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Developments to come to a circular construction economy; experiences in facilitating a local soil and sand depot

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Developments to come to a circular construction economy; experiences in facilitating a local soil and sand depot.

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Abstract. In the construction industry the ambition to come to a circular economy will, with its vast material usage, be a hard nut to crack. This paper describes a research project part of the H2020 Cityloops project, in which it was expected that soil and sand depots could be an interesting subject to study. Already for many years and in multiple municipalities, these depots help to overcome mismatches regarding quality and quantity in demand and request of soil and sand. With the ambition to close material loops the construction industry might experience these kinds of mismatches also for an increasing number of other resources in the nearby future. Having positive experiences with her soil and sand depot, the municipality of Apeldoorn was open to give insights in the flows at her open-air soil and sand depot. The conducted research helped making processes transparent and valuable insights were gained. However, considering the great variety in building materials, products and components, it currently seems possible to handle only a small number of other material flows in the same way soil and sand are being handled and stored at a depot.

1. Introduction

The urge to strive for closed material loops is felt in the construction industry. However, before the built environment can be regarded as circular, not only the material usage in buildings needs to be circular, but also the public space surrounding them needs to be established in a sustainable circular way. This is a technological as well as an organisational and a policy challenge. In the construction industry multiple principals, contractors, architects and suppliers of building materials try to reduce the need for new virgin materials, put effort in reclaiming used materials, products and building components, and reduce the amount of waste originating from their production processes.

As Magnusson, et al. [1] explain for houses, roads and other civil engineering purposes; construction also involves management of soil. Soil (as well as rock materials) from quarries or excavated from other construction sites is also used for e.g. filling, permeable layers, base layers, landscaping and as filler in concrete and asphalt. In terms of energy use and greenhouse gas (GHG) emissions, both quarrying and heavy transport give rise to negative environmental effects [1], that do not match the ambitions of a circular economy. The extraction of sand in open water, which is quite common in the Netherlands, also has a significant impact on the environment, e.g. [2, 3].

Before buildings and infrastructure can be designed for a particular location, research is needed regarding the bearing capacity of the underlying soil. Hence, the bearing capacity of the soil needs to able to resist the load. Research is also needed on the presence of any toxic substances endangering the health of contracted builders and future building or infrastructure users. In the ground no contaminations should be present in harmful quantities. If the proper quantity or quality of soil isn't present at the

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construction site, transport is needed. From a cost and environmental perspective again, the transportation of soil needs preferably to be reduced to a minimum. However, in many projects soil and sand of a better quality or in another quantity than directly available, are needed to match the aforementioned requirements. If sand is going to be used as an ingredient, also specific quality standards need to be matched, e.g. [4].

Hence, in the construction industry sand is an important resource [5]. Multiple entrepreneurial activities are offered to make sure sand of a certain quality is available at a specific location in proper quantities. These activities are often concentrated around so called soil and sand depots (in Dutch: grondbanken), where soil and sand are being collected, processed, inspected, labelled, and even can be put on display. In the Dutch municipality of Apeldoorn one already has positive experiences in reusing soil and sand locally through an open air soil and sand depot, where quantities and qualities of soil offered and requested by actors in the construction industry are registered by the municipality. It is experienced that much of the soil offered to the depot of Apeldoorn is often of a better quality than expected on beforehand.

Therefore, after assessing the quality of this important resource in shaping public spaces, the soil leaving the depot can comply with the requirements of multiple projects. We would like to extend this principle to other resources needed in (re-)developing and maintaining public spaces, so that material loops can be closed. Attention will be paid to the processes involving the soil and sand depot of the municipality of Apeldoorn. Data was collected on how much soil with which quality was being handled. These processes may form a blue print to close circles for other materials in the construction industry.

Considering that sand is an important resource to the construction industry and social and political developments are pushing the construction industry to move towards a circular economy, e.g. [2, 3], the research described in this paper focuses on the possibility to facilitate circular processes in that same industry by positioning an existing soil and sand depot as an example for other resources. Therefore, the main research question is: how can the quest for a circular construction industry benefit from the experiences gained in facilitating a local soil and sand depot?

To come to an answer to this question, Section 2 describes the theoretical background regarding the role of sand in construction processes. In section 3 the field of practice will be entered by discussing how sand is being handled before, on and after a soil and sand depot. What processes to match quantities and qualities take place in order to fill in demands? Section 4 shows the results by means of data of a local soil and sand depot in Apeldoorn. These data will be analysed in section 5 followed by a section with the discussions, after which conclusions will be drawn and recommendations are provided.

2. Theoretical background

Multiple sand typologies and qualities can be distinguished. A basic definition of sand can be found in the Glossary of Term in Soil Science [6], in which sand is defined as *a soil particle between 0.05 and 2.0 mm in diameter.* This same glossary also mentions five soil separates by the following names: *very coarse sand, coarse sand, medium sand, fine sand, or very fine sand.* Sand is as a matter of fact a specific soil textural class with soil being defined as: *the unconsolidated material on the immediate surface of the earth that serves as a natural medium for the growth of land plants* [6].

As already addressed sand is directly and indirectly an important resource, when it comes to shaping the built environment. Its direct use consists for example in offering soil for proper heights in landscaping and solid foundations for new buildings. Regarding indirect use one can think of the role of sand in the production of bricks, e.g. [7], and concrete. Global geotechnical criteria for some different forms of earthworks are concisely brought together by Kataguiri, et al. [8] in table 1.

The environmental impact of the construction industry is more than significant. Magnusson, et al. [9] identified environmental and economic benefits of reusing excavated soil and rock. They distinguished the following three situations:

- reusing soil and rock on-site, where the availability of space is an important boundary condition;
- reusing soil and rock in other projects, where coordination and joint planning are major issues;
- recycling soil and rock at a facility, where high investment costs and location optimization could be important barriers.

Table 1. List of main geotechnical criteria for reuse of excavation material in earthworks [8].

Earthworks	Geotechnical criteria
Trench backfill	Cohesion and friction angle (shear strength) Swelling and loss of strength by wetting Compaction degree (dry density and moisture content) Grain size distribution
Walls with reinforced soil	Cohesion and friction angle (shear strength) Swelling and loss of strength by wetting
Paving layers	Swelling Penetration resistance (California Bearing Ratio) Grain size distribution
Vegetation cover replacement	Organic content Clay content Cation exchange capacity Permeability coefficient Acidity (pH)
Drainage	Grain size distribution Hydraulic conductivity Loss of strength by wetting

Considering that large volumes and, therefore, weights of soil and sand are being transported when preparing construction sites and constructing buildings, the fuel and other energy use and emissions have been more than once subject of investigation. Devi and Palaniappan [10] for example studied the situation in India for the excavation and transport of soil. In their study, the fuel use, energy use and emissions were related to operational parameters and technical parameters (see table 2). Operational parameters are for example soil type, dumping distance and depth of excavation. The technical aspect considers the equipment used, like the excavators and trucks.

Table 2. The diesel and primary energy use of the excavation and transport of soil and rock [10].

		Case 1 Soft dis-integrated rock	**Case 2** Sandy clay & black cotton	**Case 3** Loose soil & weather rock	**Case 4** Loose soil & weather rock	**Case 5** Weather & hard rock
Excavation of soil only	Diesel use (l/m^3)	0.33	0.37	0.37	0.33	2.09
	Primary energy use (MJ/m^3)	14	16	16	14	89
Excavation & transport of soil to dumping site	Diesel use (l/m^3)	0.45	0.52	0.55	0.52	3.2
	Primary energy use (MJ/m^3)	19	22	23	22	135
Excavation, transport of soil & levelling at dumping site	Diesel use (l/m^3)	0.51	-	-	-	-
	Primary energy use (MJ/m^3)	22	-	-	-	-

3. Entering the field of practice

The last thing one wants is that land cannot safely be used due to polluted soil and sand. The Netherlands is a densely populated country. Approximately 17.5 million people live on a surface of 41,500 km², which puts quite some pressure on the land use. The estimation is that at around 250,000 sites the soil is strongly polluted [11]. At its peak, in 2004, 650,000 sites were thought to be seriously contaminated. After investigations, the soil at most of them appeared to be not seriously contaminated. At locations with severe soil contamination 30,000 sites were remediated, meaning that contaminants were removed or isolated. Governmental bodies have agreed on remediating and/or controlling the remaining 1,400 locations with urgent soil contamination not later than 2020 [12].

An AP04 inspection, also called batch inspection, is used to determine the ecological hygienic quality of soil. If one wants to use or reuse soil, this inspection is compulsory. The quality of the soil is then assessed [13], which starts with a preliminary historical investigation on the batch to check out if one needs to be suspicious about the soil's quality. When one has suspicion about the soil's quality, the location will be visited and the total batch will be defined. A single batch may not exceed 10,000 m^3. Per batch, one hundred grips of 0.5 m deep must be taken. If a meter is to be excavated, fifty holes of two times 0,5 m need to be drilled per batch. The various soil layers need to be distinguished, sand and clay, for example, have to be examined apart. If the preliminary investigation or field inspection shows that a small part of the batch is suspected of contamination, this will be investigated separately. In this way costs can be saved by preventing the entire batch from being remediated. The samples are examined in a laboratory, where it is determined whether the soil is clean, slightly polluted or heavily polluted [14].

The soil that does not need to be cleaned or disposed can be transported directly to another project or indirectly via the soil and sand depot. Three main classifications can be distinguished when it comes to assessing the quality of soil at the soil and sand depot, namely [15]:

- AW2000: AW stands for Background Value (In Dutch: AchtergrondWaarde). The AW2000 values for soil are determined on the basis of contents of substances, such as those occurring in the soil of natural and agricultural land that are not affected by local sources of pollution. Soil that meets the background value is sustainably suitable for any type of soil use and is assessed as clean or unpolluted soil;
- Residential: when soil does not comply with the Background Value, but does not surpass a locally established maximum value of non-original substances, the soil can still be used without remediation for residential purposes;
- Industrial: when soil does not comply with the Background Value and cannot be used for residential purposes, but does not surpass a locally established maximum value of non-original substances, the soil can be used without remediation for industrial purposes.

For the municipality of Apeldoorn, a so-called soil quality map shows the diffuse chemical quality for soil layers from 0.0 to 0.5 m below ground level (topsoil), from 0.5 to 1.0 m below ground level (intermediate layer; only for the city centre) and from 0.5 to 1.0 to 2.0 m below ground level (substrate). The map has been established on basis of the presence of the following substances: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni), zinc (Zn), polycyclic aromatic hydrocarbons (PAH), extractable non-volatile organohalogen compounds (EO_X) and mineral oil. In time, the soil quality map may, in line with standard NEN-5740, be updated for new substances, namely: barium, cobalt, molybdenum and polychlorinated biphenyls (PCBs) [16].

When composing the soil quality map, the municipality of Apeldoorn was divided into seven sub-areas. Within these sub-areas, the chemical soil quality is expected to be consistent due to similarities in usage characteristics. The municipality of Apeldoorn uses the 90 percentile value (P90) for the urban area and the 80 percentile value (P80) for the rural area. If this value is below the national background value (AW2000), the municipality will apply the area-specific soil quality class (agriculture / nature, maximum value for housing or maximum value for industry). The applicable background levels (P90 or residential or agriculture / nature) based on standard soil (10% organic matter and 25% lutum) are stated for the topsoil and topsoil in table 3 [16].

Table 3. Top soil (0.0-0.5 m below ground level) and substrate (0.5-2.0 m below ground level) based on 25% lutum and 10% organic matter [16].

Zone	Parameter (in mg / kg dry matter)													
	As	Ba	Cd	Cr	Co	Cu	Hg	Pb	Mo	Ni	Zn	PAK	oil	PCB
B3	27.0	-	1.2	62.0	-	54.0	0.8	210.0	-	39.0	200.0	6.8	190.0	-
O3	20.0	-	0.6	55.0	-	40.0	0.20	50.0	-	35.0	140.0	1.5	190.0	-

4. Results

The soil and sand depot is located at the north-east site of the built-up area of the municipality of Apeldoorn. It is an open air facility, where soil is being stored as shown in figures 1 and 2. It has already been in use for many years. During these years data have been collected on what quantity and quality of sand was offered or taken by who and when. This section presents the collected data for the time period 2011 to 2016. Although some data of 2008, 2009, 2010 and 2017 is available, it was unfortunately not possible to retrieve complete lists of transactions for these years. By conducting interviews it was possible to work out the different transport paths soil can follow within the municipality of Apeldoorn. This scheme showing the important role of the AP04 inspection process is presented in appendix A.

Figure 1. Sand stored at the soil and sand depot of the municipality of Apeldoorn (by courtesy of Robert Rouwenhorst).

Figure 2. Sand site of Apeldoorn as can be viewed from south to north at Google Maps (by courtesy of Aerodata International Surveys).

Figure 3 shows that annually between 11,332 and 22,756 m^3 of soil passes through the depot. A truck load consists normally of at maximum 20 m^3 soil and weighs in that case approximately 34 Mg. The amount of soil being offered and taken logically strongly depends on which civil engineering works and building projects are undertaken in the municipality. Figure 4 shows the large differences between the project related batch sizes of soil. In 2013 5,275 m^3 of industrial classified soil was transferred for one project via the depot. In 2015 the smallest batch for one single project, of only 19 m^3, was transferred.

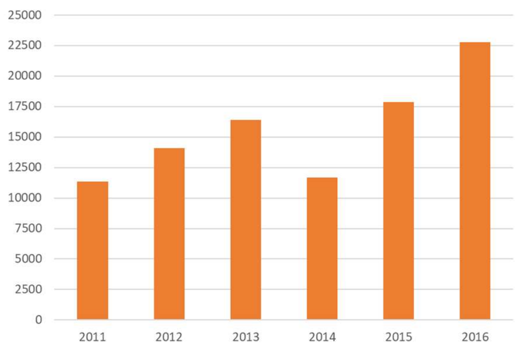

Figure 3. Amount of soil in m^3 offered by the soil and sand depot

Figure 4. Indicative batch sizes in m^3 soil per project

5. Analysis

In a former section the existence of different quality labels for soil was explained. In this section that framework is used to analyse the flows of soil at the depot of the municipality. In October 2019 it was mentioned in a presentation of the municipality that of the around 200 batches of soil transferred between 2008 and 2017 none of them was more polluted than expected on the basis of the soil quality map.

By studying the data on the batches from 2011 till 2016, the author was able to compose figures 5 and 6. The data studied clearly shows that most of the incoming soil was rated as having a proper quality for industrial purposes (see figure 5), namely between 60.5% in 2015 and 94.5% in 2013 for the annual incoming volume of soil. However, after assessing the soil's quality properly, these values were lowered to between 1.8% in 2015 and 46.5% in 2012 for the annually outgoing volume of soil (see figure 6). The assessed soil of which the quality was not clearly documented, is classified in figure 6 as 'unknown'. Setting the worst case scenario as a basis by adding this 'unknown' quality category to the figures just mentioned, the maximum percentage rose to 71.2% in 2013 for the annually outgoing volume of soil. Based on this data the researchers have no substantiated reason to doubt the claim made in the presentation: the quality of the soil after analysis is higher than expected.

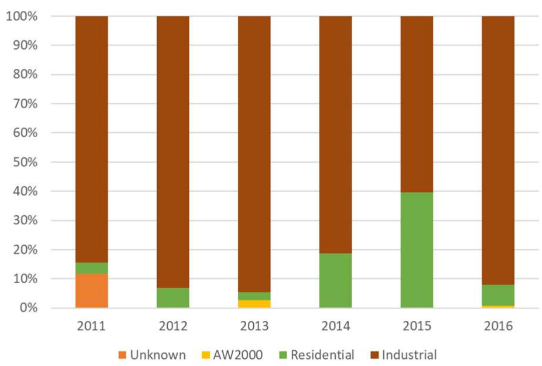

Figure 5. Estimated quality of incoming soil at the soil and sand depot

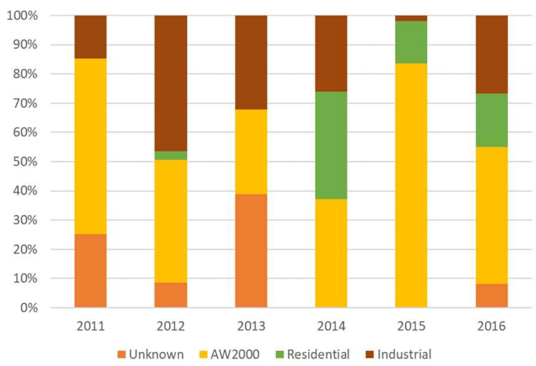

Figure 6. Assessed quality of outgoing soil at the soil and sand depot

6. Discussion

This study on the soil and sand depot of the municipality of Apeldoorn provided some interesting insights, that are in the noble opinion of the author worth sharing.

Firstly, this case shows the challenge to properly collect and store data related to incoming and outgoing resource flows. Although it seems relatively easy and straightforward to store the quantitative and qualitative information, it is without a 24-7 supervisor at the spot not easy to be unambiguously about what information exactly connects with which batches of soil in projects and at the depot. Volumes are rounded, soil from different sources could be mixed without notifications and a truck load might pass by unnoticed. A link between the physical product, soil, and the data providing information about its quality is not easily established and maintained, as could be the case for a tagged window frame for example.

Secondly, this case study shows the importance to check assumptions about the quality of resources at building sites. Standards are available on the handling of soil and soil quality can be objectively assessed by measuring the presence of multiple substances. To come to a circular economy, the construction industry needs also to be able to objectively assess the quality of other resources needed or materials coming available from for civil engineering works and constructions works. In Apeldoorn a positive effect is experienced about what opportunities can exist when assessing the quality of resources. Your resource might be more valuable than on forehand expected, resulting in a value increase for which little to no investments were to be made.

Thirdly, considering the large fuel consumption of equipment involved in handling soil and sand, a first step always needs to be if construction objectives can be met without relocating soil and sand at all. When soil and sand need to be relocated, then the distance between origin and destination needs preferably to be as small as possible and direct, by means of; without a stop at a depot. The challenge of finding an optimum between travel distances with direct replacing and shorter distances with indirect replacing applies in principle for every new building project without a closed soil balance.

7. Conclusion

Considering the data studied and unfolded in this paper, it can be concluded that the soil and sand depot in Apeldoorn fulfills its role with verve. The depot offers temporarily space for soil and sand in times that supply and demand are not well aligned. Due to preserved estimations of the soil's quality for the Apeldoorn's underground on forehand, the quality assessments on the volumes actually being transferred show smaller levels of pollution than expected. Given the fact that the batches did not undergo cleaning or purification processes to improve the soil's quality, the term upcycling does not apply. The added value of the soil and sand depot can be found in the space it has to offer to store and to combine batches, to facilitate AP04 inspection procedures and the immediate availability of this important resource.

However, currently most civil engineering works and buildings are mainly being composed of linear end-to-life components, products and materials. The main research question in this paper relates to a future in which the economy needs to be circular, namely: how can the quest for a circular construction industry benefit from the experiences gained in facilitating a local soil and sand depot? In landscaping and construction projects soil and sand are important resources that seem not easily to wear out or experience degradation. In that sense soil and sand are, compared to many other resources for constructions, relatively simple raw materials. The analysis shows that it is already rather complex to properly record the quantity and quality of soil and sand. A quick-scan on the historical background of a land plot only provides limited insights in soil quality. This should alarm us about the efforts needed to be undertaken, when it comes to investigating and administrating the historical background, former usage and current state of all other circular resources needed in construction.

It can be concluded that when the principles are applied currently in use for soil and sand, these processes will be time-consuming, prone to errors and costly. Logistic systems necessary to have all components, products and materials in place at the site in time are complex. Being a local depot, a soil and sand depot is able to operate as a node in the logistic system of the soil and sand market where supply and demand can converge. However, there will be a need for a new kind of depot for a circular construction industry in a new sort of logistic system. A system that is supported by automated sensors and a proper digital infrastructure linked to databases. The challenge will be to develop this logistic system manageably for all circular resources, because not every individual material, product or component can be thoroughly examined and tested by hand in detail. The specific principle regarding soil testing, where samples are taken from a maximum sized batch by procedures well established, does seem well applicable for multiple other already used building materials.

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Appendix: detailed process scheme for soil/sand at the municipality of Apeldoorn