW document]. https://www.coneval.org.mx/Medicion/Paginas/PobrezaInicio.aspx. Accessed 9.28.20

Consejo Nacional de Evaluación de la Política de Desarrollo Social (CONEVAL) (2020) Informe de pobreza y evaluación 2020. Coahuila, México

Da Costa-Gómez O (2020) Buildings and construction [WWW document]. Mercado Interior, Industria, Emprendimiento y Pymes - European Commission. https://ec.europa.eu/growth/industry/sustainability/built-environment_en. Accessed 1.13.21

de Guzmán Báez A, Villoria Sáez P, del Río Merino M, García Navarro J (2012) Methodology for quantification of waste generated in Spanish railway construction works. Waste Manage 32(5):920–924. https://doi.org/10.1016/j.wasman.2012.01.007

Ding T, Xiao J (2014) Estimation of building-related construction and demolition waste in Shanghai. Waste Manage 34(11):2327–2334. https://doi.org/10.1016/j.wasman.2014.07.029

European Commission (2008) Directive 2008/98/EC of the European Parliament and of the council of 19 November 2008 on waste and repealing certain directives

European Commission (2016) 2030 climate & energy framework [WWW document]. Climate action. European Commission. https://ec.europa.eu/clima/policies/strategies/2030_en. Accessed 2.9.21

European Commission (2018) EU construction and demolition waste protocol and guidelines

European Commission (2019) The European green deal

European Commission (2020a) Renovation wave [WWW document]. Energy. European Commission. https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en. Accessed 1.15.21

European Commission (2020b) A new circular economy action plan for a cleaner and more competitive Europe

European Commission (2020c) Level(s) the European framework for sustainable buildings [WWW document]. https://ec.europa.eu/environment/topics/circular-economy/levels_en. Accessed 1.15.21

European Environment Agency (2020) Construction and demolition waste: challenges and opportunities in a circular economy

Eurostat (2020a) Recovery rate of construction and demolition waste% of construction and demolition mineral waste recycled [WWW document]. Eurostat. https://ec.europa.eu/eurostat/databrowser/view/CEI_WM040__custom_354944/bookmark/table?lang=en&bookmarkId=7e4febc4-a0fd-444b-aae0-94643539ce0d. Accessed 1.18.21

Eurostat (2020b) Generation of waste by economic activity [WWW document]. Generation of waste by economic activity. https://ec.europa.eu/eurostat/databrowser/view/ten00106/default/table?lang=en. Accessed 1.18.21

Ge XJ, Livesey P, Wang J, Huang S, He X, Zhang C (2017) Deconstruction waste management through 3d reconstruction and bim: a case study. Vis Eng 5:13. https://doi.org/10.1186/s40327-017-0050-5

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

Gobierno de España (2020) Estrategia Española de Economía Circular ESPAÑA CIRCULAR 2030

Gobierno de México (2015) Informe de la Situación del Medio Ambiente en México

Gobierno Federal de México (2016) Código de Edificación de Vivienda 2010

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

Guerra BC, Bakchan A, Leite F, Faust KM (2019) BIM-based automated construction waste estimation algorithms: the case of concrete and drywall waste streams. Waste Manage 87:825–832. https://doi.org/10.1016/j.wasman.2019.03.010

Hendriks CF (ed) (2000) Sustainable raw materials: construction and demolition waste. RILEM report. RILEM Publ, Cachan

Hyman M, Turner B, Carpintero A, United Nations Institute for Training and Research, Inter-Organization Programme for the Sound Management of Chemicals, United Nations Environment Programme (2015) Guidelines for national waste management strategies: moving from challenges to opportunities

ITEC Instituto de la construcción de Catalunia (n.d.) Información ambiental de productos y sistemas [WWW document]. https://itec.es/metabase/productos-sostenibles/0/0/0/. Accessed 2.9.21

Jaillon L, Poon CS, Chiang YH (2009) Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong. Waste Manage 29(1):309–320. https://doi.org/10.1016/j.wasman.2008.02.015

Jalaei F, Zoghi M, Khoshand A (2019) Life cycle environmental impact assessment to manage and optimize construction waste using Building Information Modeling (BIM). Int J Constr Manag 1–18. http://doi.org/10.1080/15623599.2019.1583850

Jefatura de Gobierno (2011) Ley 22/2011 Residuos y Suelos Contaminados

Jiménez Rivero A, Sathre R, García Navarro J (2016) Life cycle energy and material flow implications of gypsum plasterboard recycling in the European Union. Resour Conserv Recycl 108:171–181. https://doi.org/10.1016/j.resconrec.2016.01.014

Jin R, Yuan H, Chen Q (2019) Science mapping approach to assisting the review of construction and demolition waste management research published between 2009 and 2018. Resour Conserv Recycl 140:175–188. https://doi.org/10.1016/j.resconrec.2018.09.029

Kabirifar K, Mojtahedi M, Wang C, Tam VWY (2020) Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: a review. J Cleaner Prod 263:121265. http://doi.org/10.1016/j.jclepro.2020.121265

Kartam N, Al-Mutairi N, Al-Ghusain I, Al-Humoud J (2004) Environmental management of construction and demolition waste in Kuwait. Waste Manage 24(10):1049–1059. https://doi.org/10.1016/j.wasman.2004.06.003

Kleemann F, Lehner H, Szczypińska A, Lederer J, Fellner J (2017) Using change detection data to assess amount and composition of demolition waste from buildings in Vienna. Resour Conserv Recycl 123:37–46. https://doi.org/10.1016/j.resconrec.2016.06.010

Klevnäs P, 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

Li J, Ding Z, Mi X, Wang J (2013) A model for estimating construction waste generation index for building project in China. Resour, Conserv Recycl 74:20–26. https://doi.org/10.1016/j.resconrec.2013.02.015

Li CZ, Zhao Y, Xiao B, Yu B, Tam VWY, Chen Z, Ya Y (2020) Research trend of the application of information technologies in construction and demolition waste management. J Cleaner Prod 263:121458. http://doi.org/10.1016/j.jclepro.2020.121458

Liu Z, Osmani M, Demian P, Baldwin A (2015) A BIM-aided construction waste minimisation framework. Autom Constr 59:1–23. https://doi.org/10.1016/j.autcon.2015.07.020

Liu H, Sydora C, Altaf MS, Han S, Al-Hussein M (2019) Towards sustainable construction: BIM-enabled design and planning of roof sheathing installation for prefabricated buildings. J Clean Prod 235:1189–1201. https://doi.org/10.1016/j.jclepro.2019.07.055

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), Santiago de Chile

López-López J (2019) Caracterización de los residuos de la construcción de la vivienda en México. Un modelo teórico. Universidad de Sevilla, Sevilla

López-Mesa B, Pitarch Á, Tomás A, Gallego T (2009) Comparison of environmental impacts of building structures with in situ cast floors and with precast concrete floors. Build Environ 44:699–712. https://doi.org/10.1016/j.buildenv.2008.05.017

Lu W, Chen X, Peng Y, Shen L (2015) Benchmarking construction waste management performance using big data. Resour, Conserv Recycl 105:49–58. https://doi.org/10.1016/j.resconrec.2015.10.013

Luciano A, Reale P, Cutaia L, Carletti R, Pentassuglia R, Elmo G, Mancini G (2018) Resources optimization and sustainable waste management in construction chain in Italy: toward a resource efficiency plan. Waste Biomass Valor. https://doi.org/10.1007/s12649-018-0533-1

Luciano A, Cutaia L, Cioffi F, Sinibaldi C (2020) Demolition and construction recycling unified management: the DECORUM platform for improvement of resource efficiency in the construction sector. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-09513-6

Matthew RA, McDonald B (2006) Cities under siege: urban planning and the threat of infectious disease. J Am Plann Assoc 72:109–117. https://doi.org/10.1080/01944360608976728

Medina Ross JA, México, Secretaría de Medio Ambiente y Recursos Naturales (2001) Minimización y manejo ambiental de los residuos sólidos. Secretaría de Medio Ambiente y Recursos Naturales, México

Menegaki M, Damigos D (2018) A review on current situation and challenges of construction and demolition waste management. Curr Opin Green Sustain Chem. Reuse and recycling/UN SGDs: how can sustainable chemistry contribute? Green Chem Educ 13:8–15. http://doi.org/10.1016/j.cogsc.2018.02.010

Mercader Moyano M (2010) Cuantificación de los recursos consumidos y emisiones de CO_2 producidas en las construcciones de Andalucía y sus implicaciones en el protocolo de Kioto (tesis doctoral). Universidad de Sevilla, Sevilla

Mercader-Moyano P, Ramírez-de-Arellano-Agudo A (2013) Selective classification and quantification model of C&D waste from material resources consumed in residential building construction. Waste Manag Res 31:458–474. https://doi.org/10.1177/0734242X13477719

Mercader Moyano MP, Camporeale PE, Cózar-Cózar E (2019) Evaluación de impacto ambiental mediante la introducción de indicadores a un modelo BIM de vivienda social. HS 9:78–93. http://doi.org/10.22320/07190700.2019.09.02.07

Miatto A, Schandl H, Forlin L, Ronzani F, Borin P, Giordano A, Tanikawa H (2019) A spatial analysis of material stock accumulation and demolition waste potential of buildings: a case study of Padua. Resour Conserv Recycl 142:245–256. https://doi.org/10.1016/j.resconrec.2018.12.011

Ministerio de Agricultura, Alimentación y Medio Ambiente (2015a) Real Decreto 180/2015 Traslado de residuos en el interior del territorio del Estado

Ministerio de Agricultura, Alimentación y Medio Ambiente (2015b) Plan Estatal Marco de Gestión de Residuos (PEMAR) 2016–2022

Ministerio de la Presidencia (2008) Real Decreto 105/2008. La producción y gestión de los residuos de construcción y demolición

Molar-Orozco ME, Velázquez-Lozano J, Vázquez-Jimánez MG (2020) Comportamiento térmico de tres prototipos en Saltillo, Coahuila (bloques de tierra, concreto y tapa de huevo). HS 10:22–31. http://doi.org/10.22320/07190700.2020.10.01.02

OECD (2020) The global economy risks falling ill. Interim report, March 2020 [WWW document]. OECD Economic Outlook. http://www.oecd.org/economic-outlook/. Accessed 1.13.21

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. Constr Build Mater 51:151–162. https://doi.org/10.1016/j.conbuildmat.2013.10.058

Park JW, Cha GW, Hong WH, Seo HC (2014) A study on the establishment of demolition waste DB system by BIM-based building materials [WWW document]. Appl Mech Mater. https://doi.org/10.4028/www.scientific.net/AMM.522-524.806

Parisi Kern A, Ferreira Dias M, Piva Kulakowski M, Paulo Gomes L (2015) Waste generated in high-rise buildings construction: a quantification model based on statistical multiple regression. Waste Manage 39: 35–44. https://doi.org/10.1016/j.wasman.2015.01.043

Procuraduría Federal de Protección al Ambiente (2014) Norma Oficial Mexicana NOM-161-SEMARNAT-2011

Rakhshan K, Morel J-C, Alaka H, Charef R (2020) Components reuse in the building sector—a systematic review. Waste Manag Res 38:347–370. https://doi.org/10.1177/0734242X20910463

Ram V, Kalidindi SN (2017) Estimation of construction and demolition waste using waste generation rates in Chennai, India: waste Management & Research. J Sustain Circular Econ 35(6):610–617. https://doi.org/10.1177/0734242X17693297

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

Ramírez de Arellano Agudo A (2014) Presupuestación de obras. Secretariado de Publicaciones, Universidad de Sevilla, Sevilla

Ríos O (2019) Instituto de ecología [WWW document]. Instituto de Ecología UNAM. http://www.ecologia.unam.mx/web/index.php?option=com_content&view=article&id=193. Accessed 4.22.21

Roux Gutierrez RS, García Izaguirre VM, 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, México

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

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

Tanikawa H, Hashimoto S (2009) Urban stock over time: spatial material stock analysis using 4d-GIS. Build Res Inf 37:483–502. https://doi.org/10.1080/09613210903169394

Turcott Cervantes DE, Romero EO, del Consuelo Hernández Berriel M, Martínez AL, del Consuelo Mañón Salas M, Lobo A (2021) Assessment of some governance aspects in waste management systems: a case study in Mexican municipalities. J Cleaner Prod 278:123320. http://doi.org/10.1016/j.jclepro.2020.123320

United Nations Environment Programme (2018) Waste management outlook for Latin America and the Caribbean

Villoria Sáez P, Santa Cruz Astorqui J, del Río Merino M, Mercader Moyano MP, Rodríguez Sánchez A (2018) Estimation of construction and demolition waste in building energy efficiency retrofitting works of the vertical envelope. J Cleaner Prod 172:2978–2985. https://doi.org/10.1016/j.jclepro.2017.11.113

Won J, Cheng JCP (2017) Identifying potential opportunities of building information modeling for construction and demolition waste management and minimization. Autom Constr 79:3–18. https://doi.org/10.1016/j.autcon.2017.02.002

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

Wu Z, Yu ATW, Shen L, Liu G (2014) Quantifying construction and demolition waste: an analytical review. Waste Manage 34:1683–1692. https://doi.org/10.1016/j.wasman.2014.05.010

Wu H, Duan H, Zheng L, Wang J, Niu Y, Zhang G (2016) Demolition waste generation and recycling potentials in a rapidly developing flagship megacity of South China: prospective scenarios and implications. Constr Build Mater 113:1007–1016. https://doi.org/10.1016/j.conbuildmat.2016.03.130

Wu Z, Yu ATW, Poon CS (2019) An off-site snapshot methodology for estimating building construction waste composition—a case study of Hong Kong. Environ Impact Assess Rev 77:128–135. https://doi.org/10.1016/j.eiar.2019.03.006

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

Xu C, Jia M, Xu M, Long Y, Jia H (2019) Progress on environmental and economic evaluation of low-impact development type of best management practices through a life cycle perspective. J Clean Prod 213:1103–1114. https://doi.org/10.1016/j.jclepro.2018.12.272

Yajnes M, Caruso S, Kozak D, Kozak A, Mühlmann S (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. 3er Congreso Internacional de Construcción Sostenible y Soluciones Eco-Eficientes, Universidad de Sevilla, Departamento de Construcciones Arquitectónicas I, Sevilla, pp 1035–1059

Yuan H (2017) Barriers and countermeasures for managing construction and demolition waste: a case of Shenzhen in China. J Cleaner Prod 157:84–93. https://doi.org/10.1016/j.jclepro.2017.04.137

Zahradnik P, Palmieri S, Dirx J (2020) Resolución sobre las propuestas del CESE para la reconstrucción y la recuperación tras la crisis de la COVID-19

Zaman AU, Lehmann S (2013) The zero waste index: a performance measurement tool for waste management systems in a 'zero waste city'. J Cleaner Prod 50:123–132. https://doi.org/10.1016/j.jclepro.2012.11.041