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StoPWa

Stormwater purification with construction and demolition waste

Final Report

Lahti

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HARJUMAA OMAVALITSUSTE LIIT

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sanāk!

StoPWa Final Report

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List of abbreviations

BET	Brunauer–Emmett–Teller surface-area method
CDW	Construction and Demolition Waste
DOC	Dissolved Organic Carbon
EC	Electric Conductivity
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Assessment
LDPE	Light Density Polyethylene
L/S	Ratio of the volume of water to the weight of filter material
NIR	Near Infrared
SEM	Scanning electron microscopy
SEM-EDS	Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy
TGA	Thermogravimetric analysis
TEA	Techno-economic assessment
TOC	Total Organic Carbon
TSS	Total Suspended Solids
XRD	X-ray diffraction
XRT	X-Ray Topography
XRF	X-Ray Fluorescence

1. Introduction

Contaminated stormwater generated both in coastal areas and the leaching from inland produces a risk to the quality of water bodies and the Baltic sea. The level and methods of stormwater management vary across cities and municipalities, and the problem is often overlooked. On the other hand, demolition of buildings creates vast amounts of construction and demolition waste (CDW), which is difficult to recycle and often ends up in landfills. The purpose of the project was to develop, design and build constructions for the treatment of stormwater, through which the contaminants will be removed or degraded. StoPWa project specifically aimed at finding a novel way to reuse poorly utilised fractions of CDW in stormwater treatment.

Three stormwater field pilot sites were planned with the aim of applying waste-based biofilters in stormwater treatment systems. The pilot sites were selected to represent different stormwater management arrangements in Finland, Estonia and Latvia. Each system was tailored to suit the local environment and stormwater volume, and therefore slightly different filter units and materials were designed for each site.

The six partners in the project were: City of Lahti, LUT University, University of Helsinki (UH), Tallinn University of Technology (TalTech), Union of Harju County Municipalities (HOL) and Smiltene Municipality. Lahti as the lead partner coordinated the project and organised the design and construction of the first stormwater field site. LUT University's key research areas are sustainable technologies and business, including utilisation of secondary raw materials. UH team had applied knowledge on urban hydrology and bioremediation of harmful substances. TalTech has competence in secondary raw materials and mineral processing technologies, as well as experience in water and soil cleaning technologies. All universities had the facilities for experimental studies, and students' theses and course projects were utilised in the project.

Cooperation between universities enabled a broader selection of measurement methods in the assessment of the usability of various CDW fractions. The joint efforts of microbiologists and environmental technologists were necessary in designing and analysing the experimental results of filter performance. To be replicable in different cities and environments from local CDW, waste-based filters in their design and implementation required cross-border cooperation between municipalities and researchers in the Baltic Sea region. HOL and Smiltene acted as intermediators of project results for local municipalities and external service providers. They each organised the procurement, planning and construction of a stormwater field site. In addition to partner organisations, the project's steering group had representatives from other municipalities, infrastructure service providers and waste management companies.

The purpose of this report is to summarise project's activities and results in an understandable way. The report aims to present the possibilities of CDW utilisation but also discusses factors that currently restrict the utilisation. Sustainability and techno-economic feasibility of stormwater arrangements as well as the business potential of the concept were also evaluated during the project. This report summarises the aspects and factors that are useful when considering utilisation of construction and demolition waste or implementing a stormwater management arrangement.

2. Construction and demolition waste (CDW)

2.1 Amounts, composition and pretreatment options

The construction sector has a remarkable role in the global economic engine, contributing to gross domestic product (GDP) and employment creation. It also acts as a driver of economic growth and sustainable development. Relating to the sustainability aspects, the sector also generates tremendous amounts of construction and demolition waste (CDW). For example, in the European Union (EU), CDW accounts for almost 40% of all generated waste, making it an important target to ensure its management environmentally and according to the circular economy. In the EU, a minimum of 70% by weight of non-hazardous CDW should be prepared for reuse, recycling and other material recovery (Cristóbal García et al. 2024).

Construction and demolition activities generate approximately 9.0 -- 12.5% of total waste amounts in so-called StoPWa countries; Estonia, Finland, and Latvia (Eurostat 2022). Because all waste generation has social, economic and environmental impacts, it is important to know CDW amounts also by locally. Researchers in the StoPWa project evaluated CDW amounts and composition at the beginning of the project in the year 2023. Evaluation based on the official statistical information and institutes, such as Statistics Finland, Statistic Estonia, The Estonian Environmentally Agency, and Latvian Environment, Geology and Meteorology Centre. In addition, previously reported studies accounted for the evaluation of CDW. Based on the status in 2023, Finland has the biggest amount of generated CDW in the StoPWa area, 15.1 Mt, while in Estonia and in Latvia, amounts were remarkably minor, 0.8 Mt and 2.8 Mt, respectively. The results demonstrated huge differences in CDW amounts between the StoPWa action areas. See that presented rates might be different compared to some other references due to the various practices in statistics data collection and presentation. Some data includes soil fraction in total CDW amounts, while some data excluded soil from total amounts.

Waste generation also describes a loss of valuable materials and resources within the economy, so it is interesting to know material composition if it includes some fractions for utilization. The material composition in CDW was also analyzed at the same time and with the same references during the CDW amounts evaluation. Three biggest fractions by percentages in CDW between StoPWa countries are presented in the following table (Table 2.1).

Table 2.1. Three biggest material fractions (%) of CDW without soil in three countries.

FINLAND	ESTONIA	LATVIA
Wood (25 %)	Aggregate (46 %)	Metal (24 %)
Aggregate (23 %)	Metal (29 %)	Plastic (21 %)
Plastic (15 %)	Other (18 %)	Aggregate (18 %)

Results showed remarkable differences in the CDW composition between Finland, Estonia, and Latvia. Common material in the three biggest fractions in three countries was aggregate, and its share in Estonia was almost half of all amounts, while in Finland and Latvia the shares were approximately quarter of below fifth (Appendix 1). The third biggest material category in Estonia was the class name of "other", and it was also a remarkable category in Finland and Latvia also. The remarkable share of "other" is one of the drivers that material separation needs more attention, and it will be deeper discussed in the next section.

Before CDW can be re-utilized, pre-treatment and separation of materials are necessary. Pre-treatment plays a critical role in processing CDW materials for re-utilization, and it includes three key approaches: manual sorting, size reduction, and screening. Manual sorting enables selective removal of unwanted contaminants and recovery of valuable materials. On the other hand, manual sorting is quite a labour-intensive approach.

Size reduction is also known as crushing, grinding, or shredding, and it improves material handling and increases material surface area. Screening classifies materials by particle size.

After pre-treatment, several mechanical and sensor-based separation methods become available for CDW. Conventional technologies are air separation (density-based), magnetic separation (ferrous metals), eddy current separation (non-ferrous metals), and ballistic separation (classification by shape and density). These methods are generally robust, scalable, and widely applied in CDW processing, but each has limitations in terms of material specificity or process efficiency. Advanced optical sorting technologies (e.g., XRT, NIR, XRF) provide high-precision material identification based on density or chemical composition, significantly improving purity levels, albeit at higher cost. Robotics-based sorting represents emerging solutions with strong future potential, particularly when combined with AI-driven automation and sensor utilization. It can be implicated that no single method is sufficient; instead, optimal CDW processing relies on combining pre-treatment and multiple separation techniques tailored to material characteristics. Well-designed pre-treatment and separation chains can significantly improve the quality and usability of CDW fractions, supporting their application in stormwater treatment while contributing to circular economy objectives and more sustainable practices.

2.2 Characterisation of CDW fractions

CDW fractions sourced from Finland, Estonia, and Latvia were selected and characterized in the StoPWa project to identify the most suitable candidates for stormwater filtration media. The fractions included both concrete-brick dominated materials (FLSC, EACB) and more heterogeneous mixed demolition wastes (FLSM, FLKM, EPM, LSZM), prepared as 0–5 mm and 2.5–5 mm particle size classes. A comprehensive analytical workflow was applied, combining sieve analysis and laser diffraction for particle size, automated image analysis for particle shape descriptors, scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS) for morphology and elemental composition, BET analysis for specific surface area, X-ray diffraction (XRD) for mineral identification, and thermogravimetric analysis (TGA) for thermal decomposition behaviour.

The particle size distributions (Figure 2.1) revealed that the fractions were not equivalent and should not be treated as interchangeable filter media. Sample EPM showed the most uniform size distribution, while other materials were distinctly coarser and more steeply graded. Automated image analysis showed that concrete-brick fractions (e.g. EACB) were more spherical and circular in shape, whereas mixed demolition waste fractions (e.g. FLKM) were more elongated and irregular. SEM observations confirmed this distinction: mixed wastes retained visibly heterogeneous textures, while concrete-brick fractions appeared compositionally more uniform.

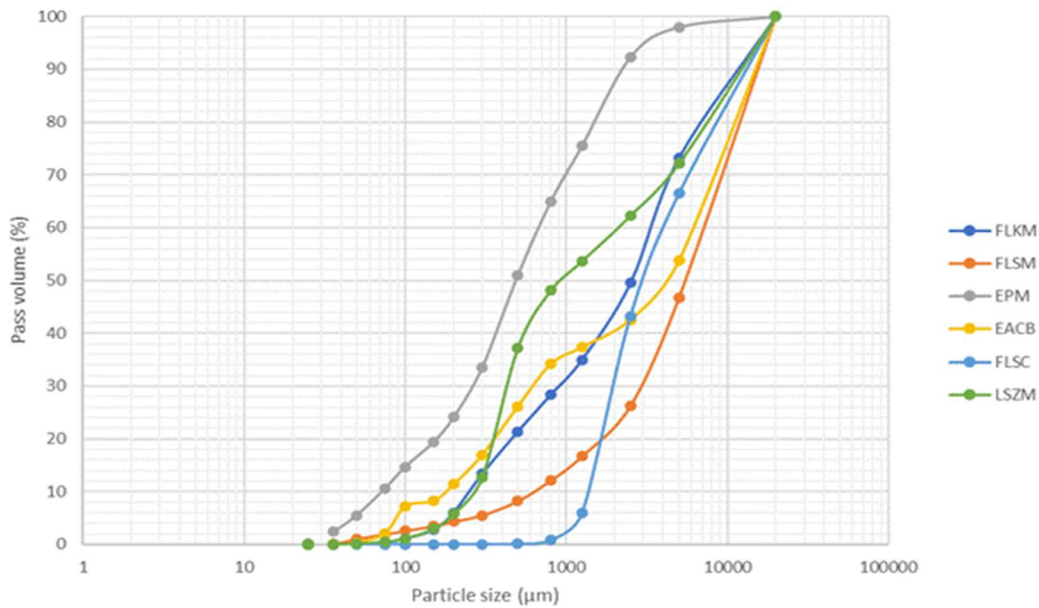


Figure 2.1. Cumulative particle size distribution of the six CDW fractions used in the StoPWa project.

Surface and compositional analyses further separated the fractions. BET specific surface area was highest in the concrete-brick fractions, especially FLSC-0-5 (33.7 m²/g) and EACB-0-5 (15.8 m²/g), with mixed waste fractions generally lower. XRD identified quartz and calcite across all samples, with albite present only in Finnish-derived materials and portlandite only in FLKM, indicating differences in cementitious history. TGA confirmed that concrete-brick fractions showed thermal decomposition behaviour typical of mineral hydrates and carbonates, while mixed waste fractions also exhibited decomposition events associated with biomass and plastics. Water-displacement porosity values ranged from 0.45 to 0.52 across the processed Finnish and Estonian fractions. Overall, the concrete-brick fractions combined high surface area and mineral stability, making them the most promising candidates for use as stormwater filtration media, while heterogeneous mixed fractions carry greater variability and require more careful characterisation before deployment. (Bolourieh et al. 2026)

2.3 Agglomeration of mixed CDW into filter media

As demonstrated, huge amounts of CDW have been created in society but it is still rather moderately utilized. The world is constantly seeking new, cost-efficient ways to reuse CDW that could open new opportunities and innovations. A certain option for CDW could be utilization as stormwater filtering material with low cost, as it was stated in the hypothesis of StoPWa project. CDW includes various waste fractions, such as brick and concrete waste, and mineral wool waste, which are difficult to recycle but those can be filtration compounds with an excellent adsorption feature as a hypothesis. The new solutions for material recycling may create new business opportunities for local enterprises and help cities and municipalities to build environmentally friendly innovations.

The aim of the StoPWa project was to develop and test a multilayer stormwater filtration system using CDW. Before CDW action as a filter material, it must be processed cost-efficiently and sustainability, and a feasible method for that purpose is the method of agglomeration. In the case of material science, agglomeration is defined as the process of combining fine particles or recycled materials into larger and uniform granules. In the public discussions, agglomeration might be known more familiar that “particles sticking together” and there are three following principles for it:

- Physical or chemical forces between individual particles
- Adhered binders on the solid surfaces, and material bridge between particles
- Chemical or physical modifications of the solids (specific process)

The processing of agglomeration can use various technologies and variables, such as mechanical pressure, heat, moisture, and additives. Agglomeration provides several advantages for materials, and in the case of filtration systems, it enhances the physical appearance of material (e.g. uniform structure, shape and size) and enables good control for porosity and external surface area, for instance.

CDW fine fraction has been recognized as a potential raw material source for re-utilization, due to its availability and low cost. Especially mixed CDW includes remarkable amounts of fine material. The more detailed material composition of studied CDW material in the project is described in the study of Suhail (2024). First agglomeration trials showed that raw material sources have not enough fractions that can act as a binding agent in the process. Therefore, recycled plastic polymers (LDPE, light density polyethylene) from the industrial side stream were added into the process, and a feasible agglomeration product was achieved (Figure 2.2). The final product of agglomerate reminds from the appearance as a light expanded clay aggregates.



Figure 2.2. LUT University agglomeration equipment (*left*) and produced agglomerated materials (*right*).

The material properties of produced agglomerates were analyzed by performing tests of compressive strength, cyclic stress, and freeze-thaw resistance. The mentioned tests describe well the ability of material to resist axial load without failure with and without specific stress ranges, as well as the influence of repeated freezing and thawing of water inside a material. Tests measuring essential features of material, because agglomeration is used as a filtration media, and it will undergo static loads due to layering of the filter beds as well as dynamic loads due to high volume of water flows. In addition, agglomerates are subjected to hydraulic pressure repeatedly during storm events and periodical loading and unloading can cause failure in materials. Poor freeze-thaw resistance can cause micro-cracks and lead to strength loss, affecting the performance and the durability of the structure, especially in the Nordic areas. The exact description of the tests and those results from the project are presented in the study of Herath Mudiyansele (2025).

It can be concluded that CDW-based agglomerates are technically feasible material for filtration media use. The processing of CDW by agglomeration is an excellent example of valorize value chain of CDW following the principle of circular economy. The biggest challenge of CDW agglomeration is the quite heterogeneous

nature of CDW, and therefore, pre-treatment actions will have a big influence to achieve uniform and homogeneous structure for materials and products.

3. CDW as stormwater filter material

3.1 Crushed CDW concrete

Laboratory scale reactors to be used as CDW packed bed column (bio)filters for the treatment of artificial stormwater were designed and assembled in the Laboratory of Environmental Technology, Department of Materials and Environmental Technology (TalTech). The downflow reactors were packed with a pre-selected composition and fractions of CDW, and water was supplied using pumps operating intermittently for 1-3 minutes every 8-12 hours (flow rate 1.83-1.91 L/min). CDW samples were mixtures of concrete, brick, tiles and ceramics (EWC code: 17 01 07). Three samples of the same composition but different size fractions: 0-16 mm, 0-25 mm and 16-32 mm were used. (Tikker et al.)

Table 3.1. Recipe for synthetic stormwater.

Parameter	Concentration, mg/L	Source	Comments
NO ₃ ⁻	3	KNO ₃	KNO ₃ 4.9 mg/L
PO ₄ ³⁻	0.3	K ₂ HPO ₄	K ₂ HPO ₄ 0.6 mg/L
Total Organic Carbon (TOC)	5	Humic acid; partially urea	Humic acid sodium salt (CAS nr 68131-04-4) 12 mg/L
Organic-N	1	Urea	(CAS nr 57-13-6) 2.2 mg/L
Zn ²⁺	0.12	ZnC ₄ H ₆ O ₄	ZnC ₄ H ₆ O ₄ 0.34 mg/L
Cu ²⁺	0.1	CuSO ₄ ·5H ₂ O	CuSO ₄ ·5H ₂ O 0.4 mg/L
Cl ⁻	1.75	NaCl	NaCl 2.7 mg/L

The duration of the experiment for each reactor was chosen based on the rationality and possibility of extending the filtration process until the potential biofilm formation in the reactor. Since the proposed composition of the synthetic stormwater (Table 3.1) did not imply the content of suspended particles, the most potential source of filter clogging was growing biomass. In turn, although the optimal pH for biodegradation processes can vary, maintaining a pH in the range of 6.5 to 8.5 usually supports effective microbial activity and degradation of pollutants.

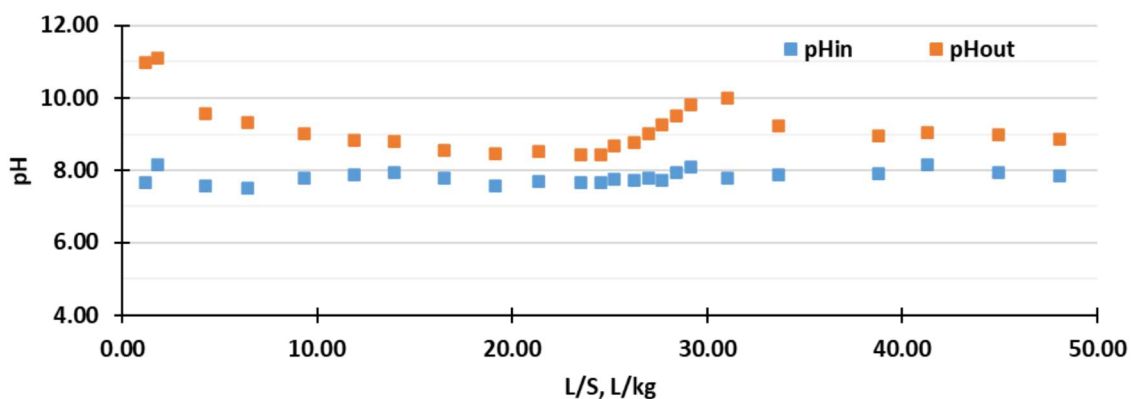


Figure 3.1. Measured pH values at the inlet and outlet of 16-32mm size fraction in repeated irrigations (L/S: ratio of the volume of water to the weight of the CDW material).

The results of the study showed that the residual alkalinity of the recycled concrete aggregates, the main component of the selected CDW, led to an increase in the pH of the synthetic stormwater outlet at the beginning of the long-term experiments, regardless of the size fraction.

Regarding the total organic carbon (TOC) removal, the efficiency is fairly promising, with no significant increase in concentration at the beginning of the experiment and in most cases with a certain removal of TOC content in the outlet water samples (Fig. 3.2). A similar concentration profile was obtained for the nitrogen measurements.

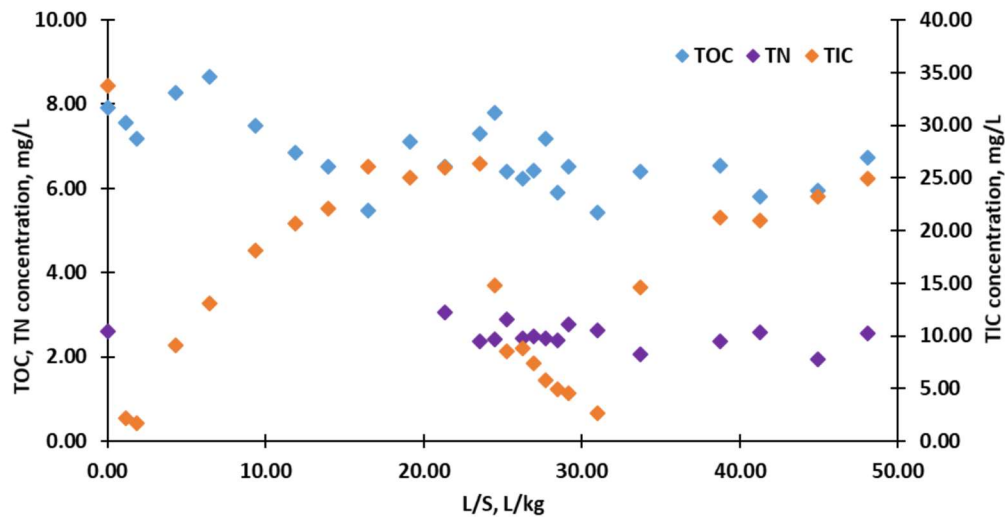


Figure 3.2. Measured TOC, TN and inorganic carbon (TIC) concentrations in repeated irrigations with synthetic stormwater.

Based on the obtained data, it can be concluded that among those studied, the 16-32 mm fraction of concrete-based CDW samples is the most feasible for subsequent pilot-scale use.

3.2 Agglomerated mixed CDW prototype filter

Experiments with agglomerated CDW filter material irrigated with synthetic stormwater were also carried out in TalTech using the same laboratory downflow reactors as in chapter 3.1. The preparation and manufacture of agglomerated CDW filter material was described previously in chapter 2.3. Three size fractions of agglomerates were used in the experiments: particle size under 4 mm, particle size above 4 mm, and an equal mixture of them both.



Figure 3.3. Agglomerate sample with a particle size fraction of >4 mm (left) and one of the reactors (right).

Regardless of the size fraction of the investigated agglomerates, only a slight increase in the outlet pH was observed throughout the entire experiment. Almost all analyzed cations and anions exhibited a decreasing trend over repeated irrigations, indicating a decline in leaching from the agglomerates. For some ions, the concentrations decreased to levels comparable to those in the inlet solution.

Total organic carbon (TOC) values exhibited a decreasing trend similar to that of most ions, eventually reaching concentrations comparable to those in the inlet solution. Overall, total nitrogen (TN) showed a promising removal trend that increased over the course of the experiment (Figure 3.4). The reductions in TN and nitrite/nitrate, together with the epifluorescence microscopy images, likely indicate that microbial growth occurred in the laboratory-scale reactors with agglomerated CDW as filter media.

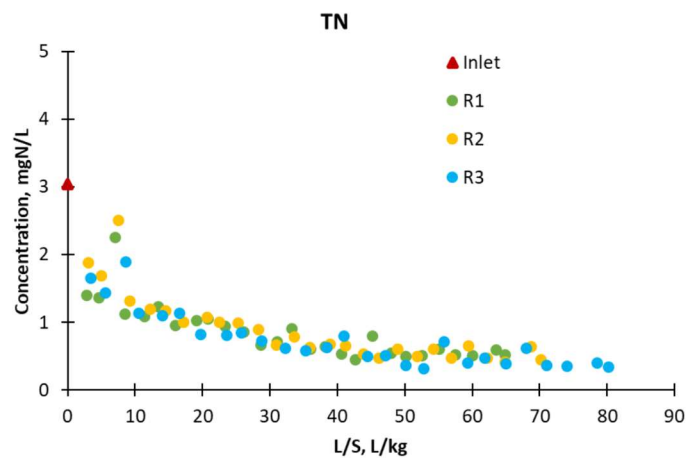


Figure 3.4. Concentrations of total nitrogen (TN) measured at the inlet and outlet for the three reactors.

In addition, the removal efficiency of zinc and copper was investigated. Although the effluent pH increased only to 8.4–8.5, which is significantly lower than in the experiments with recycled concrete, both heavy metals were still effectively removed throughout the experiment. Furthermore, the effluent concentrations of these heavy metals did not exceed the influent values.

First signs of possible biofilm residues were observed in the outlet samples from one of the reactors, starting at about halfway of the experiments. Brown, film-like structures continued to appear in nearly every subsequent sample. Epifluorescence images suggest that microbial growth likely occurred inside the reactors. However, based on these results alone, it is not possible to determine whether the observed bacteria were capable of effectively treating the stormwater.

Based on the obtained data, it can be concluded that, regardless of agglomerate size, all reactors exhibited similar performance and indications of microbiological growth. From the perspective of minimizing potential clogging, agglomerates larger than 4 mm appear to be the most suitable for subsequent pilot- or full-scale applications.

3.3 Agglomerated mixed CDW in pilot scale

Agglomerated CDW material (ACDW) was produced using large-scale agglomeration provided by Wimao Oy. Raw materials were mixed CDW residual (25%), waste wood (25%) and plastic waste (LDPE, HDPE, PP - min 60 %; PET, PS, multilayers - max 40%). The mixture was heated and agitated to form agglomerated particles. The size distribution of the ACDW produced in this way ranged from <1 to ~15 mm (Fig. 3.5). Filtralite® (expanded clay material) was used as a reference in the experiments carried out at the Soilia Soil Research Station in Lahti, Finland. Approximately 1 m³ of Filtralite® and ACDW produced by Wimao Oy from mixed waste was placed in each of six lysimeters.



Figure 3.5. Macro image of ACDW (*left*; red bar = 1 cm) and emptying the lysimeters in the end (*right*)

Approximately 300 l of tap water, a volume sufficient to saturate the material mass, was added to each lysimeter (determined by monitoring the mass of each lysimeter), and then allowed to sit for a period of six days. After six days, the water (leachate) was drained and sampled from the drainage port located in the bottom centre of each lysimeter. This cycle was repeated at total of six times. Weekly leachate samples were

submitted to ALS Laboratories in Helsinki for analysis of nutrients, total suspended solids (TSS), and total organic carbon (TOC) (Fig. 3.6). Bi-weekly composite samples of the leachate were collected for analysis of metals and persistent organic pollutants, also by ALS. In summary, and in-line with our observations from the lab-scale tests, ACDW was found to leach nutrients and metals.

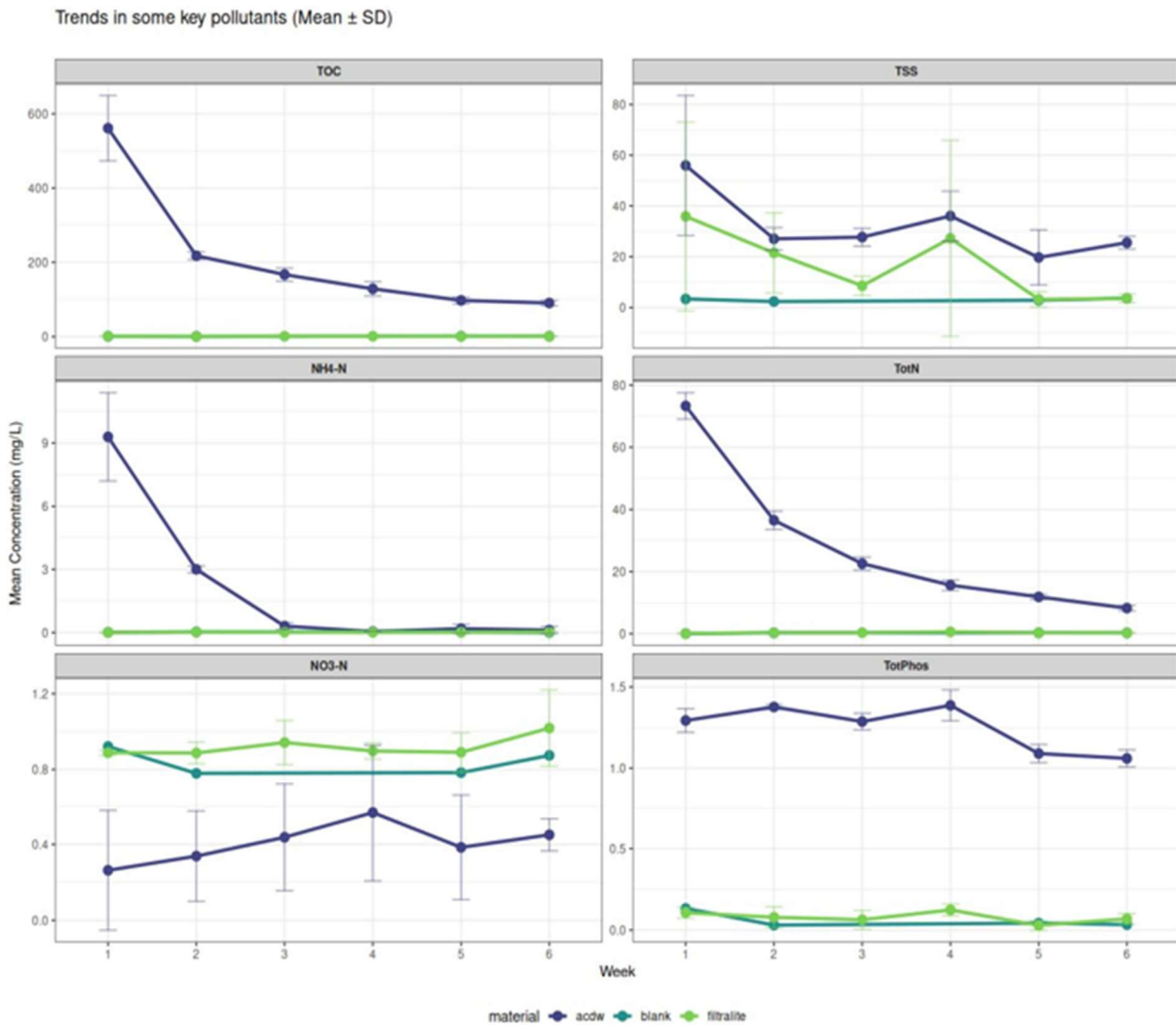


Figure 3.6. Trends in some key pollutants in ACDW, tap water and Filtralite® material leachates over the course of six cycles. Notably, the observed concentration of nitrate (NO3-N) was lowest in the ACDW.

A notable and interesting exception to this trend was nitrate (NO3-N), the concentrations of which were found to be lower in the ACDW leachate than in either the blank tap water or the Filtralite® leachate samples. This may indicate that a microbial community maybe developing in the ACDW mass that is absent in the Filtralite®, a conclusion that is supported by researchers at LUT, who observed what could be the rapid development of biofilms in this material.

Artificial stormwater experiment

At the conclusion of the lysimeter scale tests at Soilia, the lysimeters were emptied and ~10 l subsamples were collected from each (two per ACDW lysimeter, one from each Filtralite® lysimeter, nine in total). These were placed in 10 l plastic buckets in which a sampling tap had been installed. A solution mimicking artificial storm water (Valtanen et al. 2015) was mixed and three liters were added to each bucket, a volume sufficient to saturate the material. The solution was allowed to interact with the materials for a period of one week,

then was sampled and allowed to drain completely via the installed taps. These samples were analyzed by ALS for nutrients and metals.

Generally, the ACDW was found to contribute organic carbon, nitrogen (in the form of TKN), and phosphorous, but retained nitrogen in the forms of ammonium, nitrate and nitrite; as well as orthophosphate (Fig. 3.7). The results of the metals analysis was also mixed, with both ACDW and Filtralite® contributing some species, while retaining others. However, the commercially available Filtralite® outperformed ACDW overall.

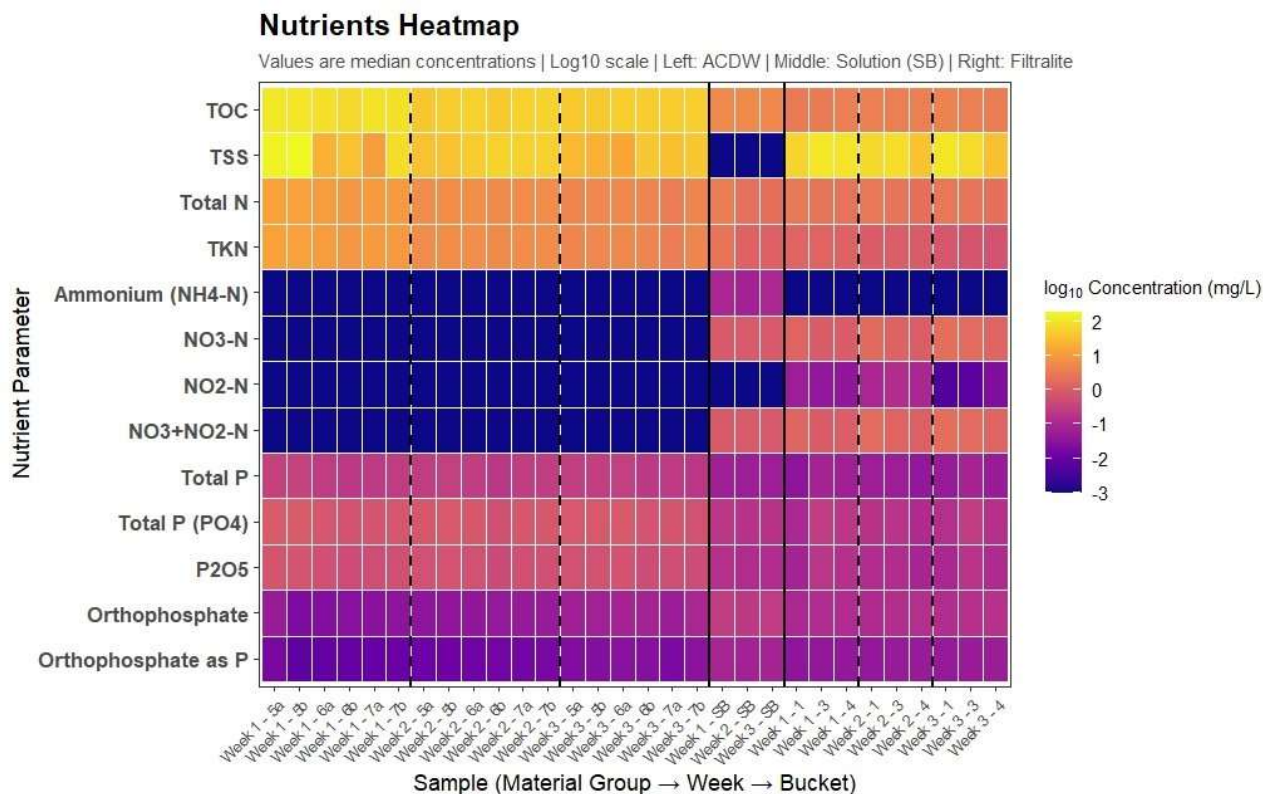


Figure 3.7. Heatmap of nutrients concentrations of artificial storm water after interacting with ACDW (left) and Filtralite materials (right). Artificial stormwater solution blanks are given in the middle.

To study the potential for the microplastics to migrate from ACDW, samples of the Filtralite and ACDW leachates from the lysimeter study were collected and filtered to extract any particles they might contain. These were then digested with 30% hydrogen peroxide to remove organic materials. Once digested, the filters were dried and taken to the FTIR laboratory at the University of Florence for analysis. This work is ongoing and final results are not yet available, however, initial findings indicate that ACDW does leach plastics.

Conclusions regarding agglomerated mixed CDW

The overall results from the previous experiments, at both the lab and lysimeter scales, indicate that use of mixed CDW, either in its raw state or as plastic bound agglomerated particles (ACDW), is not advisable. Both forms of were found to initially leach significant quantities of nutrients and metals, as well as measurable concentrations of some persistent organic pollutants. Therefore, exposure of this material to stormwater would result in the addition of contaminants to the environment rather than their removal.

3.4 Hydrodynamic of deep filtration through CDW-based media

Hydrodynamic behaviour is a key parameter for any filter medium, as it determines how water flows through the bed and what head loss the system must accommodate. LUT University evaluated the flow properties of processed Finnish (FCDW) and Estonian (ECDW) CDW fractions in size classes of 0.3–0.5 mm and 0.5–0.8 mm, using glass beads as reference material. Experiments were conducted in a laboratory depth-filtration column (internal diameter 95 mm, height 1.68 m) with packed-bed lengths of 0.3–0.6 m tested under varying water-head conditions (Figure 3.8). Pressure drop across the bed was measured over a range of superficial velocities, spanning particle Reynolds numbers from approximately 0.01 to 12.2 and covering laminar to transitional packed-bed flow regimes.

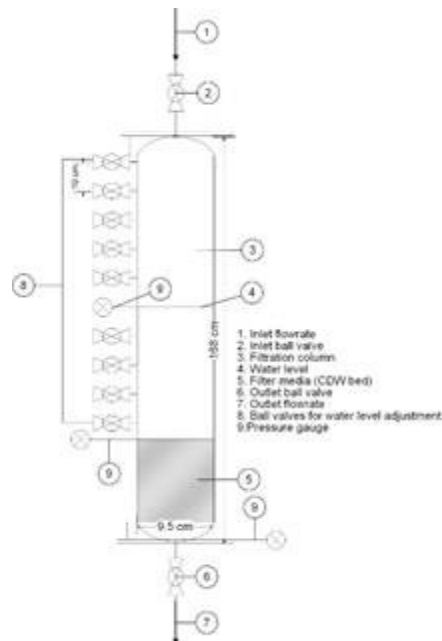


Figure 3.8. Schematic of the laboratory depth-filtration column used in the hydrodynamic experiments.

The results (Figure 3.9) showed that particle size was the dominant factor controlling hydraulic resistance: finer fractions produced substantially higher pressure drops than coarser ones, while porosity and sphericity had secondary influence. The finer FCDW 0.3–0.5 mm fraction, with its small equivalent diameter (0.247 mm), low porosity (0.45), and moderate sphericity (0.44), exhibited the greatest resistance in the dataset. The ECDW fractions were comparatively more open and, in the finer size class, more spherical, resulting in lower head loss. Pressure drop increased consistently with bed length and superficial velocity across all materials, in line with expected packed-bed behaviour.

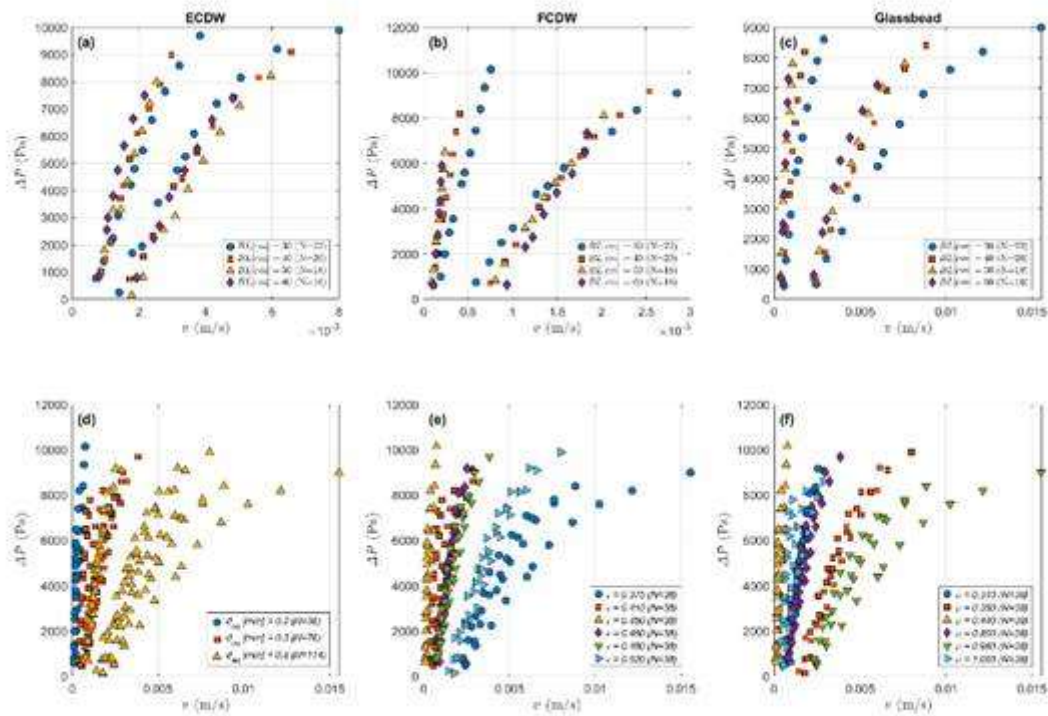


Figure 3.9. Experimental pressure drops as a function of superficial velocity for ECDW, FCDW, and reference glass beads across different bed lengths, particle sizes, porosities, and sphericities.

The classical Ergun equation described the pressure drop data better than the Kozeny–Carman equation across the studied flow range, as it accounts for both viscous and inertial contributions. Model accuracy improved markedly at higher Reynolds numbers: errors were largest at very low flow rates ($Re_p < 1$), attributed to wall effects and local packing heterogeneity, and dropped to 10–20% as flow increased. A gray-box artificial neural network (ANN) correction of the Ergun model achieved the best overall predictive performance ($R^2 = 0.87$, MAPE = 0.24), outperforming both the standard Ergun model ($R^2 = 0.83$) and Kozeny–Carman ($R^2 = 0.78$). The practical implication for filter design is that CDW fractions can be used as deep-filtration media, but head loss calculations must take into account particle size, fines content, irregular morphology, and structural heterogeneity to avoid systematically underestimating pressure drop.

4. Stormwater field pilots

In StoPWa project, three stormwater field pilot sites were designed and constructed, one in each of the participating countries. Stormwater treatment sites were implemented in Lahti (Finland), Rae Parish (Estonia) and Smiltene (Latvia). The sites were selected in cooperation with local authorities and experts to represent stormwater management needs with a reasonably large catchment area or stormwater volume. The pilot sites and their filtration units were designed with the aim of applying CDW-based biofilters as an essential part of stormwater treatment.

4.1 Lahti, Finland

In Lahti, the stormwater field site was implemented in a suburban area. The surface waters are released into Paskurinoja stream, which connects to Porvoonjoki river and eventually to Baltic sea. The aims of stormwater management were both quality control and reduction of erosion in the riverbed and surroundings. The

catchment area is 25 hectares with more than 70% urban land use. The area is occupied mostly with industrial and commercial premises, parking lots and a busy street. About 50% of the surface is impervious. The stormwater treatment site consists of a pretreatment pond, a wetland pond, a filter pond with a filter unit, and an outlet (Fig. 4.1). The site has a treatment volume capacity of 360 m³ and a flooding reserve up to 800 m³. The maximum flow capacity of the site is 450 l/s, and the estimated total annual treatment volume is about 52 000 m³. (Appendix 4)

The filter unit was designed to enable application of different filter medias and feasible replacement of material. The filter volume is about 24 m³ (dimensions 3 x 8 x 1 m) and the supporting structures are stone baskets. The current filter material is commercial expanded clay aggregate (Filtralite, granule size 10-20 mm), because the agglomerated filter material from mixed CDW could not be produced successfully with satisfactory volume and quality.

The construction of the stormwater management site was completed in July 2025, and the follow up of stormwater quality was started in December 2025. The follow-up plan included a total of 6-8 sampling events in March-May 2026. Samples were taken both from the inlet and the outlet of the site according to a common StoPWa protocol. After the project end, the site will be maintained by City of Lahti under supervision of city's stormwater engineer.

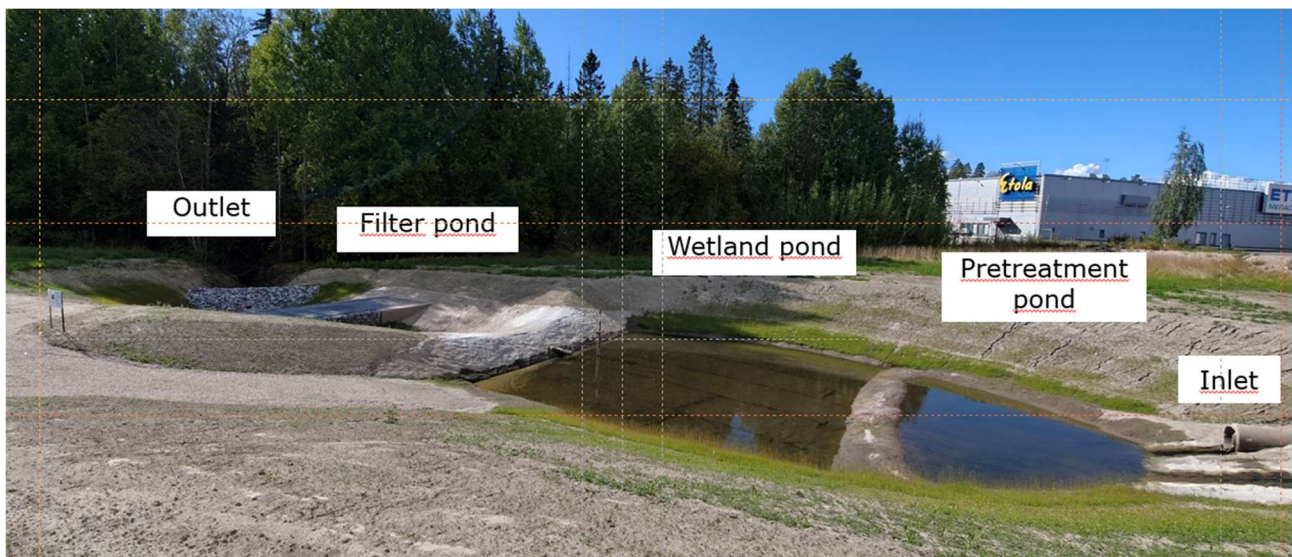


Figure 4.1. Stormwater management site in Lahti, Finland

4.2 Rae, Estonia

A cost-efficient stormwater filtration system has been designed and constructed at the Tähnase Road T5 property, located in Peetri Township, Rae Rural Municipality. There are four stormwater catchment areas in Rae Municipality: the Mõigu polder catchment, the Pirita–Ülemiste Canal catchment, the Pirita River catchment, and the Kurna Stream catchment. The Vaskjala–Ülemiste catchment area (also known as the Pirita–Ülemiste catchment), which concerns us, begins in Vaskjala and ends at Lake Ülemiste. The canal is part of the water supply system of Tallinn. The catchment area covers 28.6 km².

The filtration system consists of two multilift containers (Filter I with dimensions 2530 × 6000 × H 2000 mm, featuring a double bottom that enables gravity flow to Filter II; and Filter II with dimensions 2530 × 6000 × H

1000 mm). One container is filled with CDW concrete (crushed concrete aggregate, fraction 16–32 mm), while the other is filled with a commercial filter material (Estonian limestone aggregate, fraction 16–32 mm). The CDW originates from the Vão treatment facility operated by ATI Grupp OÜ in Estonia.

A distribution pipeline is installed above the containers in the form of a frame to ensure that stormwater passes through the filter material as evenly as possible. The filters can be operated either in parallel or in series. After passing through the filtration system, the stormwater is discharged back into the nearby ditch. Stormwater flows by gravity (via PVC De160 piping) from a nearby ditch into the IWS plastic pumping station. The water in the existing Sauki pumping station originates from paved asphalt areas within Peetri Township. New pumps from the KSB product range have been installed in both pumping stations to convey stormwater to the new filtration system.

To replace the filter material, the distribution pipeline located above the container must first be disconnected using quick couplings and removed. Thereafter, the multilift container, together with its contents (e.g. crushed concrete aggregate), can be transported by truck equipped with a multilift hook to the nearest licensed waste handling facility. (Appendix 5)

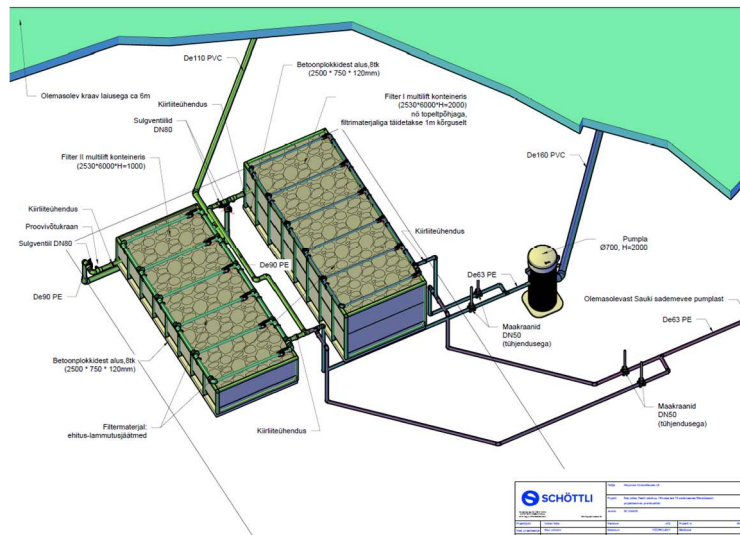


Figure 4.2. 3D view of the stormwater filtration system in Rae municipality, Estonia



Figure 4.3. Filter system pipe connections and fencing around the site

4.3 Smiltene, Latvia

In Smiltene, the stormwater field site was constructed in Smiltene Old Park at the upper pond of the existing pond cascade near Dakteru iela 14A. Stormwater from building roofs, streets and paved areas is conveyed towards Lake Vidusezers through a cascade of four ponds. The upper pond receives runoff from an approximate catchment area of 3.4 ha, and the ponds are subject to rapid growth of aquatic vegetation. The aims of stormwater management are to improve the water quality and also to reduce the risk of pond overgrowth, and integrate the technical solution into the historic park landscape while providing safe access to the pilot site.

The stormwater treatment site consists of an inlet manhole, a subsurface treatment unit with replaceable filter material, a sampling manhole and an outlet to the upper pond. The designed stormwater pipeline is a PP multilayer stormwater pipe OD315 SN8 installed in an open trench with ground anchors, with a total length of 15.0 m. The inlet structure is a reinforced concrete ring manhole \varnothing 1000, H=1.50-2.00 m, with a concrete base, sedimentation section, built-in wall grate, cover slab and grated cover. A separate stormwater sampling manhole \varnothing 400, H=1.00-1.50 m, has been installed downstream of the treatment unit.

The selected treatment unit is a certified ACO Stormwater Management unit capable of supporting the StoPWa pilot filtration technology. The constructed solution provides for a mixed construction waste filter material to be placed between two membranes, and the filter material / filter elements are replaceable. The filter material is identified as construction and demolition waste (CDW) fractions consisting of concrete, bricks and tiles with a size fraction of 16-70 mm. The filter unit is specified as a GRP tank with a treatment flow of $Q=5$ l/s, maximum overflow of 24 l/s, filter field area of 0.77 m², filter volume of 0.23 m³ and total tank volume of 966 l.

The completed site arrangement also includes park and landscape works around the treatment system in order to restore the area disturbed during the construction process. The outlet and the technical structures are integrated into the park by a stone embankment above the treatment units and slope strengthening with geocells anchored in the ground.

After completion, stormwater samples are taken from the sampling manhole and from the inlet/outlet arrangement according to the common StoPWa protocol. The completed system includes controlled conveyance to the pond cascade and an overflow function so that rainfall flows exceeding the treatment capacity do not create flooding risk in the surrounding park area. Long-term maintenance includes inspection of the inlet grate and sedimentation section, removal of accumulated sediment and oil residues where needed, replacement of the CDW filter material, and maintenance of the outlet, stone embankment, geocells and vegetation around the upper pond.



Figure 4.4. Stormwater management site in Smiltene and the tanks before installation.

4.4 Stormwater sampling results

Follow-up and monitoring of the sites was done by repeated stormwater sampling and analyses. Stormwater samples were taken from the inlet and outlet of the stormwater treatment system according to the previously prepared protocol (Appendix 7). Levels of suspended solids (TSS), nutrients, organics, and dissolved metals were analysed from the samples by a local accredited laboratory. Preliminary results in the three stormwater sites are presented in the table below. For heavy metals, dissolved concentrations were measured using a 0.45 µm filtration and ICP-MS analysis. Samples were taken during March-June 2026. The chemical analyses of Smiltene site were not available by the end of the project.

Table 4.1. Basic information of stormwater management sites

Site	Lahti	Rae	Smiltene
Maximum capacity (m³/h)	360	42	18
Filter material	Filtralite	CDW concrete	CDW concrete
Granule size range	10-20 mm	16-32 mm	16-32 mm
Number of stormwater samples	6	5	-

Table 4.2. Preliminary results of stormwater management sites in three locations

		Lahti		Rae		Smiltene	
		IN	OUT	IN	OUT	IN	OUT
pH		7,5	7,7	7,5	7,7		
EC	uS/cm	34	43	811	775		
Total Suspended solids (TSS)	mg/L	101	20	8,8	5,7		
Total Organic Carbon (TOC)	mg/L	9,7	7,0				
Dissolved Organic Carbon (DOC)	mg/L	8,5	6,4	37	33		
Total Nitrogen	mg/L	1,9	1,2	3,7	3,0		
Total Phosphorus	mg/L	0,14	0,06	0,16	0,13		
Cu	ug/L	10,5	8,6	3,1	3,9		
Ni	ug/L	3,3	2,9	1,4	2,7		
Pb	ug/L	0,3	0,2	0,1	0,3		
Zn	ug/L	210	58	16	27		

5. Environmental sustainability of stormwater treatment options

In the StoPWa project, Life Cycle Assessment (LCA) was applied to evaluate the environmental sustainability of stormwater treatment systems, and this chapter summarizes the main lessons learnt from conducting two LCA studies on stormwater treatment systems. By developing a filtration system that utilizes construction and demolition waste (CDW) based materials, the project examined innovative solutions that combine effective stormwater treatment with resource recovery.

Stormwater treatment systems should not be evaluated only based on their ability to remove pollutants. They also require construction materials, transport, installation work, maintenance, possible replacement of filter media, and end-of-life management. These activities can cause environmental benefits and environmental burdens. Therefore, to ensure that these solutions are truly sustainable, LCA is used to evaluate their environmental performance across all life-cycle stages, including construction, operation, maintenance, and end-of-life stages.

LCA is a methodology that can be used to support decision-making and assess the environmental sustainability of different stormwater treatment options. In the StoPWa context, LCA plays a crucial role in addressing several important questions, including:

- Which life cycle stages are most important for environmental performance?
- How do construction materials, transport, maintenance, and end-of-life management influence sustainability?
- What are the potential environmental advantages and challenges of using recycled construction and demolition waste-based filter materials?
- How can future stormwater treatment systems be designed with lower life cycle impacts?

The insights presented in this handbook are based on the master's thesis by Weerawardhana (2024) and the broader findings gained from LCA studies conducted in the Sustainability Science Department at LUT University. These studies focused on comparing different stormwater treatment systems, including the StoPWa pilot site in Lahti. More detailed results are presented in two scientific articles (Weerawardhana et al. 2026; Weerawardhana et al. n.d.).

5.1. LCA Methodology

In both studies, LCA was applied to evaluate the potential environmental impacts of stormwater treatment systems. The assessments followed the general principles of ISO 14040 and ISO 14044 standards. The functional unit was defined as the total volume of stormwater treated over an assumed 30-year lifespan, and the system boundary was cradle-to-grave.

The LCA modeling was carried out using Sphera LCA for Experts software (version 10.5.0.78) and the Sphera MLC database. Inventory data for the construction stage were mainly collected from project documents, while data for maintenance and end-of-life stages were supported by literature sources, due to the relative newness of the studied technologies and the limited availability of long-term primary data. The environmental impacts were assessed using the ReCiPe 2016 midpoint approach. The selected impact categories included global warming potential, human toxicity cancer, terrestrial acidification, terrestrial ecotoxicity, fossil depletion, land use, freshwater eutrophication, marine eutrophication, freshwater ecotoxicity, marine ecotoxicity, and human toxicity non-cancer.

5.2. Key Findings

The LCAs conducted for stormwater treatment systems provides a comprehensive understanding of the environmental trade-offs associated with their implementation. A key finding is that these systems offer clear environmental benefits during the operational phase, primarily by reducing pollutant loads discharged into receiving water bodies. However, these benefits are offset by environmental burdens arising from other life cycle stages, resulting in a clear burden shift that must be carefully evaluated in decision-making.

From a water quality perspective, stormwater treatment systems play an important role in mitigating impacts related to eutrophication and toxicity categories. The removal of the pollutants, mainly nitrogen (N), phosphorus (P), and heavy metals, including zinc (Zn), copper (Cu), and lead (Pb), is the key driver behind these environmental benefits. These substances are key contributors to the degradation of aquatic ecosystems, and their effective removal can significantly improve environmental performance in impact categories such as freshwater and marine eutrophication, ecotoxicity, and human toxicity (non-cancer). However, the magnitude of these benefits is highly sensitive to influent pollutant concentrations and treatment efficiency, highlighting the importance of site-specific water quality data and the strategic placement of systems in more polluted areas.

In parallel with these operational benefits, the LCA highlights the presence of notable environmental burdens associated with other life cycle stages. Construction, maintenance, and end-of-life (EOL) processes contribute significantly to impact categories such as global warming potential, human toxicity cancer, terrestrial acidification, terrestrial ecotoxicity, fossil depletion, and land use. Among these stages, the construction phase is often the dominant contributor across most impact categories, emphasizing the importance of material selection, design choices, and construction practices. Transport-related impacts also emerge as an important factor, particularly when heavy materials, such as stone, soil, and sand, are transported over long distances.

In addition, the end-of-life management of the materials contributes considerably to the overall environmental impact. The handling and disposal of inert materials, including excavated soil, used filter materials such as sand, stones, and other aggregates, can generate significant impacts if not properly managed. These findings underline the importance of adopting circular economy principles, such as material reuse and recycling, to reduce environmental burdens associated with disposal.

Regarding the environmental sustainability of the CDW-derived filter, the LCA results provide some insights into its potential advantages and challenges. The main potential advantage is that they can support the circular economy by creating useful applications for waste-derived materials and reducing the need for virgin raw materials. Moreover, the filter material effectively removes some pollutants such as nutrients and heavy metals from stormwater thereby contributing to lower water related impacts, especially in eutrophication and toxicity-related categories. However, the LCA also shows that recycled materials are not inherently more environmentally beneficial in all cases. Their overall performance depends on several factors, including the energy required for processing, transport distance, material quantity, durability, replacement frequency, possible leaching of substances, and end-of-life management. Therefore, these materials should not be assumed to be environmentally beneficial solely because they are recycled waste, but they should be assessed based on both their water treatment performance and their overall life-cycle impacts.

The LCA studies indicate that achieving environmentally sustainable stormwater treatment involves more than just effective pollutant removal. Factors such as material selection, construction practices, transportation distances, maintenance requirements, system lifespan, and end-of-life management all play

a crucial role in determining overall environmental performance. In the StoPWa project, using filter materials derived from construction and demolition waste offers a promising opportunity to integrate stormwater treatment with improved CDW recycling. However, their use should be supported by careful assessment of long-term treatment efficiency, leaching behavior, durability, and disposal impacts.

6. Techno-economic feasibility

The techno-economic feasibility of construction and demolition waste (CDW)-derived filtration systems was evaluated using a systematic techno-economic assessment (TEA) framework to determine their practicality for decentralized stormwater treatment applications under Nordic conditions. The assessment focused on whether waste-derived filtration materials can provide a technically viable, economically competitive, and circular alternative to conventional commercial filter media currently used for urban stormwater management. The analysis considered CDW-derived agglomerated filtration materials and benchmarked their performance against expanded clay, processed clay, and biochar using harmonized technical, operational, and economic assumptions.

The techno-economic assessment adopted a cradle-to-grave system perspective, considering raw material acquisition, processing, transportation, installation, operation and maintenance (O&M), replacement, and end-of-life management over a 50-year operational lifespan. A decentralized stormwater filtration unit operating under representative Nordic conditions was selected as the functional unit to ensure comparability across scenarios. Economic feasibility was assessed through key performance indicators, including Net Present Cost (NPC), Levelized Cost of Treatment (LCOT, €/m³ treated water), and cost per pollutant removed (€/kg), enabling direct comparison between circular CDW systems and conventional filtration materials.

Results indicated that CDW-derived filtration systems demonstrated strong techno-economic competitiveness due to low material cost, local availability, and lower processing requirements compared with thermally processed conventional materials. Expanded clay and processed clay require high-temperature thermal treatment, while biochar production depends on pyrolysis and costly feedstock preparation, increasing their economic burden. In contrast, CDW-derived systems benefit from low-cost or near-zero-cost feedstock and comparatively low-temperature crushing, sieving, and agglomeration processes, reducing production-related expenses. Local sourcing of CDW additionally lowers transportation costs and improves circularity performance.

The assessment further demonstrated that circular end-of-life pathways significantly improved economic performance. Recycling and reuse scenarios generated reduced overall costs through avoided disposal expenses and recovered material value, whereas landfill disposal increased total life-cycle burden. Among evaluated alternatives, CDW reuse and recycling scenarios exhibited the lowest Net Present Cost values, outperforming conventional filtration materials over the 50-year assessment period. Although benchmark materials occasionally demonstrated higher contaminant-removal efficiencies, CDW-derived systems provided a favourable balance between treatment performance, economic feasibility, and circularity potential. Sensitivity analysis further revealed that operational expenditure, maintenance intervals, and replacement frequency were among the most influential parameters affecting long-term economic performance.

6.1 LCCA

A life-cycle cost assessment (LCCA) was further conducted to evaluate the long-term economic viability of CDW-derived stormwater filtration materials across their entire service life. The LCCA framework considered all direct costs associated with filter production, operation and maintenance, transportation, and end-of-life management. The assessment followed a cradle-to-grave perspective and assumed a representative filter lifespan of 50 years, reflecting common service-life assumptions for stormwater treatment systems and decentralized infrastructure applications. A representative field-scale installation developed in Lahti, Finland, containing approximately 15 tons of filter material, was used as the reference scenario.

The production phase included costs associated with CDW acquisition, crushing, sieving, agglomeration, installation, labour, transportation, and energy requirements. Results showed that production costs were dominated by agglomeration and installation activities, while transportation contributed comparatively less to total expenditure. However, the analysis demonstrated that production costs represented only a minor fraction of total life-cycle costs. Instead, operation and maintenance activities emerged as the dominant economic component of the filtration system. Scheduled maintenance, monitoring, and cleaning activities repeated throughout the service life contributed more than 80% of the total expenditure, highlighting the importance of maintenance optimization for long-term cost reduction.

End-of-life scenarios strongly influenced total economic performance. Conventional landfill disposal generated the highest overall cost due to transport, gate fees, and waste handling. In contrast, recycling scenarios through re-agglomeration, casting, or reuse significantly reduced total life-cycle expenditure and improved economic efficiency. Recycling through casting demonstrated the greatest cost reduction, emphasizing the importance of circular material recovery for reducing environmental and economic burdens associated with stormwater filtration systems. The findings support the practical viability of integrating CDW-based materials into decentralized stormwater infrastructure while simultaneously supporting circular economy principles.

6.2 Key findings and business potential evaluation

The results from both techno-economic and life-cycle cost analyses indicate strong commercialization potential for CDW-derived stormwater filtration systems, particularly in regions emphasizing circular economy implementation and sustainable urban water management. Several characteristics support their business viability, including low-cost and locally available feedstock, lower production intensity relative to conventional filtration materials, reduced transportation burden, and opportunities for end-of-life recycling and reuse. Compared with commercial alternatives such as expanded clay, processed clay, and biochar, CDW-derived systems provide economically attractive performance while simultaneously reducing landfill disposal of construction waste.

The increasing demand for decentralized stormwater treatment technologies in urban environments, combined with stricter environmental regulations and circular economy policies, provides favourable conditions for future implementation. In Nordic regions, where freeze–thaw cycles, intermittent hydraulic conditions, and climate resilience are increasingly important considerations, low-cost and durable filtration materials represent an attractive opportunity for municipalities, infrastructure operators, and recycling industries. Moreover, the use of waste-derived materials aligns with EU sustainability targets and resource-efficiency objectives, increasing the scalability potential of CDW-based filtration technologies. While pilot-scale validation and long-term field performance remain necessary before full commercialization, the present

findings establish a strong scientific and techno-economic basis for future industrial development and deployment.

7. Summary and conclusions

The StoPWa project explored how construction and demolition waste (CDW) can be reused as filter materials for stormwater treatment, addressing both water pollution and the large volumes of underutilised waste generated in the construction sector. The work combined laboratory experiments, pilot-scale testing in three countries, and environmental and economic assessments.

Two main filter materials were investigated. Crushed CDW concrete proved to be technically feasible but not so effective in water treatment. Laboratory and field results showed a limited performance in removing key pollutants such as suspended solids, organic carbon, nutrients and some heavy metals from stormwater, with the 16–32 mm fraction being the most suitable for practical use. The material's natural alkalinity initially increases pH, but overall treatment performance is promising and relatively stable. In contrast, agglomerated mixed CDW, produced by binding fine waste fractions with recycled plastics, showed mixed and largely negative results. Although laboratory tests indicated significant nutrient removal and microbial activity, pilot-scale studies revealed that the material can also leach nutrients, metals and potentially microplastics into water. This means it may worsen water quality rather than improve it. As a result, the report concludes that mixed CDW and plastic-bound agglomerates are currently not advisable for stormwater filtration without further development.

Three stormwater field pilot sites were designed and constructed in the project in Finland, Estonia and Latvia. The sites had variable designs, dimensions, filter applications and filter materials to provide a broader comparison and to enable the use of local CDW materials. Preliminary stormwater monitoring results showed a reduction in the suspended solids and nutrient levels, but variable results in the heavy metal levels.

Life Cycle Assessment (LCA) showed that stormwater treatment systems provide clear environmental benefits during operation by reducing nutrient loads (nitrogen and phosphorus) and toxic metals entering water bodies. However, these benefits can be offset by environmental burdens especially from construction but also from transport, maintenance and end-of-life handling. Using CDW can support circular economy goals and reduce the need for virgin materials, but sustainability depends strongly on factors such as transport distance, durability and potential leaching. From an economic perspective, CDW-based filters are competitive due to low material cost, local availability and reduced processing requirements compared to conventional materials like expanded clay or biochar. Overall, CDW-based solutions offer strong potential for cost-effective and circular stormwater management.

Several knowledge gaps remain. The long-term performance and durability of CDW filters in real conditions are still uncertain, especially regarding clogging, ageing and pollutant breakthrough. The risks of contaminant leaching—particularly from mixed CDW and agglomerates—require further investigation. In addition, questions remain on microbial processes within filters, optimisation of material processing methods, and the possible leaching of microplastics. Finally, scaling up production and ensuring consistent material quality remain key challenges for wider implementation of CDW. Further pilot studies and standardisation are necessary before large-scale adoption.

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Appendices

Appendix 1: Volume and composition of CDW in Finland, Estonia and Latvia

Appendix 2: CDW characterization report

Appendix 3: Leaching tests from CDW materials

Appendix 4: Lahti stormwater site design

Appendix 5: Rae stormwater site design

Appendix 6: Smiltene stormwater site design

Appendix 7: Stormwater sampling protocol

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