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THE ROAD TO CIRCULARITY: A FRAMEWORK FOR AND EXPERIENCES IN COLLECTING ROAD DATA IN A CIRCULAR RENOVATION PROCESS

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Abstract. The construction and transport sectors both have a substantial impact on the environment. The construction, maintaining and renovating of roads involves both these sectors and the environmental impact of this work can be reduced. The basic principle of a circular economy is to close material loops and so retain the highest utility, quality and value of products, components and materials as possible. An important question in this respect is how to qualify and quantify material flows. Material and project passports seem to be part of the solution to improve insights and sharing information on quantities and qualities of materials used in construction projects. This paper has used a literature study on material passports and has taken into account current project management software used by a municipality, in order to share a framework for organising and collecting road construction data. Furthermore, various scanning equipment and procedures were employed onsite in an experiment in collecting actual road data. This resulted in a large amount of different data files that have been interpreted and incorporated into the existing database structure of the municipality. The insights gained may help other researchers, principals and contractors in the road construction industry in collecting and storing reliable data necessary to renovate roads circularly.

Keywords: Road renovation, circularity, collecting data, material characteristics.

1. Introduction

The construction industry is under pressure to strive for closed material loops. As part of the European Horizon 2020 project Cityloops, municipalities are developing and testing tools that help enhance a circular economy. However, before the built environment can be regarded as circular, not only the material loops in buildings need to be closed, but also the loops in infrastructure projects. In Cityloops, the municipality of Apeldoorn has been collaborating with Saxion UAS to create a circular road-renovation project. This project can use comparable circular principles as applied to buildings, e.g. reducing the need for materials, designing for disassembly, reusing used components, products and materials (e.g. [1, 2]). Experiences with consumer products and buildings show that in order to achieve a circular economy, there needs to be an awareness of the specifications characterising them (e.g. [3]). Therefore, this paper starts with a theoretical framework of material characteristics that are necessary to enable others to close material loops. This information can be recorded in material and project passports (e.g. [1, 4]), which seem to be part of the solution to improving insights and sharing information on quantities and qualities of materials used in construction projects.

Although this literature study might be able to provide insights into which information is required, it is not always possible to collect all the information needed. On the one hand, collecting, organising and storing data takes time and costs apply. On the other hand, data might already be available from the stakeholders involved. With this in mind, six interviews were conducted with experts who were able to give insights into road renovation projects and the collecting and storing of road data.

The construction and maintenance of infrastructural projects are often commissioned by public entities. Considering these public entities are experienced professional principals, it is likely that they have at least part of the data needed for material passports. However, in moving from a linear to a circular economy it might well be possible that extra data is required to know in more detail what materials in which quantities and with what qualities are at our disposal. Therefore, the main research question in this project is: how can material characteristics be obtained for renewing roads circularly in residential areas? The research project, disseminated in this paper, focuses on how to match required and available data around a particular road renovation project in the Dutch municipality of Apeldoorn. The aim was to renovate the residential paved road at Griffiersveld, and adjacent public space, as circularly as possible.

2. Theoretical framework

2.1. Circularity and data

The concept of a circular economy has gained momentum, as Kirchherr et al. [5] aptly put it, when analysing 114 definitions in order to create greater clarity in understanding this concept. They concluded that circular economy within their iteratively developed coding framework, can be defined as *"an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes"* [5, p. 229]. When introducing this concept to the construction industry, where large amounts of materials are used, it soon became clear that relatively little seems to be known about which materials are applied where. Hart et al. [6] mention that buildings and infrastructure both *"are characterised by long lifespans, numerous stakeholders, and hundreds of components and ancillary materials that interact dynamically in space and time"*. From this perspective not only buildings can be regarded as material banks, but also infrastructure and other materialised public space.

Being a set of data, material passports contain information that enables us to understand the background of a particular material and therefore the possibilities to reuse, recycle and recover it. In some cases these material passports are also known as product passports or circularity passports [4]. In 2009 by means of Life Cycle Analysis (LCA) Huang et al. [7] studied how the impact on the environment of asphalt pavements varies when using different process and pavement parameters. The quality of data for these parameters is of vital importance. Heinrich & Lang [4] distinguished four categories of information in a material passport, namely process, biological, chemical and physical information. Based on interviews and by studying multiple existing methods to store information on materials and products, Goselink [8] defined a top five of requirements for a material passport, namely:

(1.) it needs to include a bill of materials (BOM) with quantities, material composition, and location (GIS) of the materials on site;

(2.) inspection and maintenance history of the materials on site needs to be recorded in the passport;

(3.) it includes technical lifetime expectancy of materials on site, so information on production date, manufacturer's or contractor's lifetime expectancy adjusted with information from the field;

(4.) renovation or "end-of-life" options of the materials are addressed;

(5.) the setup of the material passport complies with a uniform system and clear definitions.

Although much information might be available, it is seldom easily or freely accessible at one central point. Building Information Modelling (BIM) is a potential gamechanger in the construction industry, as Honic et al. [9, 10] put it. Charef and Emmitt [11] also explored how BIM can help practitioners to adopt a circular economy approach and identified seven new roles for BIM, when it comes to a circular economy. In the Netherlands, Pavement Information Modelling (PIM) has been introduced for infrastructure projects, specifically asphalt roads [12]. In PIM a particular road (section) can be incorporated as an object with multiple underlying layers to store information in. From big to small, one can distinguish object, element, construction part, component, and construction unit. A construction unit might be a mixture containing multiple building materials. At the building material level a different set of qualitative and quantitative characteristics applies than at the level of a complete road section. Some of the qualitative and quantitative characteristics might also be attributed to specific GPS-locations [12].

2.2. Collecting road data automatically

To be able to learn more about the quality and quantity of road materials, visual inspections are commonly used. More recently a broader range of sensors, besides the obvious use of video equipment, can be applied, which may or may not be mounted to a means of transport. This section addresses some of these automated data collection methods, not just for the sake of completeness but with attention to conciseness.

Data can be collected in the built environment for example, with the assistance of Unmanned Aerial Vehicles (UAVs). This enables effective and efficient data collection by means of a protocol to fly camera equipped UAVs around objects, for example provided by [13]. Regulations may apply and obstacles may be present when flying UAVs visible to the naked eye over populated areas with a flight height of 35 m, but Biçici & Zeybek [14] demonstrated that automated detection of road surface distress through point clouds generated from UAVs photogrammetry is within reach.

Experiences in using Ground Penetrating Radar (GPR) systems to detect cracks in roads have also been recorded (e.g. [15]). The processing technique used here, made it possible to detect cracks larger than 1.3 mm in width. Experimental results indicated that the GPR system can reliably be applied to automatically detect road cracking in practice. Although this GPR system was moved at walking pace on a trolley across the cracks, it is also possible to mount it in front or at the back of a motorised inspection vehicle.

Gamma spectrometers can also be attached to inspection vehicles, or again UAVs [16], to collect data that provides insights into the composition of a road and the underlying soil texture. Due to specific gamma signatures of stones, it is also possible to distinguish differences in asphalt mixtures.

Some sensors are much smaller than the aforementioned ones, an interviewee suggested considering the

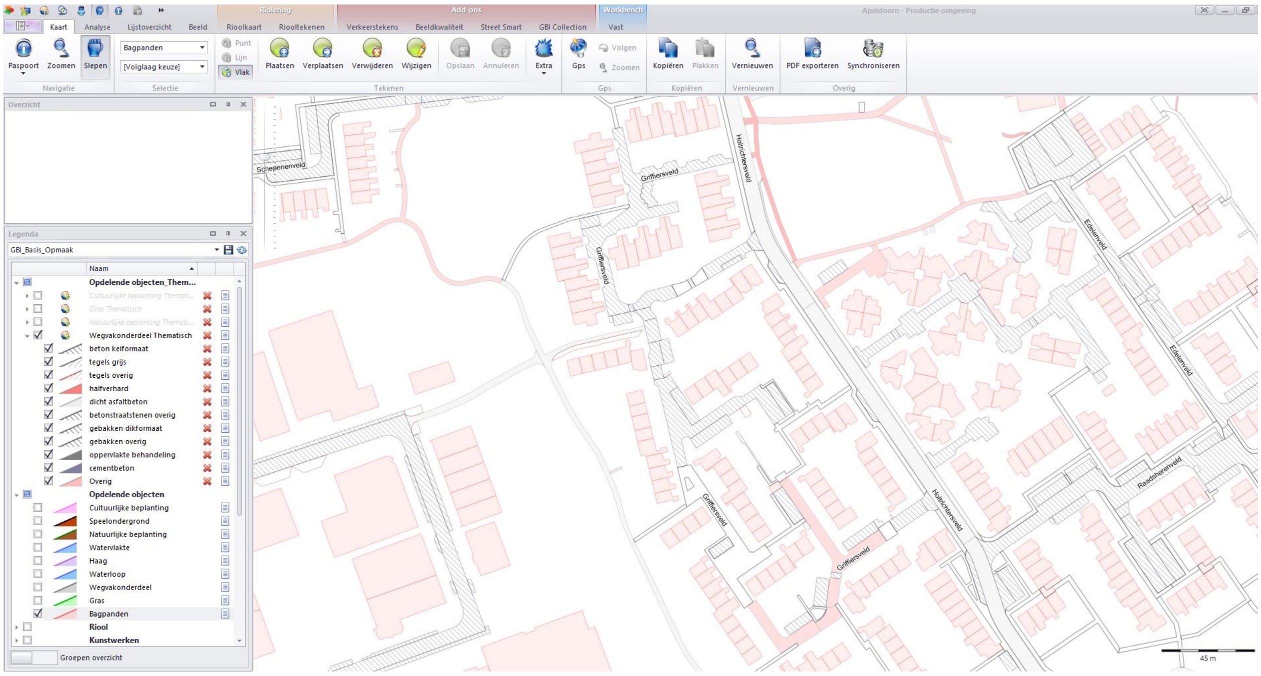

Figure 1. Screenshot of the GBI asset management system showing Griffiersveld in Apeldoorn.

use of motion sensors in mobile phones that, in combination with GPS, can enable researchers to estimate traffic density and the flatness of the road surface. Last, but not least stationary sensors can also be used by placing them alongside or even in roads.

3. Entering the field

Efforts of multiple stakeholders are needed to collect and store data appropriately. Considering that Dutch municipalities were managers of approximately 86 % of all roads in the Netherlands in 2019, it is interesting to take a closer look at which data is available to and needed by them. This is over 120 000 km of roads [17], with speed limits from walking pace up to 50 km/h within city limits and up to 80 km/h outside the built-up area.

The municipality of Apeldoorn aims to close materials loops. In order to be able to facilitate this transition to circularity, it is necessary to be aware of which materials are in use and at which location. Applications exist to help municipalities manage and maintain their public works. Apeldoorn adopted a GIS-based Gemeentelijk Beheer Informatiesysteem (GBI – Municipal Management Information System) of Antea-Group to store data relating to the management and maintenance of public works. According to three of the interviewees, a visual inspection takes place to make sure the roads are clean, whole and safe, approximately once every two years. Inspections like these make it possible to check if the municipality's information in GBI still corresponds with the actual situation (see Figure 1). When aesthetics, usability and/or safety fall short in real life, an intervention will be planned. An intervention might consist of relatively simple repairs up to a complete renovation of the road and surrounding public space.

When taking a closer look at the key in Figure 1, information about Griffiersveld is also available regarding the different road materials in use. The neighbourhood in which the area under consideration is located, was built in the late seventies. The following road product categories can be distinguished: concrete pavers, concrete paving slabs, other types of paving slabs, semi-paved, dense graded asphalt concrete, clay brick pavers, presence of surface treatment, or other materials. For concrete and clay brick pavers two particular product sizes have their own categories, as these products are very common in this municipality. After becoming familiar with the selected case, Griffiersveld, and with the way road information is currently stored at the municipality of Apeldoorn, it is now time to take a closer look at the results of the extra data that was collected on site in two scan projects.

4. Results

An MS Excel file extracted from the GBI-system shows that the municipality of Apeldoorn distinguishes up to 53 different characteristics for each road section. These characteristics include the road's identity, location, typology, inspection date, year of origin, maintenance year, appearance, safety level, width, surface and perimeter of the particular road section. A significant number of these 53 characteristics are particularly useful when focusing on the quality of asphalt roads, but are less relevant to roads consisting of concrete pavers or paving slabs. Furthermore, it is striking to see that many cells addressing the qualitative characteristics of road sections are empty, due to

FIGURE 2. Lines of measurement in Griffiersveld.

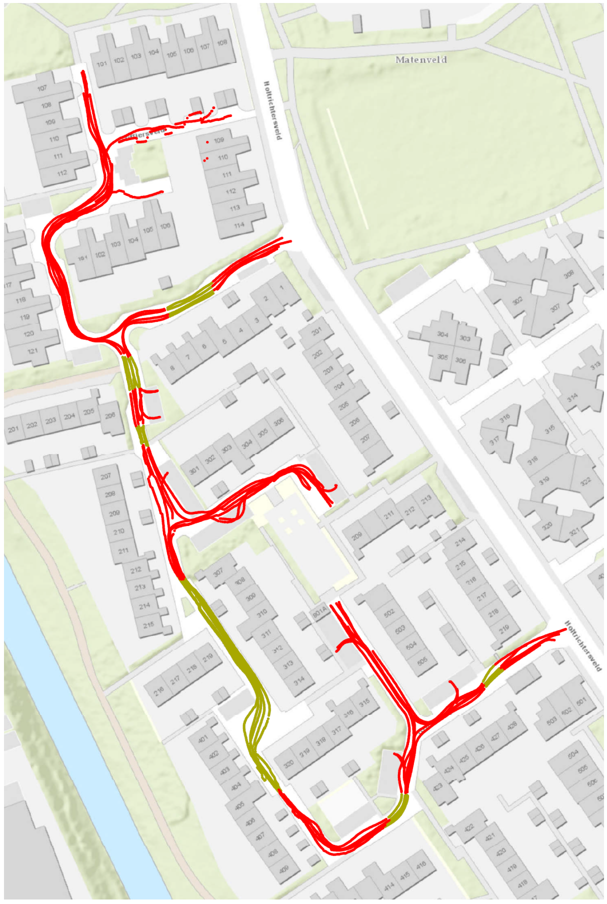

FIGURE 3. Applied pavement materials (red = concrete pavers, green = concrete paving slabs).

missing data. Available data helps assess the quality of a road section by means of pavement unevenness, grout width, appearance and safety. Quantities by means of the total number of pavers or paving slabs, their original sizes and original product mass are currently not provided. The main actors involved are not addressed either, so it might not be an easy task to learn more about the product's manufacturer, the road's contractor, contracted repairmen, inspector or principal.

In order to test if we can easily complete the data automatically, an initial scan of Griffiersveld was made on the 7$^{\text{th}}$ of April 2020. An IDS RIS Hi-Pave ground penetrating radar system at the back and a gamma spectrometer at the front of a van were used. The van drove approximately five times through Griffiersveld resulting in a dataset, that seems to consist of lines, but are in fact measuring points in close proximity (see Figures 2 and 3). The data collected by the gamma spectrometer offered insights into radioactivity levels (in Bq/kg) of pavements. The ground penetrating radar made it possible to assess the type of pavement and its thickness, namely around 5 cm thick concrete paving slabs and 8 cm thick concrete pavers. Furthermore, it was possible to get insights into the thickness of the sand package under the pavement, that seems to vary from 1.4 to 22.0 cm.

In a second scan process Light Detection and Ranging (LiDaR) data and panoramic high resolution images were collected on the 17$^{\text{th}}$ of June 2020. The scan equipment was mounted on the front of a van. This data, consisting of point clouds and images, gave insights into the location and status of surfaces and objects located in and adjacent to Griffiersveld. Pavers, paving slabs and edge beams can be checked regarding typology, colour, thickness and condition. Furthermore, a GIS-based inventory was made of inspection chambers (or manholes), road gullies, street poles, light posts and street furniture (Figure 4).

5. DISCUSSION

The adopted asset management system originates from a time in which linear principles prevailed over circular principles. Although much data is stored in GBI, items currently available do not necessary align with items that are part of material or project passports or with the actual situation in real life.

The first set of scans made it possible to check if the upper surface of the road indeed consists of the materials as laid down in the asset management system, but only by means of its typology and thickness. The thickness of the layer of soil directly underneath the surface layer was also scanned. However, this characteristic could only be assessed for approximately a sixth of the length of the whole street. At other locations the sand base was not present or too thin to be detectable by the applied sensors.

Furthermore, the pavement was scanned for differences in typologies of crushed stone aggregates in the upper layer by means of their radiation values. It is,

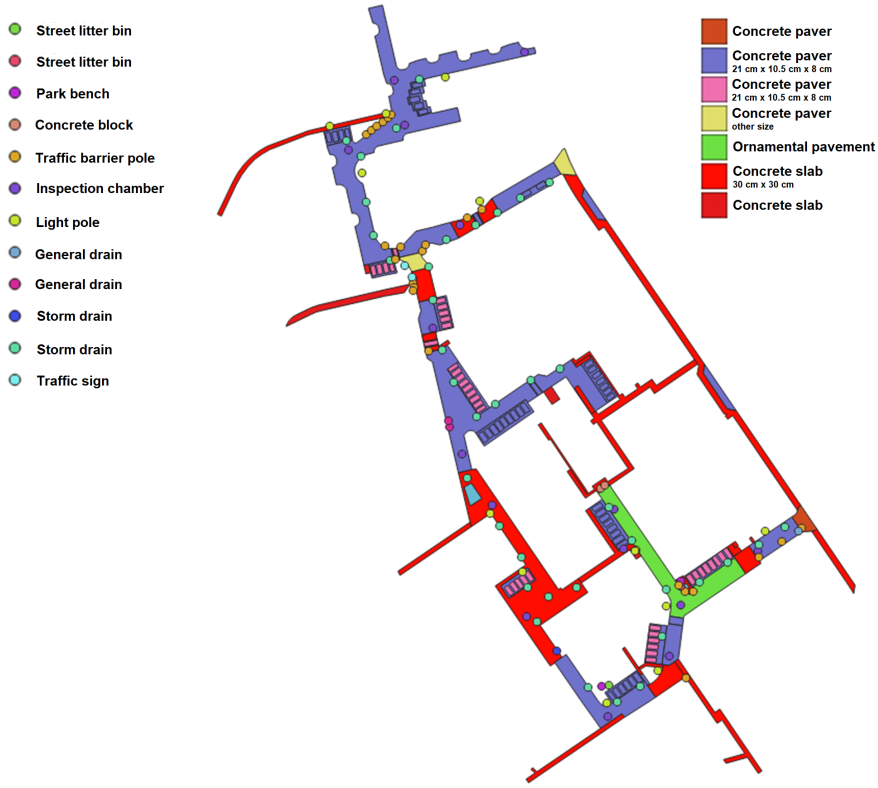

Figure 4. Results of scanning Griffiersveld through collecting images, radar and laser data.

however, not clear how these radiation values can be linked to the quality of the road, or the necessity for repairing and replacing the road.

Due to the data collection method during the first scan process, material differences remained unnoticed by the sensors around two speed bumps consisting of pavers instead of slabs. Also multiple footpaths were outside the scope of the data collection. However, in particular places sensors did notice that the thickness of the upper layer of the road changed, while this was not properly recorded in GBI. The asset management system mentioned the presence of concrete paving slabs here, but in fact concrete pavers are in place. These were probably put there after repairs had been made.

The second set of scans resulted in point and surface data, where collected images were manually inspected to assess the products present. When comparing the collected information with the information stored in the asset management system, the collected data could be used to complete or update the information in the asset management system for multiple locations in the street. Two locations of approximately $1\,\mathrm{m}^2$ and $10\,\mathrm{m}^2$ had been paved using concrete paving slabs, while this was not stored as such in GBI. Also a small footpath consisting of concrete pavers along a parking place was spotted by the sensors, but had not yet been stored in GBI. The sensors also provided extra information regarding a pavement planter that was not properly assessed in GBI. At one location, a cycle path stored in the asset management system and consisting of asphalt, was unnoticed by the sensors.

Lastly, neither the asset management system, nor the scans picked up a basketball court in Griffiersveld. The road, parking space and footpaths surrounding it were scanned and are included in the GBI data, but the municipality was unfamiliar with the court itself and therefore also the materials present.

6. Conclusions

In a circular economy material loops are closed and materials are used, maintained, repaired and re-used with the lowest environmental impact and the highest user-value possible. To accommodate a circular economy it is necessary to know what materials are currently in use. Data that qualifies and quantifies the materials in place, is necessary to prepare materials for future life cycles. In this research project the municipality of Apeldoorn was able to discover, whether the available and newly collected information on its asset Griffiersveld, meant that it was already futureproof from a circular perspective.

Data addressing the quality of asphalt roads can be stored in the asset management system. The experiment conducted on a road consisting mainly of concrete with two different road scanning processes, showed that differences exist between stored and actual data. At Griffiersveld these differences were in general relatively small, but not insignificant. It is also important to bear in mind that this was only one street in which multiple areas were paved differently than expected and a basketball court had been evidently overlooked.

Hence, false assumptions existed concerning the materials the municipality had in use. Although an asset management system is in place and much data has already been stored, the framework of Goselink [8] shows that information on mass, exact product dimensions, and the composition of products is lacking. Furthermore, lifetime expectancy and re-use options of materials, products and components in public space have not yet been assessed or registered. The consistency in naming elements is also an area for improvement. The most challenging aspect may well be how to assess the remaining technical lifetime expectancy of the materials in place and how to make sure that this remaining circular lifetime rules out linear arguments focusing on the need to use virgin materials.

The research also demonstrated that although a ground penetrating radar system and a gamma spectrometer can give additional insights to the asset manager, the LiDaR system with high resolution imaging currently provides data that is closer to the traditional process of a visual on-site inspection. Therefore this process tends to be favoured by the respondents interviewed. The use of a UAV equipped with a high-resolution camera, when legally acceptable, also appealed to multiple interviewees.

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