
THE LIVING LAB FOR MUD: INTEGRATED SEDIMENT MANAGEMENT BASED ON BUILDING WITH NATURE CONCEPTS

L. Sittoni^{1,2}, E.M.M van Eekelen^{1,3}, F. van der Goot^{1,4} and H.E. Nieboer^{1,5}

ABSTRACT

In 2017, EcoShape has initiated the Living Lab for Mud (LLM). The aim of this Living Lab is to develop integrated knowledge and technologies to improve understanding and implementation of management, use and reuse of fine and soft sediments, often coupled to the application and re-installation of coastal ecosystems such as salt marshes and mangroves. Common worldwide issues in estuarine environments are turbidity increase, degradation of water quality and enhanced siltation on the one hand, and coastal erosion, degradation of salt marshes and mangroves and recurrent flooding on the other hand. This indicates that smart sediment management is more prominently necessary. Meanwhile, coastal development activities demand large quantities of sediment as building material.

The LLM aims to address the full range of these issues in a very practical way. Within several pilot and full-scale projects in the Netherlands and abroad, various aspects and processes of sediment management are studied for further integration. By conducting several pilots in specific settings that study a specific combination of these aspects and processes, the LLM aims to derive Building with Nature (BwN) concepts that can drive site-specific sustainable solutions. Pilots include optimization of strategic sediment disposal to nourish coastal mudflats, using natural hydrodynamic processes (Mud Motor, The Netherlands), onshore ripening of mud into clay to build dikes (Clay Ripening pilot, The Netherlands), enhancing sediment trapping to encourage mangroves restoration and coastal accretion (Demak, Indonesia), utilization of fine dredged material for island construction (Marker Wadden, The Netherlands) and construction of new salt marshes (Marconi, The Netherlands).

This paper will further elaborate on the ongoing activities within the LLM and give an overview of the first insights and lessons learned from all the five pilot projects.

Keywords: Sediment management, Beneficial use of sediment, Fine sediments, Building with Nature, Dredging.

INTRODUCTION

Throughout the world, different coasts, shores, lakes, and rivers must deal with excess sediment or sediment shortages. The natural balance between the erosion and deposition of sediment is disrupted by human interventions such as dams in a river, port developments in an estuary and dredging activities for the maintenance of existing ports and waterways. Disruption of the natural balance creates areas of sediment starvation (i.e., coastal erosion) and areas of sediment abundance (i.e., siltation in harbors), Winterwerp and Wang (2013), Winterwerp et al. (2013) and Vörösmarty et al. (2003), Brils et al. (2017). Human developments and natural ecosystems are directly affected by this sediment unbalance, with implication on industrial activities (e.g. navigation, logistic and tourism industry); space for living, flood safety and impact of climate change (e.g. loss of coastal areas and more frequent flooding) and food security (e.g. loss of productivity).

Optimizing sediment management by integrating human developments into the natural sediment balance is one of the greatest challenges as well as greatest opportunities of our present days' dredging industry. Sediment is a precious resource that should not be blocked behind dams or dispersed at sea but needs to be reintegrated in the natural cycle.

¹ Stichting EcoShape, Spuiboulevard 210, 3311 GR Dordrecht, The Netherlands;

² Senior Adviser, Deltares, PO Box 177, 2600 MH Delft, The Netherlands, T: +31 (0)642808578, Email: luca.sittoni@ecoshape.nl

³ Lead Engineer Environment, Van Oord Dredging and Marine Contractors BV, PO Box 8574, 3009 AN Rotterdam, The Netherlands, T: +31(0)610943575, Email: erik.vaneekelen@ecoshape.nl

⁴ Senior Environmental Engineer, Royal Boskalis Westminster N.V., PO Box 43, 3350 AA Papendrecht, The Netherlands, T: +31 (0)638402822, Email: fokko.vandergoot@ecoshape.nl

⁵ Hydraulic Engineer, Witteveen+Bos, PO Box 233, 7400 AE Deventer, The Netherlands, T: +31 653787470. Email: henk.nieboer@ecoshape.nl

Worldwide, various initiatives and programs exist that focus on the development and testing of sustainable and nature-based approaches for optimizing sediment management and reuse. The Central Dredging Association (CEDA) started a Working Group on Beneficial Use of Sediments in 2017 (<https://dredging.org/ceda/working-groups>), which collected the latest case studies and listed the most important worldwide initiatives regarding beneficial use of sediments in an Information and a Position paper soon to be published.

THE LIVING LAB FOR MUD AND BUILDING WITH NATURE

The Living Lab for Mud (LLM) is one such initiative created and managed by the consortium EcoShape – Building with Nature in The Netherlands. The main objective of the LLM is to develop, show and share innovative knowledge and techniques regarding the sustainable use and re-use of fine sediments (i.e., mud) based on the Building with Nature approach (EcoShape 2017). The LLM is a big living lab. It links five LLM concepts which are tested in five full-scale EcoShape pilot projects in The Netherlands and Indonesia (Figure 1). In these pilots we learn-by-doing. We test innovative fine sediments-based solutions to: reduce flood risk and increase resilience to climate change; enhance ecosystem restoration and nature development; improve water quality; transform sediment into alternative building material and improve the navigability of waterways.

In all LLM pilots, we apply the principle of Building with Nature (BwN). BwN means using the ecological, physical and socio-economic system as a starting point for our engineering solution, therefore moving towards integration with the natural sediment balance (De Vriend et al. 2015 and De Vriend and Van Koningsveld, 2012). Examples of natural processes we use and investigate are currents, waves, sediment dynamics, evapotranspiration and plant growth. We also study local governance and stakeholder engagement and sustainable business models. It is the strategic ambition of The Netherlands and the Dutch Water Sector to apply the knowledge developed with the LLM in practice and to extend the LLM experts network both nationally and internationally, since estuaries, coastal areas and inland waters elsewhere in the world face similar sediment management challenges and opportunities.

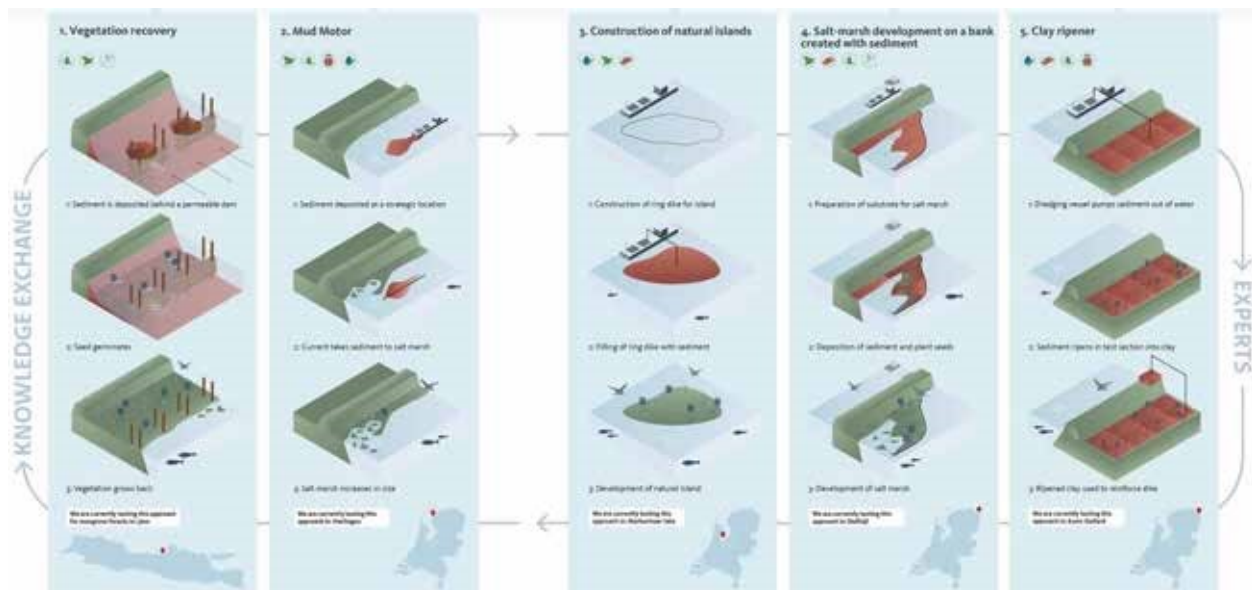


Figure 1. Representation of the five LLM concepts. The LLM concepts are tested in five pilot projects. From left to right: Vegetation recovery, Demak, Indonesia; Mud Motor, Harlingen, The Netherlands; Construction of natural islands, Lake Marken, The Netherlands; Saltmarsh development on a bank created with sediment, Delfzijl, The Netherlands; Clay Ripener (Kleirijperij, Delfzijl, The Netherlands. Generic knowledge regarding fine sediment physics, project implementation and governance is developed within each pilot. The knowledge and experts network are shared across the pilots, making the LLM a genuinely international living lab. Image by EcoShape.

THE LIVING LAB FOR MUD PILOTS

The LLM includes five pilots as described in Figure 1. These pilots transition through:

- Trapping sediment to enhance vegetation recovery (pilot Mangrove restoration in Demak, Indonesia <https://www.ecoshape.org/en/projects/building-with-nature-indonesia/>);

- Strategic disposal of dredged material to encourage salt marsh or wetland development (Mud Motor in Harlingen, The Netherlands <https://www.ecoshape.org/en/projects/mud-motor/>);
- Construction of natural islands with dredged material (Marker Wadden, The Netherlands <https://www.ecoshape.org/en/projects/marker-wadden/>);
- Develop salt marshes on a bank created with sediment: studying the effect of sandy and fine sediment and vegetation (Marconi, The Netherlands <https://www.ecoshape.org/en/projects/saltmarsh-development-marconi-delfzijl/>); and
- Producing clay soil through ripening dredged material (Clay Ripener, in the remainder of the text referred to as Kleirijperij, The Netherlands <https://www.ecoshape.org/en/projects/clay-ripening-pilot-project/>).

These pilots cover the range between fluid and consolidated mud, and between very limited human intervention and more involved human intervention. These pilots integrate physical understanding of mud dynamics, ecology and vegetation science, state-of-the-art operational know-how on handling and constructing with very soft material, and often complex innovative multi-party and multi-agency public-private-academic collaboration.

In this paper we present an overview of the latest status, general results and lesson learned of three ongoing pilots: 1. Kleirijperij; 2. Marker Wadden; and 3. Mangrove restoration in Demak. We chose these pilots as they are all currently in execution with preliminary results fresh of the press. In this paper we present a general introduction to these pilots and the most important results to date. For additional information and background of all pilots, we refer to previous publications (Van Eekelen et al., 2017) and the EcoShape website (www.ecoshape.org). For a description of the full EcoShape Program and all EcoShape pilots we refer to the other WODCON XXI paper of van Eekelen et al. (2018).

Kleirijperij: Ripening Mud To Clay, Delfzijl, The Netherlands

The Port of Delfzijl is located in the Ems River estuary near its confluence with the Wadden Sea. Since a few decades, the turbidity caused by the Ems River has been increasing due to an increase in suspended sediments concentration (van Maren et al. 2015). This leads to an increase in required maintenance dredging for the harbors in the Ems Estuary, such as Delfzijl. At the same time, the clay that is needed to maintain or strengthen the dikes in the area is bought and brought in from distant locations.

In the pilot Kleirijperij, that started in April 2018, sediment is dredged from the harbor channel of Delfzijl and the nature area Breebaart. It is directly transported on land across the dike into several compartments. There it is allowed to ripen for three years into clay soil. The ultimate objective of this pilot is to test different ripening strategies concerning efficiency in ripening and in delivering quality clay. At its termination in 2021, the pilot will have to deliver 70,000 m³ of clay for use in a demonstration project of the green dike concept 'Brede Groene Dijk' (Brede Groene Dijk, ref Van Loon et al. 2015). This dike has a grass-covered embankment with a slope that is less steep than in regular embankments in the Netherlands.

While ripening dredged material is not new, for the first time this pilot aims to produce clay that meets the requirements for application in dikes from ripening local dredged sediment. Simultaneously, this pilot contributes to decreasing the turbidity of the Ems River and improving its water quality. The Kleirijperij pilot represents therefore an attractive win-win opportunity which harnesses BwN processes such as evaporation and consolidation and ripening, to turn excess dredged sediment into a resource, by creating clay soil for dikes. This pilot therefore creates an opportunity for bringing river sediment on land, which is a natural process in undiked river deltas, instead of dispersing it at sea. The sediment is brought back to its natural cycle.

Clay for dikes in the Netherlands requires clay of a specific class (determined mainly by the Atterberg Limits and water content), a maximum salt and organic content. During ripening, the dredged mud thus needs to lose water. Salt and organic content have to decrease. In order to monitor the performance of the Kleirijperij on its ability to deliver dike clay, measurements are taken: during deposition; regularly throughout the year; and in detail one per year. During deposition, online measurements were taken for density and general dredge material characterization. Mud level is regularly measured with settling plates and fiber optic measurements, an innovative method. Drainage water is also measured from the sand drains. In-depth material characterization with cores and sediment samples is carried out once per year in September.

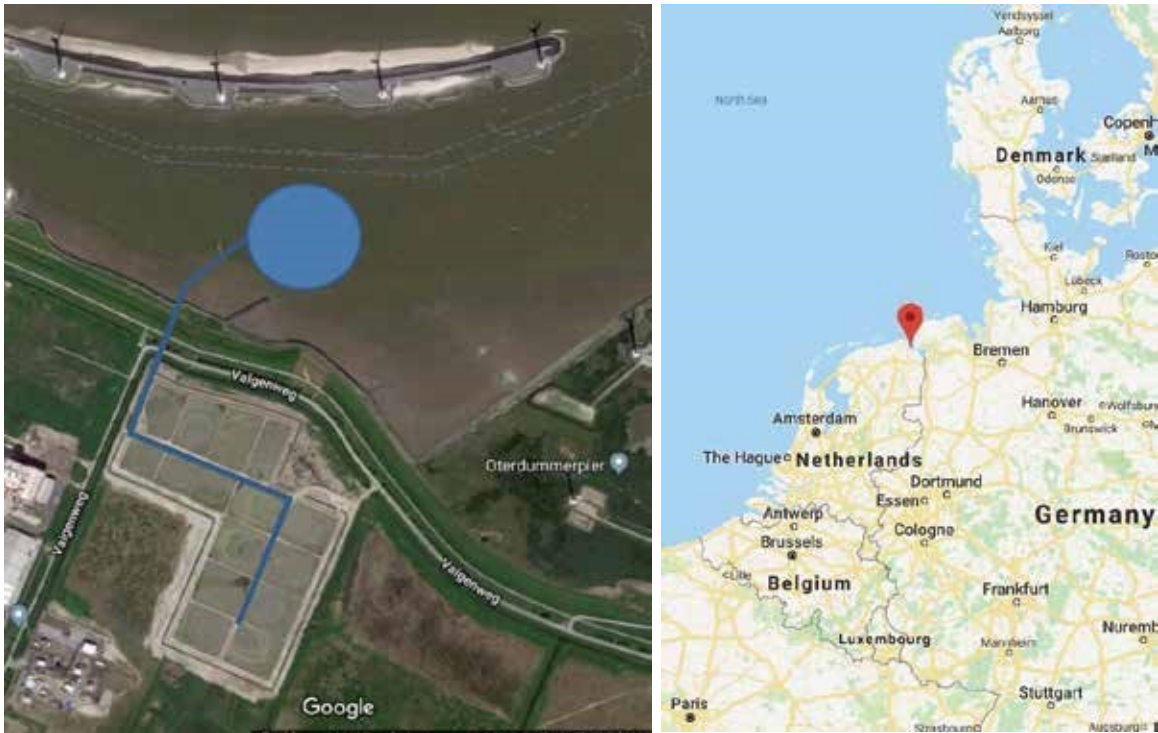


Figure 2. The Kleirijperij site of Delfzijl seen from Google maps (left), about two months after deposition of the first layer. 15 cells are filled with dredged sediment coming from the entrance channel of the Delfzijl harbor (blue circle, approximate location) and transported directly to the cells with a pipeline (blue line). On the right map is the location of the Kleirijperij in The Netherlands.

The dredged sediment is deposited in 25 test cells varying in depth (15 in Delfzijl, Figure 2, and 10 in Breebaart), covering an area of about 22 ha. Various deposition and ripening strategies are tested in the cells such as different deposition layer thickness, dry or wet consolidation, seeding vegetation or enhancing ripening by mechanical tools. During ripening, the cells will be monitored to test consolidation and desalination rates.

At the time of writing of this paper (summer 2018), deposition is completed in Delfzijl while construction has begun in Breebaart. Deposition in Delfzijl took place in two subsequent events. The first filling event started on April 5th, 2018 (official opening of the pilot), and a second filling event took place in July. The cells were filled with a height of 0.4-1.6 m. The initial density of the dredged material was slightly below 1.2 kg/l. The overlying water was drained from the cells about two weeks after deposition. Soon after drainage, a crust formed on top of the deposited mud (Figure 3). Preliminary measurements indicated dewatering rates in line with theoretical expectations, with faster dewatering rates in thinner deposits and with underlying drain. To facilitate dewatering, the crust was broken mechanically. Under the crust, the mud was still rather fluid, except in the cell with a thickness of deposited mud of 0.4 m, that showed very rapid dewatering. In June 2018 a second layer was deposited.



Figure 3. Image of one cell of the Kleirijperij taken on 16th of August (day 135), therefore about one month after the second layer was deposited. Photo EcoShape.

The Kleirijperij pilot is part of the broader Eems-Dollard 2050 program (see <https://eemsdollard2050.nl/> for further information). The Kleirijperij is a collaboration between EcoShape, the Province of Groningen, the water authority 'Hunze en Aa's', the Delfzijl port authority Groningen Seaports, the nature organization Groninger Landschap and the Dutch Ministry of Infrastructure and Water Management. The project partially financed by the Waddenfonds and the Dutch National Flood Protection Program HWBP.

Securing Eroding Delta Coastlines, Demak, Java, Indonesia

In the tropics, alluvial coasts are often muddy and covered with mangrove forests. In Demak, a stretch of 20 km of coastline along the north coast of Java is facing severe erosion problems. These are mainly due to groundwater extraction -which causes land subsidence- and the removal of natural mangrove forests to build extensive aquaculture. The conventional response to the eroding processes is the implementation of hard hydraulic structures, such as concrete seawalls. Besides this being a relatively expensive solution in a region like Demak, the physical boundary condition for these types of structures is unsuitable: the soft seabed provides insufficient stability for these large structures resulting in collapse over time. Furthermore, the rigid structure blocks the sediment-laden flows and reflects the incoming waves rather than dampening them. Reflected waves initiate scour along the foot of the structure resulting in instability (Van Wesenbeeck et al., 2015). In 2015, a large-scale BwN pilot was initiated, aiming to provide coastal security and supporting the revitalization of at least 6,000 ha of aquaculture ponds along a 20 km shoreline in the Demak district (Central Java), thereby improving the resilience of 70,000 vulnerable inhabitants of the area. This is accomplished through the implementation of both social and physical coastal safety measures.

Coastal field schools are set up to train local community groups in sustainable aquaculture practices, alternative livelihoods and sustainable restoration and maintenance of the mangrove greenbelt. Best aquaculture practices have boosted productivity and income of farmers, inspiring farmers to replicate the approach in 100 ha own ponds. In addition, community groups will receive continued (financial) support to enhance sustainable aquaculture and livelihood practices further while engaging in the restoration of mangroves through the so-called biorights mechanism.

Rather than implementing ineffective hard structures to provide coastal safety, a low-tech engineering solution was developed to restore the severely deteriorated mangrove green belt (Figure 4). Permeable dams made of bamboo and brushwood were constructed in front of the existing coastline, within the intertidal zone. The permeable dams reduce the wave energy and provide sheltered areas where the sediment-laden waters can deposit the fine sediments. Layer by layer, the grid cells behind the permeable dams are filled up. Once sufficiently filled, mangrove seeds can settle in the freshly deposited sediment layer, slowly restoring the mangrove greenbelt with no need for planting mangroves. When a sheltered area has filled up with sediment and mangroves have sufficiently regrown, a new permeable structure is built seaward of the previous one to gradually extend the shore zone from the coast. Once the mangrove greenbelt has been restored, the mangroves can once again attenuate the waves and build up sediments to counterbalance subsidence and sea level rise to a certain extent.

Since the start of the project, a total of 2,600 m of dams have been constructed by the project together with the Indonesian government (Figure 5). The Indonesian government is replicating the approach across Java, investing 1.5 million EUR in 2016, and joint guidelines are being developed to share lessons learned and best practices. Two years after the construction of the first dams, monitoring results show a net sedimentation of 30 centimeters at some locations behind the dams, whereas control sites show a net erosion of 5 cm. Monitoring results show that the concept clearly works, however, recent observations indicate that subsidence might be more severe than previously anticipated. To halt subsidence as a result of groundwater extraction, effective integrated water resource management on a landscape scale, including the city, is to be implemented to stimulate the use of alternative fresh water sources.

Although the pilot project is only halfway, initial results show that by making use of relatively low-tech solutions, restoration of degraded muddy coasts is feasible. Furthermore, this pilot shows that social awareness is of utmost importance for sustainable coastal zone management and that communities and governments can be successfully mobilised. These insights contribute to delivering tools and building blocks to the overarching vision of the LLM development.



Figure 4. Sedimentation behind permeable dam constructions. Photo by Wetlands International.



Figure 5. Aerial view of permeable dams at the pilot project location. Photo by Wetlands International.

Knowledge Innovation Program Marker Wadden (KIMA)

Lake Marken in the center of the Netherlands is one of the largest freshwater lakes in Western Europe. Since the lake was closed off from Lake IJssel, the ecological situation has deteriorated severely because of the turbidity caused by fine sediments. The nature conservation organization Natuurmonumenten and the Dutch government have joined forces to improve the natural environment in Lake Marken by capturing silt from the lake and using it as building material for an archipelago of marsh islands (Figure 6). The islands are designed to be an attractive location for birds.



Figure 6. Aerial view of Marker Wadden under construction, April 2018. Photo by Natuurmonumenten.

After the construction of a ten-hectare trial island in 2014, the construction of a 600-hectare island began in 2016. Part of the island will be opened for the public in 2018. The development of the Marker Wadden is monitored closely to develop knowledge about building with mud as a form of Building with Nature. Enclosed by sandy ridges, clay and fine sediments are used in the Marker Wadden to establish a productive marsh landscape. The behavior of each type of sediment is studied. This ecosystem has been open from the outset for sustainable leisure activities; other sustainable features may eventually also be possible.

The Marker Wadden scheme aims to demonstrate that fine sediments can for example be used as a construction material for land reclamation, dike reinforcement and soil improvement. If the Marker Wadden scheme turns out to be successful, the knowledge acquired about building with mud in freshwater systems can also be used in saltwater environments in the Netherlands and other parts of the world.

The construction of the first phase of the Marker Wadden happen in parallel to the Knowledge and Innovation Programme Marker Wadden (KIMA). The KIMA programme will contribute to the efficient and effective construction of the first and subsequent phases of the Marker Wadden, connecting fundamental research to applied research, aside to the construction project. The goals of this programme go beyond the goals of construction, not only geographically but also in terms of time and research themes. KIMA has been set up to link fundamental and applied research, coordinate collaboration between sectors and disciplines and stimulate innovation. Partners in KIMA are Rijkswaterstaat, Natuurmonumenten, Deltares and EcoShape, forming the collaborative 'diamond' between Government, NGO, Science and industry.

The KIMA includes three major knowledge lines:

1. Fundamental and applied research and scaling-up of the practical applications of this research in the areas of: building with mud and sand; development of ecological systems; and adaptive governance;
2. Monitoring of the Marker Wadden;
3. Coordination of all monitoring and research in Lake Marken and strengthening of the knowledge base in this area.

KIMA includes also an existing physical lab on the Marker Wadden islands. This lab welcomes researchers, scientists and students to test their (sediment and ecology-related) technologies and solutions. For more information, please contact Mrs. Sacha de Rijk at sacha.derijk@deltares.nl.

CONCLUSIONS

In the LLM we develop and test innovative engineering solutions following the BwN approach to integrate human developments into the natural sediment balance. The LLM is a living lab that connects five pilots with fine sediment (i.e., mud) as the central connecting theme. Fine sediment is an essential natural resource, sometimes in the form of turbid water, sometimes as soft mud or ripened clay soil, that is often a basic ingredient to critical human activities, such as hydraulic or geotechnical infrastructure; flood risk protection or nature development. Within the LLM we share mud-related knowledge across and beyond the pilots with many national and international parties and experts. We also connect with parallel and similar activities that focus on Beneficial Use of Sediment and Circular Economy and Sediment. Our next ambition is to scale-up the LLM, by increasing the network of experts and expertise connected with it; by adding interesting pilots covering existing knowledge gaps or widening its geographical boundaries; and ultimately to apply the solutions we test within the LLM at operational scale in large sustainable human and nature development projects.

With this objective in mind, in this paper we decided to focus on three existing and on-going pilots Kleirijperij, Mangrove Restoration, and KIMA to take the opportunity to invite the reader and the audience to work with us on these pilots, to pay a visit to the sites or to initiate other mud-related pilots together.

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