Waste Management 162 (2023) 102–112

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Strategies to promote construction and demolition waste management in the context of local dynamics

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ARTICLE INFO

Keywords:
Circularity in the construction sector
Construction and demolition waste (CDW)
Local scale strategy
Micro and small construction company
Municipality

ABSTRACT

Achieving a broad analysis of construction and demolition waste (CDW) management without considering local scale dynamics, and its detailed characteristics, is a constraint that has made it challenging to optimally engage in an integrated assessment of the circular economy principles in the construction sector. In this sense, this research demonstrates that investing in local strategies is important, involving municipalities and micro and small construction companies. Firstly, the results reveal the importance of having controlled sites, under local responsibility, for the preliminary storage of CDW, creating in waste producers the habit of separating waste onsite, reducing costs and limitations for municipalities. Secondly, frequent supervision actions at construction sites are also important at this scale, as they facilitate progress in terms of encouraging compliance with mandatory legal procedures and good practices for CDW management. But it is easier to improve practice through direct onsite procedures than it is with bureaucratic legal requirements alone. Thirdly, procedural control, implemented by municipal technicians in conjunction with other strategies, also helps to promote CDW management, this being associated with processes of public and private construction works subjected to license or prior control, in opposition to what has been accomplished so far. But the research also demonstrated that regular awareness, training, and supervision actions might increase the likelihood of improvements in behaviour on the local scale, in the sense that stakeholders acquire new habits, which, over time, might lead to better results locally and, as a consequence, influence other scales of intervention.

1. Introduction

Construction and demolition waste (CDW) policies and practices are very important subjects to be considered in the context of the efficiency of the construction sector (Kabirifar et al., 2020a), specifically when considering a circular economy approach (Oluleye et al., 2022). Since 2007 research has increased substantially in this area (Li et al., 2022b), focusing mainly on environmental sciences, engineering, green and sustainable science, and technology. In general, these challenges are important to frame in terms of future research, but also it is vital to frame CDW management within the respective scale of analysis (Santos et al., 2019; Gálvez-Martos et al., 2018), where different types of actions can be considered for implementation to improve sustainability mechanisms (Kabirifar et al., 2020b; Cruz, Gaspar & de Brito, 2019).

On larger scales, for example in Europe (Zhang et al., 2022), the challenges to promoting circularity in CDW management are closely related to generalist policies and trends of action and research (Wu et al., 2019; Umar et al., 2017), although strategies are usually adapted or implemented at different rhythms in each country, considering its specific characteristics (Luciano et al., 2022; Aslam et al., 2020; European Commission, 2017; Rodríguez et al., 2015). Around the globe there are realities where companies actively seek to take part in sustainable markets to be competitive, adding a green value, but also other realities where environmental awareness is not yet mature (Doussoulin & Bittencourt, 2022). These trends are often related to the balance between costs and the effectiveness of solutions for waste recovery (Ichinose & Yamamoto, 2011); the interconnection with new technologies (Li et al., 2020); or even the cooperation between actors with different levels of responsibility, also including determinants of behaviour (Chen et al., 2019; Bakshan et al., 2017; Wu et al., 2017; Li et al., 2018, 2015). But particular challenges appear at smaller scales. For instance, issues arise relating to the proximity of facilities, and modifications of behaviour

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https://doi.org/10.1016/j.wasman.2023.02.028
Received 16 November 2022; Received in revised form 19 February 2023; Accepted 22 February 2023
Available online 23 March 2023

often require collaboration between stakeholders (Ramos et al., 2023; Santos et al., 2019; Martinho et al., 2015). In this context, it is important to realise that without the local scale working properly, it is unlikely that the major objectives of circularity in the construction sector will be fulfilled.

From this perspective, this research project emerged considering specific constraints and knowledge gaps that were identified concerning the dynamics of CDW management on a local scale reality, from an operational point of view. This perspective means, specifically, studying the relationship between municipalities (Santos et al., 2019; APA, 2018) and micro and small construction companies (Ramos & Martinho, 2022, 2021) based on the fact that particular constraints make CDW management even more challenging on this scale (Ramos et al., 2023). This research project focused on the implementation of three local strategies, in terms of operationalisation and cooperation. The implementation of these local strategies was accompanied by capacitation, training, and supervision.

2. Construction and demolition waste management within smaller scales perspective

2.1. Constraints and challenges

The main purpose of this subchapter is to identify the driving factors that are most often recognised at smaller scales, for instance regions or municipalities, because they have specific constraints for CDW management when compared to national scales or wider territories. On the other hand, on smaller scales, it is important to understand the challenges that local stakeholders face, in terms of their capacity to act. In this sense, and because specific literature for CDW management on smaller scales is scarce, in terms of detailing specific experiments, or solutions, some of the references used describe general problems that are recognised, but are more often discussed in reports by local authorities or stakeholders rather than in scientific literature.

In the context described, CDW management challenges arise most of the time because of a lack of proximal infrastructure and its resulting relationship with cost efficiency (Penteado & Rosado, 2016; Sobotka & Sagan, 2016); limited budgets; staff availability, in terms of time; and the absence of a workforce with expertise (Swetha et al., 2022; Ramos & Martinho, 2021; Seror & Portnov, 2020). For instance, in Australia, Crawford et al. (2017) propose that for small communities it can be difficult to tackle some challenges, in terms of CDW management solutions, project priorities, financial incentives, and even company culture, because each group has its distinct characteristics.

Results from Wu et al. (2017), in this case referring to mainland China, express that CDW management intention is not a significant determinant of the subsequent behaviour of construction companies. The most important factors are economic viability, followed by the implementation of oversight actions and an organisation's background with environmental awareness, as also stated in the last case by Li et al. (2022a). However, Jin et al. (2019) identified that there is a research gap regarding human factors in CDW management that needs more attention in the future. And Li et al. (2022a) also state that more investigation is needed into different project stakeholders.

Additionally, it is vital to assess the availability of waste treatment facilities, especially intermediate waste management solutions, as proposed by Ichinose & Yamamoto (2011) for the case of Japan, or the cross-regional alternatives for CDW management, suggested by He et al. (2022) for China, that might have positive results in improving operational aspects. With a complementary perspective, Ma et al. (2020) reflect on the constraints of recycling plants in China, for instance the variable sources of CDW for recycling, the lack of design for minimisation, the absence of regulation for onsite sorting, the lack of coordination from government administration, and the need of a traceability system.

Also, Bao et al. (2020) discuss, for Hong Kong, the importance of considering a circular approach to the construction sector, with onsite recycling opportunities, and reincorporating CDW directly into the construction work, although identifying several challenges: site space constraints, the difficulties in trading recycled products within a narrow window of opportunity, the lack of support from off-site facilities, a lack of a demand–supply platform for exchanging information, and levels of government support. Specifically, recycled materials might have a higher cost than comparable raw materials, due to logistic conditions, for example the distances between buyers, suppliers, sellers, and consumers, as stated in a comparison between Brazil and France (Dousoulin & Bittencourt, 2022). So, it is also essential to consider this in the project phase, to plan real costs for materials and CDW management, and savings as a result of recycling, as supported by Ibrahim (2016), when assessing policies and practices in Massachusetts, in the United States of America. Furthermore, because CDW generated often ends up as mixed waste, this complicates the implementation of circularity principles into the construction sector (Crawford et al., 2017).

The discussion about the success of environmental taxes also plays an important role in terms of policy decisions, for instance in China (Wang et al., 2018). It is necessary to consider that higher taxes might lead to consequences that are harder to control, such as the reality of illegal dumping, a severe problem observed in several countries (Ramos & Martinho, 2023; Rodríguez et al., 2015; Yuan et al., 2011). This frequent CDW abandonment in some realities represents a loss of material that otherwise could be recycled (Ibrahim, 2016) because the mineral fraction is its main component (Ramos & Martinho, 2023; Sormunen & Kärki, 2019; Coelho & De Brito, 2011).

In these conditions, generally, reinforcing compliance with good practices on construction sites is needed (Mahajan et al., 2017; Ibrahim, 2016), including CDW separation (Menegaki & Damigos, 2018; Lockrey et al., 2016; Saez et al., 2013; Begum et al., 2009), presenting the advantages that can outweigh the disadvantages of a time-consuming activity (Rondinel-Oviedo, 2021). This can be performed by explaining that the treatment cost will be more affordable (Mahajan et al., 2017), and negative environmental impacts might be mitigated, for instance carbon dioxide emissions (Jung et al., 2015). For these purposes, effective communication tools are vital in achieving collaboration and improvement, implementing training actions to resolve knowledge gaps for all levels of workers (Al-Otaibi et al., 2022; Begum et al.; 2009), including addressing specific difficulties with legal framework compliance, as stated for Spain by Gangolells et al. (2014).

Furthermore, it is common to identify the non-existence of systematised data about CDW at these smaller scales (De Melo et al., 2011). Nevertheless, new methods have been developed to overcome the constraints, for instance those created by Kleemann et al. (2017) for the city of Vienna, in Austria, for the estimation of demolition waste in areas for which local data does not exist, using remote image matching for different periods. Or even harnessing data retrieved by Bernardo et al. (2016), for the Lisbon Metropolitan Area, in Portugal, using data collected from real demolition works and statistical information to determine CDW outputs, depending on the variables considered for the study area, such as correlations with population density, buildings ageing index, buildings density, and land occupation type. These new tools can improve supervision in different phases, but overall, improve planning supervision.

2.2. The Portuguese context

As in other European countries (European Commission, 2017), the construction sector was also identified in Portugal as an important, intensive use economic activity, and the Portuguese plan to encompass a circular economy strategy (PCM, 2017) points to regional and local agendas to promote solutions trying to mitigate constraints and inspire capacities. Also, Portugal has, since 2008, a specific legal framework for CDW management. That legislation was replaced by the new Portuguese law on waste (Decree-Law n.° 102-D/2020, of 10th December, with

subsequent amendments) (PCM, 2020), which now incorporates the subjects related to CDW.

Although the legal framework has existed for more than a decade, different constraints regarding CDW management have been identified by stakeholders at a political level, responsible for associations of the sector, or waste management operators (Ramos et al., 2023; European Commission, 2017; Martinho et al., 2015), namely: the need to reinforce legal procedures; the necessity to enhance recycling processes, resolving heterogeneity in the territory regarding the existence of CDW management solutions; the availability of a consistent market for recycled materials; and a lack of synergies between stakeholders.

On a level involving municipalities, the main constraints were identified through a survey conducted in 2018 by the national waste authority (APA, 2018): the absence of proximal solutions for CDW preliminary storage; gaps in information about cost issues; lack of oversight actions regarding legal procedures or good practices onsite, exacerbated by the lack of workforce, resources, and technical expertise; and procedural control regarding legal requirements.

Moreover, in Portugal, more than 95% of construction companies are micro and small companies (IMPIC, 2020): micro companies include entities with less than 10 workers and a turnover equal to or less than €2 million, while small companies present less than 50 workers and a turnover equal to or less than €10 million. These companies face many constraints associated with accomplishing good practices onsite and legal framework compliance, which is a challenge to the implementation of the circular economy principles in the smaller scale construction sector (Ramos & Martinho, 2022, 2021).

3. Method

3.1. The research approach

3.1.1. The case study

A region in Portugal was selected as a case study for the assessment of the local scale context for CDW management, named *Baixo Alentejo*, composed of 13 municipalities. It is a rural area of 8,543 km^2, with 115,326 inhabitants, leading to a low population density, averaging only 13.5 inhabitants per km^2 (INE, 2020). This region is characterised by a lack of final and intermediate infrastructure for CDW recycling (Martinho et al., 2015), making the costs of transporting CDW difficult to afford (Ramos et al., 2023). Although some local solutions have been tested over time, in a few municipalities, attempts to make equipment available or to create controlled sites under municipal responsibility for CDW storage have always experienced numerous limitations. Also, the reuse of components or construction materials is not yet a common practice in the region. Moreover, knowledge gaps exist in information regarding CDW management on a local scale context (Ramos et al., 2023), making more difficult the decision-making process.

The study area and the results presented refer to part of a wider research project, where in a previous phase diverse activities were implemented: the assessment of the influence of construction company size in CDW management practices (Ramos & Martinho, 2022, 2021); several workshops were developed during 2021 with municipal technicians and representatives of micro and small construction companies, concluding that the absence of cooperation between local stakeholders was influenced by important technical knowledge gaps, and a lack of local facilities or equipment for CDW management (Ramos et al., 2023); and the assessment of a serious problem in local scale contexts, both in terms of cost for municipalities, but also concerning the loss of material resources to the construction industry, namely the illegal dumping of CDW (Ramos & Martinho, 2023).

3.1.2. The terminology

The territorial typologies criteria from Eurostat (2019) were applied, considering the classification of the regions into: predominantly urban regions, intermediate regions, and predominantly rural regions. For the local scale context, within the current research project, the criteria for predominantly rural regions was applied, corresponding to the European Nomenclature of Territorial Units for Statistics, level 3 (NUTS 3), where at least 50% of the population lives in areas outside of urban clusters, with a population density usually less than 300 inhabitants per km^2 and/or fewer than 5,000 inhabitants.

The waste studied in this research project is composed of all the waste resulting from the construction activity, interpreted within the Statistical Classification of Economic Activities in the European Community (NACE), namely section F ("Construction"). In this context, the use of the terminology "construction" in the present research refers to a wider range of specific activities related to the construction sector, including the site preparation, new construction, rehabilitation, demolition, amongst others. With the same approach, terminology such as "construction work", "construction site", and "construction company" was used with the same wide-ranging approach.

Furthermore, a distinction was not made between construction waste, rehabilitation waste, and demolition waste, although differences exist in terms of the quantities generated and its physical composition (Coelho & De Brito, 2010). This approach was made following the definition of this waste stream in the European Directive 851/2018, of the European Parliament and of the Council of May 30th, amending the Directive 2008/98/EC on Waste (European Parliament, 2018): "waste generated by construction and demolition activities". Moreover, in the field, during the research project, it was not possible to determine whether the CDW delivered to facilities under municipal responsibility or illegally dumped CDW was a result, for instance, of new construction activity or demolition activity.

3.1.3. Objective and hypotheses

Within the research approach mentioned, and to tackle the identified local challenges facing CDW management on a local scale, the main objective of the research project was to test strategies, in cooperation with local stakeholders, to try to overcome the identified constraints and understand the factors that can lead to success.

From this perspective, three hypotheses were formulated: H1 – Municipal controlled solutions dedicated to CDW preliminary storage, with criteria established for its reception, help to mitigate municipal constraints; H2 – Supervision actions, executed by municipal technicians with expertise, on construction sites, improve the implementation of good practices and legal requirements by micro and small construction companies; and H3 – Procedural control is a vital instrument that, if implemented in coordination with legal requirements and established criteria, could improve CDW management control.

3.2. Local strategies

3.2.1. The identification of local strategies and the involvement of stakeholders

In this research project, three strategies were defined to test the improvement of CDW management in the context of local dynamics: i) Local Strategy 1 (LS1), to promote the CDW preliminary storage under municipal responsibility (hereinafter referred to as "Preliminary storage"); ii) Local Strategy 2 (LS2), to capacitate and to supervise good practices and legal procedures on construction sites managed by micro and small construction companies (hereinafter specified as "Supervision onsite"); and iii) Local Strategy 3 (LS3), referring to procedural control with respect to construction works, depending on the legal criteria applicable (hereinafter stated as "Procedural control"). The three strategies are described in more detail in subchapter 3.2.3.

Municipalities were free to choose the strategies they wanted to be involved with, in order to both support ideas that the municipalities had already developed but needed improvement, and to maintain motivation amongst decision makers as municipal leaders were to be interacting with causes they believed in. The implementation of the strategies started in November 2021 and finished in October 2022, although some

adjustments were needed, which are outlined below on a case-by-case basis.

An initial period to train and inform the municipal staff about CDW management topics was established. During the first stage, this capacitation component was implemented via videoconference, because of Covid-19 pandemic restrictions, with a small number of municipalities at each session, to facilitate answering questions and clarifying doubts. At the second stage, capacitation and training actions were reinforced in person. In the third stage, frequent awareness, training, and supervision initiatives took place in the region studied, together with local stakeholders, for 30 days in 2022, distributed between April and October. In this last phase, communication with the municipal staff and waste producers was implemented to try to improve CDW management.

From the 13 municipalities of the *Baixo Alentejo region,* only six accepted to test the local strategies. The non-participating municipalities declined due to constraints about the available resources, and for political reasons.

3.2.2. *The concept behind the design and implementation of the local strategies*

The design for the local strategies considered the main objective of understanding how it is possible to improve CDW management on a local scale dynamic, on an operational level, involving municipalities and micro and small construction companies and interconnecting this with a behavioural change approach. To accomplish this objective, the conception and implementation of the local strategies were inspired by the "COM-B Model of Behaviour", established by Michie et al. (2011), which considers three main drivers for behavioural change study: capability, motivation, and opportunity. The adaptations made to the original conceptual model relies on the reality of the construction sector, specifically in the context of proximity dynamics. In this context, Fig. 1 presents the concept behind the research project.

Some examples are given to better illustrate the relation between the local strategies and the behavioural change drivers, whether for municipalities or micro and small construction companies. First, the component "capability" relies upon the comprehension that behaviour arises from the physical capability to execute (*e.g.* the physical capability of the employees from the company to deliver separated CDW to the municipality) and from the knowledge to accomplish (*e.g.* the expertise of municipal technicians to supervise CDW management good practices). Second, the component "motivation" tries to understand whether the behaviour is a result of acquired habits (*e.g.* procedures implemented by municipal supervisors as a habit) or if it is a reflection of an action (*e.g.* if procedures are undertaken by companies because it is understood that doing so can reduce CDW treatment costs). Third, the component "opportunity" attempts to comprehend whether the behaviour modification is dependent on the physical resources available (*e.g.* a municipal site for CDW preliminary storage) or motivated by the influence of external forces (*e.g.* "pressure" placed on construction companies by municipal technicians, through communication about compliance with legal requirements).

3.2.3. *Description of local strategies and criteria for implementation*

3.2.3.1. LS1 – Preliminary storage. For LS1, the main objective was to evaluate the different variants of local solutions previously implemented by the municipalities for CDW preliminary storage arising from individuals, smaller amounts generated by construction companies, and CDW generated as a result of municipal construction works. Specifically, it involved dedicated spaces with differing criteria, but also the provision of equipment, such as multibenne containers for local CDW storage on construction sites before its transportation to municipal facilities. The recording of data regarding CDW management under municipal

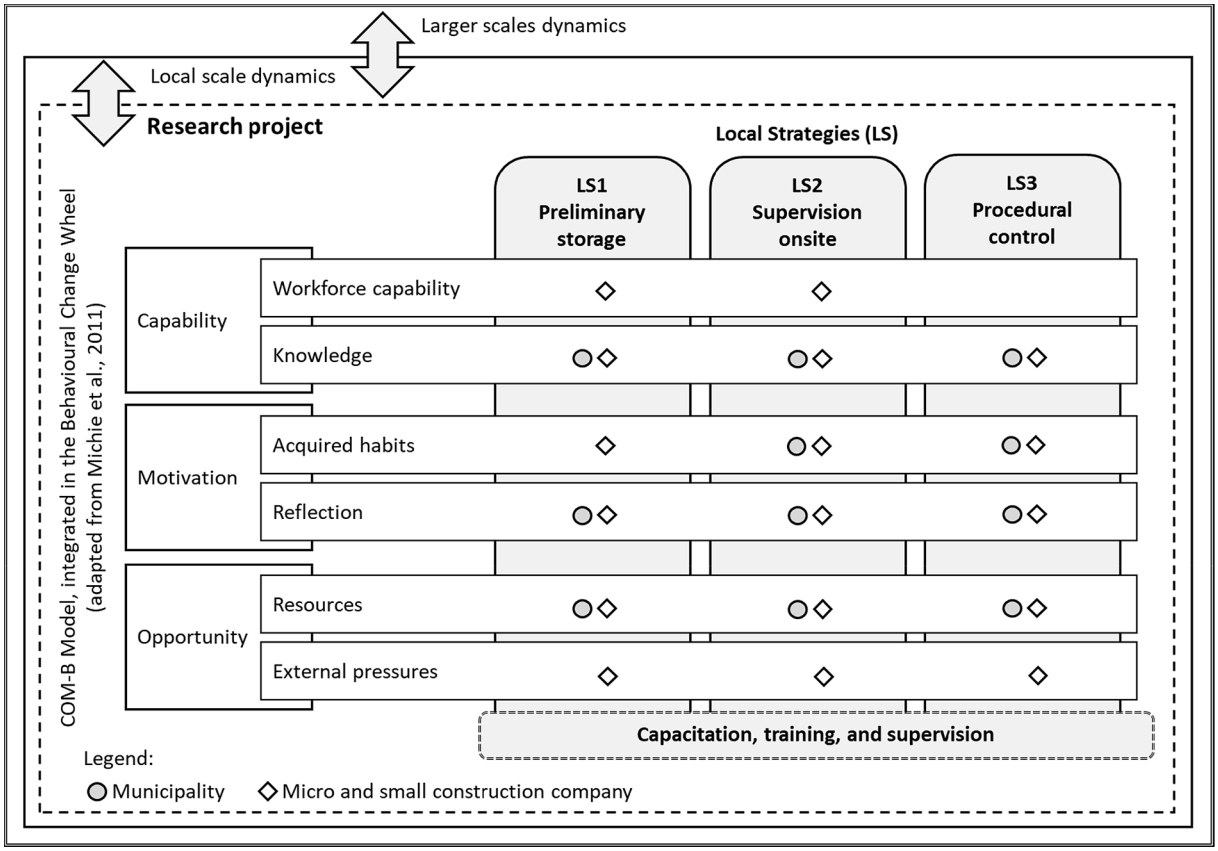


Fig. 1. The conceptual model for the implementation of the local strategies within the research project.

responsibility, in most cases non-existent before the implementation of the strategy, was proposed and implemented to comply with the objectives of the research project, collecting quantitative data. It was also recommended to reinforce oral communication about good practices concerning CDW management.

For operationalising LS1, the following data was requested each month: the type of waste received, classified with the 6-digit codes of the European List of Waste (ELW) (European Commission, 2014); the respective estimated quantity (or weight, if CDW was delivered to an authorised waste management operator, equipped with a weighbridge); and the perception of the onsite separation of CDW, due to the implications on costs it has for municipalities.

3.2.3.2. LS2 – Supervision onsite. The LS2 aimed to involve municipal technicians in the supervision of CDW management good practices on construction sites, predominantly the adherence to legal requirements. It was established that the focus would be on frequent visits to preselected private construction sites with municipal responsibility, subjected to a license or prior notification, and were being executed by micro and small construction companies, because it is the reality in which municipal technicians intervene most often. Moreover, construction works without a licensing process are difficult to track, and public construction works are habitually executed by medium and large construction companies, who are more familiar with compliance with legal procedures and good practices (Ramos & Martinho, 2022; 2021).

The evaluation in each visit was made considering two groups of criteria. In the first group, concerning an operational perspective at the construction sites, the following topics were assessed: i) organization of the construction site, regarding CDW; ii) separation of non-hazardous CDW; iii) management of hazardous CDW; and iv) confirmation of an authorised final CDW destination. The second group of aspects considered the following from the point of view of legal bureaucratic compliance: v) data registration of CDW management; and vi) electronic waste guides for CDW transportation.

3.2.3.3. LS3 – Procedural control. Concerning LS3, the objective was to evaluate the level of control for CDW management on licensing processes, under municipal responsibility. In this case, two different realities were considered: public construction works, and private construction works subjected to a municipal license or prior notification. These CDW management requirements are expressed directly in the new Portuguese law on waste (PCM, 2020) and are interconnected with Portuguese legislation concerning the construction sector.

To implement it, the following information was required for each specific process evaluated, whether private or public: i) characteristics of the intervention; ii) the CDW estimated for the intervention (supported by the indicators of Coelho & De Brito, 2011, 2010); and iii) the CDW declared at the end of the process.

3.3. Criteria to evaluate progress

Evaluation criteria were created to measure the progress of the implementation of each local strategy, with the aim of being minimal and easy to implement. The objective was to have a clear perception of what was happening at each point in time, as well as to reduce the subjective evaluation of criteria among municipal technicians. A 3-points ordinal scale was used for the subjects to be evaluated, always using entire numbers: "1″ (bad) if there was evidence that none or the very few of the requirements were implemented; "2" (medium) if it was observed or demonstrated that part of the requested strategies were executed, and "3" (good) if there was evidence that most or all of the main requirements were understood and implemented. For some aspects, a qualitative approach was also used to assess and discuss the results.

A *Microsoft Excel* format file was prepared and shared with each municipality, systematised to align with the criteria to be evaluated. A support document was also prepared, with instructions tailored to each of the local strategies, instructions about their operationalisation, and also complementary information about the legal framework or good practices applicable. All data was reported monthly, with supervision and feedback provided before starting the new data collection period.

3.4. Statistical analysis

To support the interpretation of results obtained during the field work of this research project, a statistical analysis was made on LS2 and LS3, performing the Wilcoxon signed-rank test, for two-tailed exact *p*-values, regarding differences in mean response. This test was chosen bearing in mind the sample size, leading to non-normality in most cases when inspected with the Shapiro-Wilk test, but also the ordinal scale of evaluation considered for each case (see subchapter 3.3). A value of $p \leq 0.05$ was considered as the minimum acceptable significance level, corresponding to a 95% confidence level.

For the two aforementioned local strategies, two specific moments were considered for evaluation. For LS2, with the objective of assessing if evolution has occurred, the matched-pairs chosen were: the first visit to private construction works subjected to a municipal license or prior notification, and then the behaviour measured between the second and the fifth visits. Regarding LS3, a comparison of each process of public construction work was undertaken between the project phase and the conclusion of the work, where legal procedures are mandatory.

4. Results and discussion

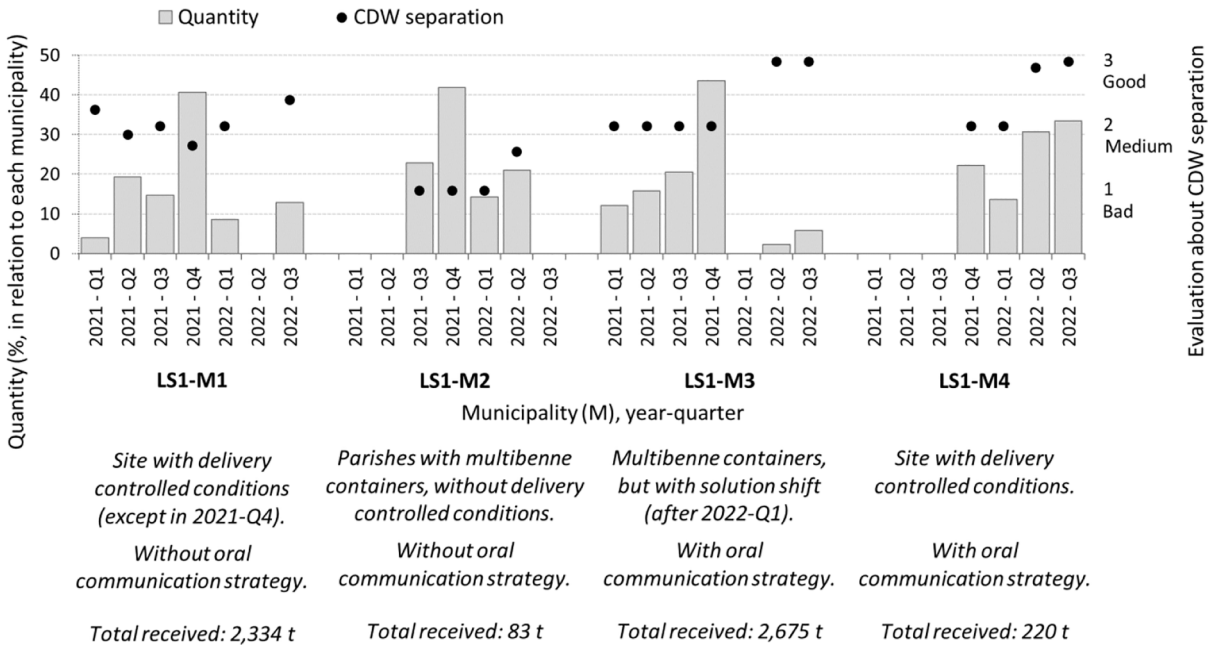
4.1. Preliminary storage

Four municipalities were involved in LS1 (*i.e.,* LS1-M1, LS1-M2, LS1-M3, and LS1-M4). It was not possible to consider all of them using identical criteria, mainly because it was not feasible to adapt their pre-existing solutions during the timescale of the project, due to investment constraints and a lack of political will. Nevertheless, these multiple conditions allow for the qualitative evaluation of different instances of the problem.

In Portugal, if reuse is not possible, it is mandatory to separate CDW on construction sites, into the following types: the mineral fraction (*i.e.,* concrete, bricks, tiles), wood, metal, glass, plastic, and gypsum. However, it is common that CDW appears as mixtures, mainly composed of the mineral fraction, but including other light-weight materials. In this context, for LS1 the CDW is evaluated in terms of the quality of the mixture received determined by the cost of the treatment that the municipality pays to the waste management operators, when this data is available or, when cost is unavailable, using the perceived quality, as a qualitative measure of the CDW received in municipal equipment or at controlled sites. Specifically, the evaluation was quantitative for municipalities LS1-M2 and LS1-M3. The approach was mostly quantitative, but also complemented with a qualitative assessment, in municipalities LS1-M1 and LS1-M4.

In the two aforementioned cases, criteria were established to harmonize criteria among municipal staff, related to the cost of the different types of CDW (*i.e.,* the mineral fraction is much more affordable to treat than CDW mixtures of the mineral fraction with high amounts of plastic, wood, or other types of waste). According to a market consultation performed for the region in 2022, in cases where the mineral fraction is clean, the cost for CDW treatment is about €20 per tonne. However, if the mineral fraction has high amounts of other waste, the treatment cost can rise to €90 per tonne or more.

In this perspective, Fig. 2 presents the amount of CDW, as the percentage of the total amount received by each municipality, because different realities and magnitudes had to be examined individually, avoiding distortions when behaviour evaluation was the key aspect to be assessed.



Legend: LS1 - Local Strategy 1 (Preliminary Storage).
Fig. 2. Municipal local solutions for CDW preliminary storage.

Regarding LS1-M1, there has been a controlled and secured site for preliminary waste storage since 2021, including CDW. The site is used by individuals, but more frequently by micro and small construction companies, who can deliver CDW without being charged any tariffs. However, the employee responsible for controlling the site was not present in the fourth quarter of 2021, for personal reasons, when a high volume of mixtures of CDW was accumulated. In this case it is possible to recognise that when a site is not adequately controlled, it presents disadvantageous results for the municipality, in terms of the amounts of CDW received (even from other neighbouring municipalities), uncontrolled mixtures of CDW, and the resultant higher costs for treatment. Nevertheless, although this site does not charge a tariff, this situation demonstrates the need that waste producers from a local scale dynamic have for intermediate CDW management solutions (corroborated by Ichinose & Yamamoto, 2011).

For LS1-M2, multibenne containers for CDW preliminary storage have been available in each parish since the third quarter of 2021, without control concerning who delivers CDW, although the sites have a fence, and a key has to be requested. CDW is delivered without any associated tariffs. Is it possible to recognise that when equipment is dispersed throughout the territory then CDW collection works. But again, when the solution does not involve control over CDW separation, it results in receiving uncontrolled mixtures of CDW, leading to high costs for the municipality regarding its treatment.

Concerning LS1-M3, multibenne containers for construction companies executing construction works without a municipal license or prior notification process were available from 2005 until the end of 2021. The service had a cost for waste producers, although it did not cover the full costs of providing the CDW collection service and subsequent treatment. In this case, there is a perception that charging a low cost for CDW management is not a deterrent in terms of conditioning the behaviour for delivering CDW to controlled sites (supported, in general, by Wu et al., 2017; Penteado & Rosado, 2016; and Sobotka & Sagan, 2016). Nevertheless, since the beginning of 2022, the decision was made to limit the preliminary storage service to only CDW arising from small repairs and minor do-it-yourself construction and demolition activities, within private households. It is evident that although the amount of CDW received decreased significantly, since most construction companies were not allowed to use the site anymore, the unsorted mixtures of CDW also decreased, benefiting the municipality in terms of the cost of CDW treatment. Since it is a recent change, it is not possible to study the wider effect of this shift, for example an increase in the illegal dumping of CDW (as stated by Rodríguez et al., 2015; and Yuan et al., 2011).

At LS1-M4, three controlled sites have existed since 2017, one in each parish, although there is little control over the quantities received, the conditioning of the CDW, or even the quantities that are eventually delivered to final waste management operators in terms of a lack of internal registers (also observed by De Melo et al., 2011). Nevertheless, the municipality agreed to implement the LS1, but only in the most representative site in terms of the CDW quantity received, beginning in the fourth quarter of 2021. On this site there is no charge for CDW producers, and an employee is responsible for controlling the reception of CDW in multibenne containers, by individuals or by micro and small construction companies, where the employee provides frequent oral instruction about the specific criteria of CDW accepted (in line with what is substantiated by Al-Otaibi et al., 2022; and Mahajan et al., 2017). It is evident that in this case, the quality of the CDW received benefits from the controlled conditions existing, namely from the oral awareness, avoiding constraints for the municipality in terms of the cost of treatment.

4.2. *Supervision onsite*

The Portuguese law on waste (PCM, 2020) establishes that the reuse of construction materials must be encouraged. When not possible, waste producers must guarantee CDW separation on construction sites. Disposal of CDW in a landfill is only allowed after it has been subjected to separation. In addition, good practice in terms of hazardous CDW, recommends that they are stored for the minimum period possible at the construction site, and that they are sealed in appropriate containers for each material, properly identified, in a ventilated place, protected from atmospheric agents, on a waterproofed floor, and with retention recipients.

A complementary legal framework exists regarding the regulation of waste transportation, including for CDW, where the waste generated should always be accompanied by an electronic waste monitoring guide, for traceability and supervision purposes. It is mandatory to keep a

register onsite detailing a summary of the CDW generated and its transportation.

In this context, LS2 relies on the implementation and supervision of legal requirements and good practices regarding CDW management on construction sites by micro and small construction companies, specifically at private construction works with a municipal license or an associated prior notification process. Four municipalities were involved (*i.e.,* LS2-M1, LS2-M2, LS2-M3, and LS2-M4). This supervision work implemented by municipal technicians relied on constant awareness, training, and supervision. This component was oriented towards municipal technicians, but also the representatives of micro and small construction companies involved, due to transversal and consistent knowledge gaps identified, but also with a view to replicating the knowledge at other present and future construction sites.

In the beginning, no criteria were established regarding which specific companies should be visited. The purpose was to allow municipal technicians to try out the procedures and gain confidence in supervision actions over time, including in public construction works, although these are beyond the scope of the research project, it would allow them to train in other realities and procedures.

From May 2021, the objective was to revisit five pre-selected private construction sites subjected to a municipal licensing process or prior notification, in each municipality involved, making five visits to each construction site in total, until October 2022, trying to encompass a conjoint evolution over time. This evidence is presented in Table 1. The number of visits established for each municipality was a compromise due to the lack of staff available to implement this strategy, but also the small number of construction works in progress in the area studied that were expected to last for the entire monitoring period, allowing to evaluate the evolution over time. In this case, the main research goal was to provide an example to replicate in the future, even if it was not necessarily fully representative.

Because it was the main objective of LS2 to measure the evolution of the pre-selected criteria over time, the objective of the first visit was to register the current situation on construction sites, before any training. Frequent visits were then implemented to raise awareness and teach the participants how to comply with the legal procedures and good practices required for effective CDW management. The results are presented in Table 2, with average values, for each visit. The evolution was not linear in all visits and between municipalities, but exhibits a general improvement over time.

In more in-depth analysis, the evolution was scored, using average values, to measure the development observed between the second and the fifth visits. The results are presented in Fig. 3. In general, it can be observed that compliance with the operational aspects onsite (*i.e.* construction site organization, non-hazardous CDW separation, hazardous CDW management, and licensed authorised final destination) achieved, in general, a better score in the first visit than the legal bureaucratic issues did (*i.e.,* onsite registers and traceability), with an average of 1.38 against 1.15, respectively. These results are closer to the worst evaluation ("1″ – bad) than the average ("2" – medium). When measuring the evolution between the second and the fifth visit, the results have the same tendency, with the operational aspects achieving a general average improvement of 0.39, against the legal bureaucratic aspects, with a general average improvement of 0.24, demonstrating, in the latter case, a slower tendency to evolve, and a resistance to comply with these types of procedures.

A clear improvement in the compliance with CDW operational management practices over time can be observed. Comparing the first visit with the period between the second and the fifth visits, in general, statistically significant differences are evident ($p \leq 0.001$). Evaluating each element, it can be concluded that the majority of cases present statistically significant differences between the two periods considered, namely: construction site organisation regarding CDW management ($p \leq 0.003$); non-hazardous CDW separation ($p \leq 0.002$); and authorised final destinations for the CDW generated ($p \leq 0.011$). Only the test for hazardous CDW management onsite was not statistically significant ($p \leq 0.066$). During the supervision process, it became evident that the management of this type of waste is particularly difficult to implement, due to knowledge gaps, relevant and consistent doubts about how to classify CDW as hazardous or not (*e.g.,* through the packaging labels), and how to store it in the proper conditions, as previously mentioned in this subchapter.

When comparing the legal bureaucratic aspects between the two previously mentioned time periods, statistically significant differences are evident ($p \leq 0.018$). Moreover, the differences remain statistically significant when the aspects are considered individually, namely for the procedures regarding the recording of CDW management data onsite ($p \leq 0.027$), but also the existence of documentation evidencing the CDW transport to an authorised final destination ($p \leq 0.017$).

Considering the results of LS2, there is the perception that more awareness and training must be done, to achieve better results over time (supported by Ramos et al., 2023; Li et al. 2022a; Jin et al., 2019; and Wu et al., 2017), focusing on the application of good practices onsite (corroborated by Rondinel-Oviedo, 2021; and Mahajan et al., 2017). This is because both municipal technicians and more significantly micro and small construction companies had not had sufficient opportunities in the past to cooperate and to demonstrate their doubts and seek clarification to address them (Ramos et al., 2023). Also, the pre-existence of substantial technical knowledge gaps is a challenge (Ramos & Martinho, 2022; 2021).

4.3. Procedural control

In general, the Portuguese legal framework for CDW is considered solid (European Commission, 2017). In terms of procedural control, it makes distinctions between private construction works subjected to a municipal licensing process or prior notification and public works. In private construction works, it is only mandatory to have records about CDW management during the construction phase (*i.e.,* data proving the CDW generated and transported to an authorised site), delivering it when required for the conclusion of the licensing process. In the project phase of public construction works, it is necessary to outline a specific CDW Prevention and Management Plan. Within the conclusion of the process, this Plan may also restrict the administrative acts that would license the project as complete, in cases of non-compliance with CDW management legal requirements.

The reality is that, in general, Portuguese municipalities are not assessing legal procedures to comprehend if CDW is being controlled in terms of procedural control (APA, 2018). Moreover, when documentation is delivered for evaluation, it is necessary to verify whether the declared CDW complies with the expectations for the construction work executed. But this analysis is infrequently undertaken. This context justifies, specifically in this research project, the importance of LS3 in

Table 1
Construction companies visited during the local strategy about supervision onsite.

Municipality	Construction companies visited initially (n.°)		Subsequent visits to construction companies (n.°)	
	Executing a public construction work	Executing a private construction work *	Construction works visited *	Total visits
LS2-M1	1	14	5	25
LS2-M2	3	9	5	25
LS2-M3	1	7	5	25
LS2-M4	1	10	5	25
Total	**6**	**40**	**20**	**100**

Legend: LS2 – Local Strategy 2 (Supervision onsite); M – Municipality; * Private construction work (with a municipal licensing process or prior notification).

Table 2
Results of the supervision of onsite actions for private construction works, for each visit.

Visit	Conformity analysis (average) *					
	Operational aspects (on construction site)				Legal bureaucratic aspects	
	Construction site organisation	Non-hazardous CDW separation	Hazardous CDW management	Authorised final destination	Procedures (onsite records)	Transport (traceability records)
1	1.35	1.50	1.05	1.60	1.05	1.25
2	1.80	1.90	1.05	1.70	1.20	1.35
3	1.90	2.05	1.15	1.75	1.25	1.40
4	2.05	2.15	1.20	1.90	1.35	1.45
5	2.10	2.20	1.25	2.10	1.50	1.60

* Using a 3-points ordinal scale: "1" (bad), "2" (medium), and "3" (good).

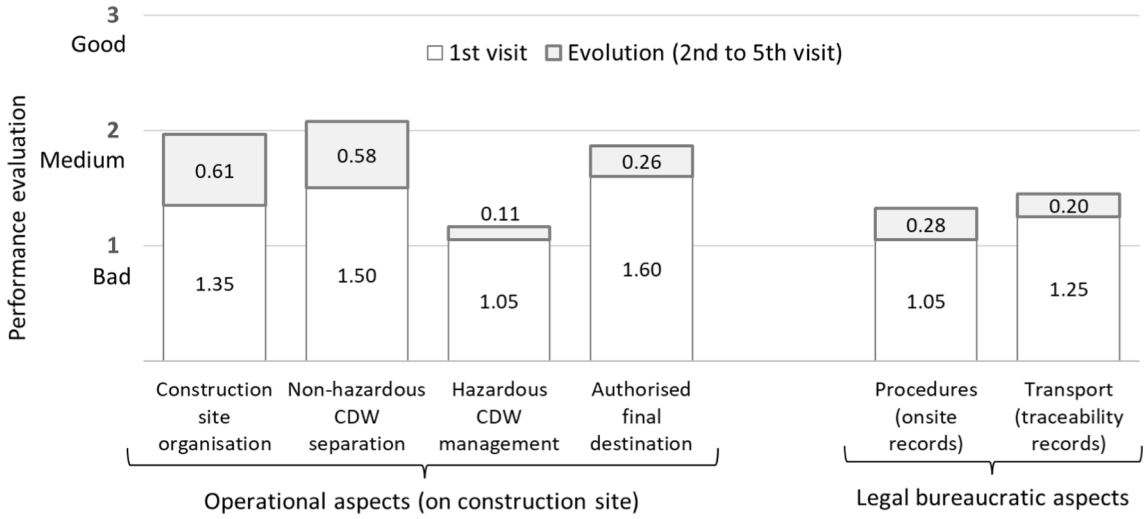


Fig. 3. The evolution of results following the supervision of onsite actions for private construction works.

raising awareness and improving the capacity on a municipal level for municipal technicians to implement this type of procedure.

The LS3 was implemented with three municipalities (*i.e.,* LS3-M1, LS3-M2, and LS3-M3) and the results are presented in Table 3. The outcomes demonstrate, for the private construction works analysed, that the applicants do not present evidence of CDW management when seeking the conclusion of the licensing process. Although only one municipality decided to be involved in this analysis, the insight acquired through the supervision process in the *Baixo Alentejo* region, also supported by the literature review (APA, 2018; Martinho et al., 2015), is that this reality is replicable for Portuguese municipalities in general, with the exception of some existing good examples.

The fact that the CDW Prevention and Management Plan is mandatory for public construction works, which are frequently executed by medium to large construction companies, with more technical knowledge (Ramos & Martinho, 2022, 2021), might indicate that the pre-existing knowledge of the companies might be an essential condition for better conformity with mandatory legal requirements. It means that, in the project phase, the aforementioned Plan is being presented together with the required documentation in 26 of the 32 assessed processes. Nevertheless, 50% of these applications have a bad conformity evaluation regarding the correct presentation of the document. For instance, in some cases the Plan is presented as a blank template, without any information about the predicted CDW to be generated during the construction phase, as it should be.

Regarding the conclusion phase of public construction works, 27 of the 32 processes assessed presented the mandatory Plan. However, 66% of these processes had a bad conformity evaluation. In this case, the

Table 3
Processes assessed and results regarding the local strategy for procedural control.

Type of Construction work	Phase evaluated	Assessment (in relation to each phase/processes evaluated)						
		Processes evaluated (n.°)	CDW generation					
			Predicted (project) or declared (conclusion) (%)	Conformity analysis **				
				General (average)	Distribution, by category (%)			
					1	2	3	Total
Private * (LS3-M1)	Conclusion	11	0	1.00	100.0	0	0	100.0
Public (LS3-M2, LS3–M3)	Project	32	81.3	1.94	50.0	6.0	44.0	100.0
	Conclusion		84.4	1.56	66.0	12.0	22.0	100.0

Legend: LS3 – Local Strategy 3 (Procedural control); M – Municipality; * Private construction work (with a municipal licensing process or prior notification): ** Using a 3-points ordinal scale: "1" (bad), "2" (medium), and "3" (good).

errors relate to the lack of documentation proving the correct transportation of CDW to an authorised site (in Portugal, an electronic waste monitoring guide, or proof that the declared CDW is below an acceptable level of conformity for the type of intervention executed). In the present research (Table 3), it means that if the CDW declared was less than 20% of the expected quantity, the classification attributed is bad; if the CDW declared is between 20 and 49% of the expected quantity, the classification is medium; and it is determined to be good for the remaining cases.

Performing a statistical analysis comparing the project phase *versus* the conclusion of the process, there is not a statistically significant difference between them (p greater than 0.05). This corroborates that in both phases it is necessary to reinforce the implementation of procedures in public construction works, in conjunction with a strong awareness and training component, involving municipal technicians and the applicants to the processes.

In this situation, it is essential to capacitate and try to implement the assessment of these processes, whether referring to private or public construction works because, without this component, CDW management on a local scale will not be possible to improve substantially, cooperating with other stakeholders (Ramos et al., 2023) and local strategies, and changing habits.

5. Conclusions

The legal framework regarding CDW management is well-established in several countries and contexts. Nevertheless, various constraints and challenges remain, and several of them relate to local dynamics. In these cases, without the contribution of smaller scale organisations, namely municipalities and micro and small construction companies, it will not be possible to successfully realise the principles of the circular economy, as these principles were designed to meet the demands of other contexts and realities, namely larger scales of analysis. At a smaller scale there are unique challenges regarding the lack of knowledge, habits, cooperation and an absence of solutions reducing distances and costs.

Specifically, the existence of controlled sites under municipal responsibility for CDW preliminary storage is essential to establish a reduction in distances to facilities, and the respective costs of the process, eventually minimising the reality of the illegal dumping of the CDW generated. In all cases, the sites must have controlled conditions in terms of access and an oral communication strategy to inform waste producers, teaching them how to use the facility and why it is important. The reception of sorted CDW is advantageous to municipalities because of the cost of treatment, and this is the main justification for investment in this strategy, not only in terms of the present benefits but also when considering the future, creating habits.

For supervision onsite of private construction works subjected to a licensing process or prior notification, which are often controlled by municipalities, the results show that with the frequent supervision of municipal technicians, it is possible to achieve an evolution in the procedures implemented onsite by micro and small construction companies. However, changes in behaviour regarding the mandatory legal bureaucratic aspects might be more difficult to achieve, or at least take more time to present results than the operational aspects at construction sites. Also, hazardous CDW management needs to be reinforced through awareness and training.

Municipal technicians are also frequently involved in the assessment of processes regarding private and public construction works but are not consequent at the conclusion of the processes to evaluate and penalise applicants that are not declaring mandatory documentation about CDW management. It is crucial to raise awareness about the importance of this strategy, in cooperation with other strategies, to better lead CDW management on a local scale to a higher level of performance.

In this research, it was demonstrated that the implementation of local strategies is essential to effectively promote CDW management in a context of proximity, at an operational level, involving municipalities and micro and small construction companies. Though it is vital to cooperate with the stakeholders involved in this specific reality, through frequent awareness, capacitation, training, and supervision actions, to help them to evolve continually, be motivated to achieve results, and learn to be independent.

These findings are important not only for rural areas, as is the context of the Portuguese study undertaken and evaluated here, but also for less developed countries, or regions where there is evidence of the same contextual conditions, such as the lack of proximity solutions for CDW management and gaps in cooperation between local stakeholders. The results obtained are also useful for areas where there are important gaps in local information, not facilitating political decisions based on technical information, which would serve as a driving force for positive changes to the planning process.

In a complementary way, society must be integrated into the strategies and solutions since occurrences such as the illegal dumping of CDW are difficult to catch. From this perspective, the involvement of citizens with a strong awareness of environmental problems might play an important role, together with more frequent supervision actions onsite, so the feeling of impunity in terms of illegal behaviour and best practices can be shaped by new circumstances.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

The authors would like to thank the municipal technicians and the representatives of the construction companies who collaborated on this research project.

The authors acknowledge financial support from the “(De)construct for Circular Economy” project, financed by the EEA Grants Environment Program (08_Call#2_(Des)construir_Economia_Circular). This work was also supported by the Portuguese *Fundação para a Ciência e a Tecnologia* (FCT) under the project LA/P/0069/2020 granted to the Associate Laboratory ARNET, and the strategic project UIDB/04292/2020 granted to MARE - Marine and Environmental Sciences Centre.

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