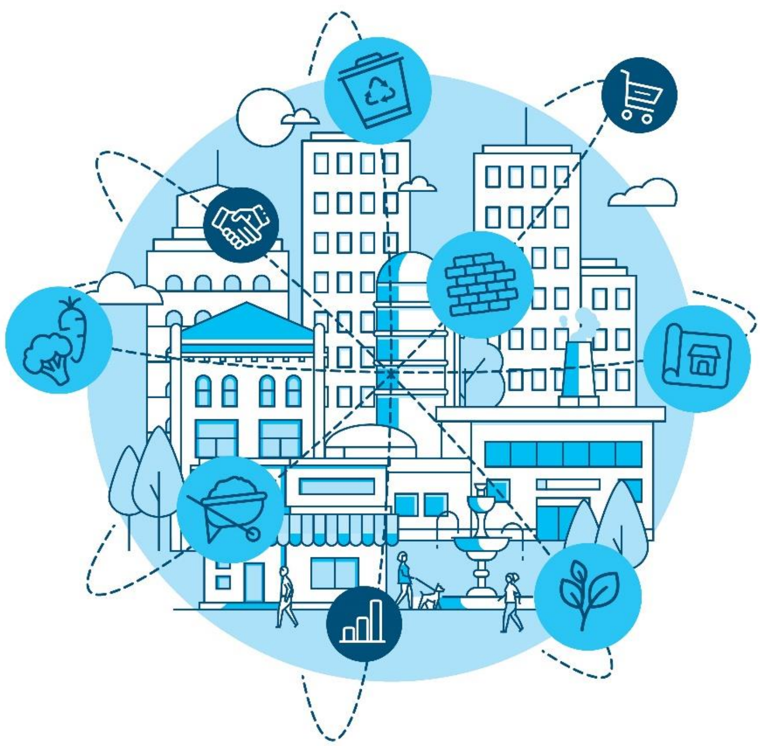
Collecting and storing data in a circular road renovation process

Saxion – Bram Entrop



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Abstract	Founded on a literature study and taking into account current project management software used by the municipality of Apeldoorn, this paper shares how to organise and collect construction road data. In an experiment various scanning equipment and procedures were employed onsite to collect actual road data, which have been incorporated in this municipality's database structure. The gained insights might help other researchers, principals, civil servants and contractors in the road construction industry to collect and store reliable data necessary to renovate roads circularly.
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Summary

The environmental impact of the construction sector as well as the transport sector is significant. Serving both sectors the environmental impact of constructing, maintaining and renovating roads can be reduced. The basic principle of a circular economy is to close material loops retaining the highest utility, quality and value of products, components and materials 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 our insights in and to share information on quantities and qualities of materials used in construction projects. Founded on a literature study and interviews on material passports, and by taking into account current project management software used by the municipality of Apeldoorn, this paper shares a framework to organise and collect construction road data. Furthermore, in an experiment various scanning equipment and procedures were employed onsite to collect actual road data. This resulted in a large amount of different data files that have been interpreted and incorporated in the existing database structure of the municipality. The gained insights might help other researchers, principals, civil servants and contractors in the road construction industry to collect and store reliable data necessary to renovate roads circularly.

Samenvatting

De milieu-impact van zowel de bouwsector, als de transportsector, is aanzienlijk. Het kan beide sectoren helpen om de milieu-impact van de aanleg, het onderhoud en de renovatie van wegen te verminderen. Het basisprincipe van een circulaire economie is het sluiten van materiaalkringlopen met behoud van de hoogst mogelijke bruikbaarheid, kwaliteit en waarde van producten, componenten en materialen. Een belangrijke vraag daarbij is hoe materiaalstromen te kwalificeren en te kwantificeren. Materiaal- en projectpaspoorten vormen mogelijk een deel van de oplossing om ons inzicht te verbeteren in en om informatie te delen over hoeveelheden en kwaliteiten van (bouw)materialen. Op basis van een literatuuronderzoek naar materiaalpaspoorten, afgenomen interviews en door rekening te houden met de door de gemeente Apeldoorn gebruikte projectmanagementsoftware, presenteert dit rapport een raamwerk voor het organiseren en verzamelen van data. Verder zijn in een experiment twee verschillende scanmethodes ingezet om ter plaatse actuele data te verzamelen. Dit heeft geresulteerd in een grote hoeveelheid verschillende databestanden die zijn geïnterpreteerd en verwerkt in de bestaande databasestructuur van de gemeente. De verkregen inzichten kunnen andere onderzoekers, opdrachtgevers, ambtenaren en aannemers in de wegenbouwsector helpen om betrouwbare data te verzamelen en op te slaan, zodat wegen circulair kunnen worden gerenoveerd.

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1. Introduction

Due to multiple European and national policies and agreements (e.g. “A new circular economy action plan; for a cleaner and more competitive Europe”, “Rijksbrede programma Nederland Circulair in 2050”, and “Grondstoffenakkkoord”), the urge to strive for closed material loops is felt in the construction industry. In the European Horizon 2020 project Cityloops municipalities develop and test tools that help in enhancing 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.

Within Cityloops the municipality of Apeldoorn prepares in collaboration with Saxion University of Applied Sciences (UAS) a circular road renovation project. For this project comparable circular principles might apply as for buildings, e.g. to reduce the need for materials, to design for disassembly, to reuse used components, products and materials (e.g. [1, 2]). Experiences with consumer products and buildings in coming to a circular economy, show that it is preferred that one is aware of specifications characterizing them (e.g. [3]). Therefore, this paper starts with a theoretical framework on which material characteristics are necessary enabling others to close material loops. This information can be put down in material and project passports (e.g. [1, 4]), which seem to be part of the solution to improve our insights in and to share information on quantities and qualities of materials used in construction projects.

Although this literature study might be able to provide insights in which information is required, it is not always possible to collect all qualitative and quantitative information needed to work out the material and project passports. On the one hand, collecting, organising and storing data take effort and costs apply. On the other hand, data might already be available in the hands of the actors and stakeholders involved. Therefore, six interviews were conducted with experts who were able to give insights in road renovations projects and collecting and storing road data.

The construction of and maintenance on infrastructural projects are often commissioned by public entities. Considering these public entities are experienced professional principals, it is likely that they have at least a part of the necessary data available to complete the data necessary for these aforementioned passports. However, in coming 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 was: how can material characteristics in renewing roads circularly in residential areas be obtained? The research project, disseminated in this paper, focused on how to match required and available data around a particular road renovation project in the Netherlands municipality of Apeldoorn. The ambition was expressed to renovate circularly the residential paved road of Griffiersveld, and the public space directly surrounding it. The neighbourhood, where the area of consideration is located, was constructed in the second half of the seventies.

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 to create transparency 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” (p. 229, ibid). When introducing this concept to the construction industry, where large amounts of materials are being 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 utterly important. 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 need to be laid down in the passport.
3. It includes technical lifetime expectancy of materials on site, so information on production date, manufacturer’s or contractor’s life time expectancy adjusted with information from the field.
4. Renovation or ‘end of life’ options of the materials are being addressed.
5. The setup of the material passport complies with an uniform system and clear definitions.

A material passport is an instrument that provides insights in the origin, original and current properties, composition and even future abilities of a material, product or component.

Therefore, a passport enables one to get grip on the environmental impact and financial value of regarded material, product or component. So besides the production date, it seems relevant to also be and stay familiar with the origin of the materials, products and components. However, not all information in a material passport is necessarily available anytime and/or to anyone. One does not want to give way the location of a precious and valuable material for example.

In the Netherlands, some manufacturers of metal façade systems are already applying a so called Façade Identification System (FIS) with tags in or QR-codes on window and door frames (e.g. Alkandor). These tags and QR-codes can be scanned and link to production information stored in an online database.

Although much information might be available, it is seldom easily and free of charge accessible at a central point. Building Information Modelling (BIM) might be a potential gamechanger in the construction industry, as Honic et al, [9, 10] put it. Charef and Emmitt [11] also explored how BIM may help practitioners to adopt a circular economy approach and they identified seven new roles for BIM, when it comes to a circular economy.

Seven new BIM uses in a circular economy [11]:

1. digital model for sustainable end-of-life,
2. material passport development,
3. project database,
4. data checking,
5. circularity assessment,
6. materials' recovery processes
7. materials' bank.

Next to BIM, we have Pavement Information Modelling (PIM) in the Netherlands for infrastructure projects, specifically asphalt roads. In PIM a particular road (section) can be incorporated as an object and decomposed in multiple steps with for each step the opportunity to store information. 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 some means of transport. For the sake of completeness but with attention to conciseness, this section addresses some of these automated data collection methods.

In the built environment data can for example be collected with the assistance of Unmanned Aerial Vehicles (UAVs). Enabling one to collect data effectively and efficiently, a protocol to fly camera equipped UAVs around objects is for example being provided by Entrop and Vasenev [13]. Regulations might apply and obstacles can be in place, 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 are also reported using Ground Penetrating Radar (GPR) systems to detect cracks in roads (e.g. [15]). The processing technique they used, made it possible to detect cracks larger than 1.3 mm in width. Their 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 motorized inspection vehicle.

Gamma spectrometers can also be attached to inspection vehicles, or again UAVs [16], to collect data that provide insights regarding 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 to consider motion sensors in mobile phones that, in combination with GPS, enable researchers to estimate traffic density and the flatness of the road surface. Last, but not least sensors can also be used immobile by placing them alongside or even in (asphalt) roads.

3. Entering the field

Efforts of multiple stakeholders are needed to collect and store the data appropriately. Considering that the Dutch municipalities were in 2019 the managers of approximately 86% of all roads in the Netherlands, it is interesting to have a closer look at which data is available and needed at these organisations. This is over 120.000 km of roads [17], at which one is allowed to drive with speeds 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 associates with the ambition to close materials loops, as is shown by her participation in the European H2020 Cityloops project. In order to be able to facilitate this transition to circularity, it is necessary to be aware of which materials are in use at what location. Applications exist to help municipalities to manage and maintain their public works. The municipality of Apeldoorn adopted a GIS-based Gemeentelijk Beheer Informatiesysteem (GBI – Municipal Management Information system) of AnteaGroup to store data related to managing and maintaining public works. According to three of the interviewees, roughly every two years a visual inspection takes place to make sure the roads are clean, whole and safe. Inspections like these make it possible to check if the municipality's information in GBI still correspondents 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.

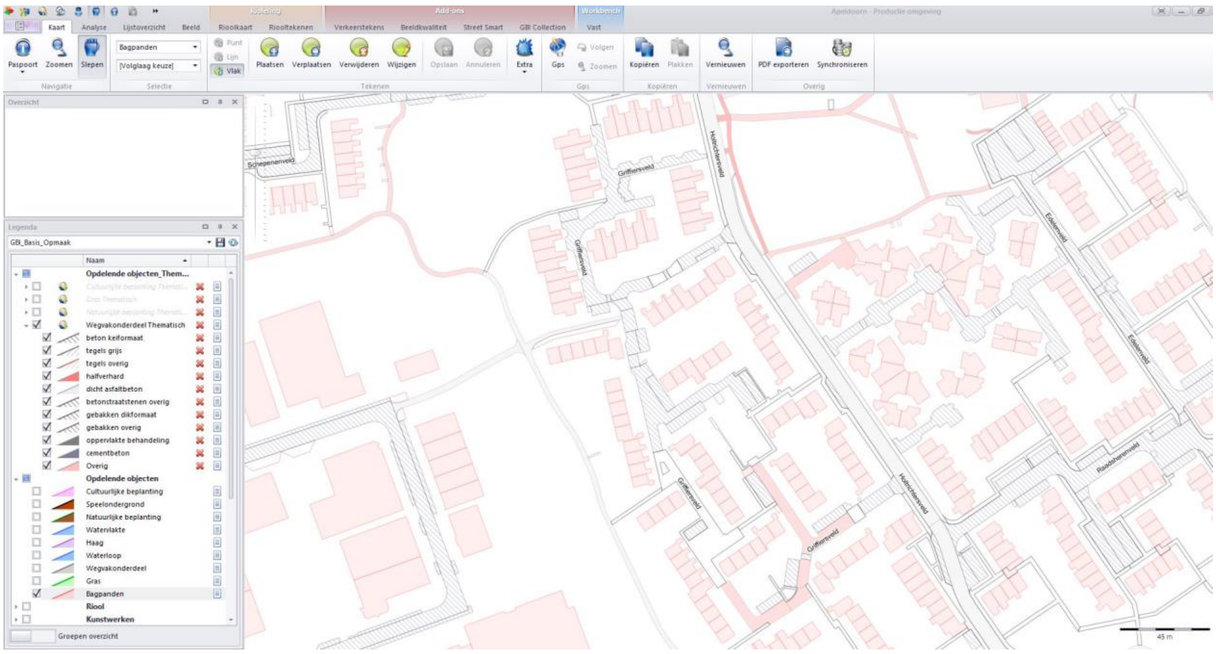

Figure 1. *Screenshot of the GBI asset management system showing Griffiersveld in Apeldoorn (by courtesy of Henk Pannekoek).*

When having a closer look at the legend in Figure 1, information for Griffiersveld is for example available regarding the different road materials in use. The following road product categories are distinguished: concrete bricks, concrete tiles, other types of tiles, semi paved, dense graded asphalt concrete, clay bricks, presence of surface treatment, concrete pavement, or other material. For concrete and clay bricks two particular product sizes have their own categories, because these products are that common in this municipality. Being familiar with the selected case, namely Griffiersveld, and with the way road information is currently stored at the municipality of Apeldoorn, it is time to have 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 address among others 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 part of these 53 characteristics focus on the quality of asphalt roads, which are logically not specified when road sections with pavers or tiles are being considered. Furthermore, it is striking to see that many cells addressing the qualitative characteristics of road sections are empty, because data is simply missing.

The structure to store data is available, but not all data is collected. The data that is available helps to 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 bricks or tiles, 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. When one wants to be able to retrieve information about which manufacturers and/or contractors provides the best lang lasting roads, or when wants to know where to invoke warranty this kind of information seems again wishful. When it comes to consumer products, brands and company logo’s is all over the place, but in the construction industry contractor only consider branding during construction.

In order to test if we can easily complete the data automatically, a first scan of Griffiersveld was made on the 7th 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 in 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 tiles and 8 cm thick bricks. Furthermore, it was possible to get insights in the thickness of the sand package under beneath the pavement, that seems to vary from 1.4 to 22.0 cm.

Figure 2. *Lines of measurements in Griffiersveld*

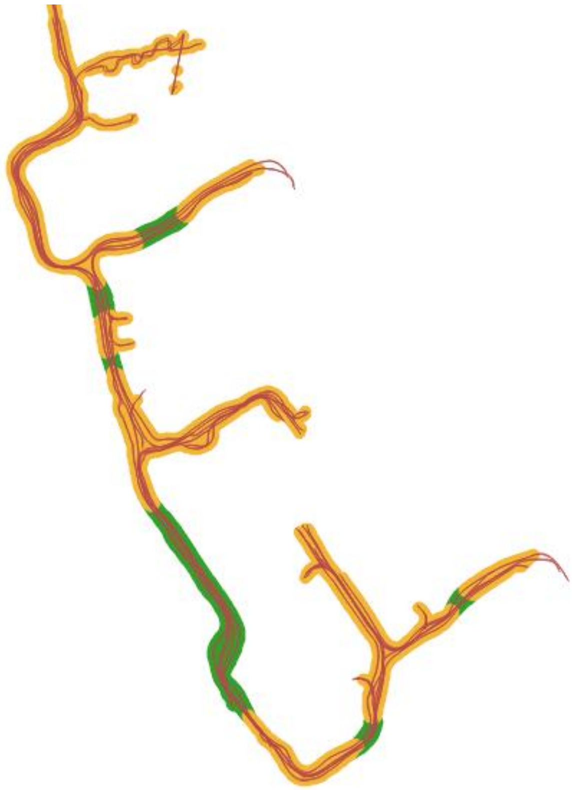

Figure 3. *Applied pavement materials (yellow = concrete bricks, green = concrete tiles).*

In a second scan process Light Detection and Ranging (LiDaR) data and panoramic high resolution images were collected on the 17th of June 2020. The scan equipment was mounted at the front of a van. This data, consisting of point clouds and images, gave insights in the location and status of surfaces and objects located in and directly around Griffiersveld. Pavers, tiles 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).

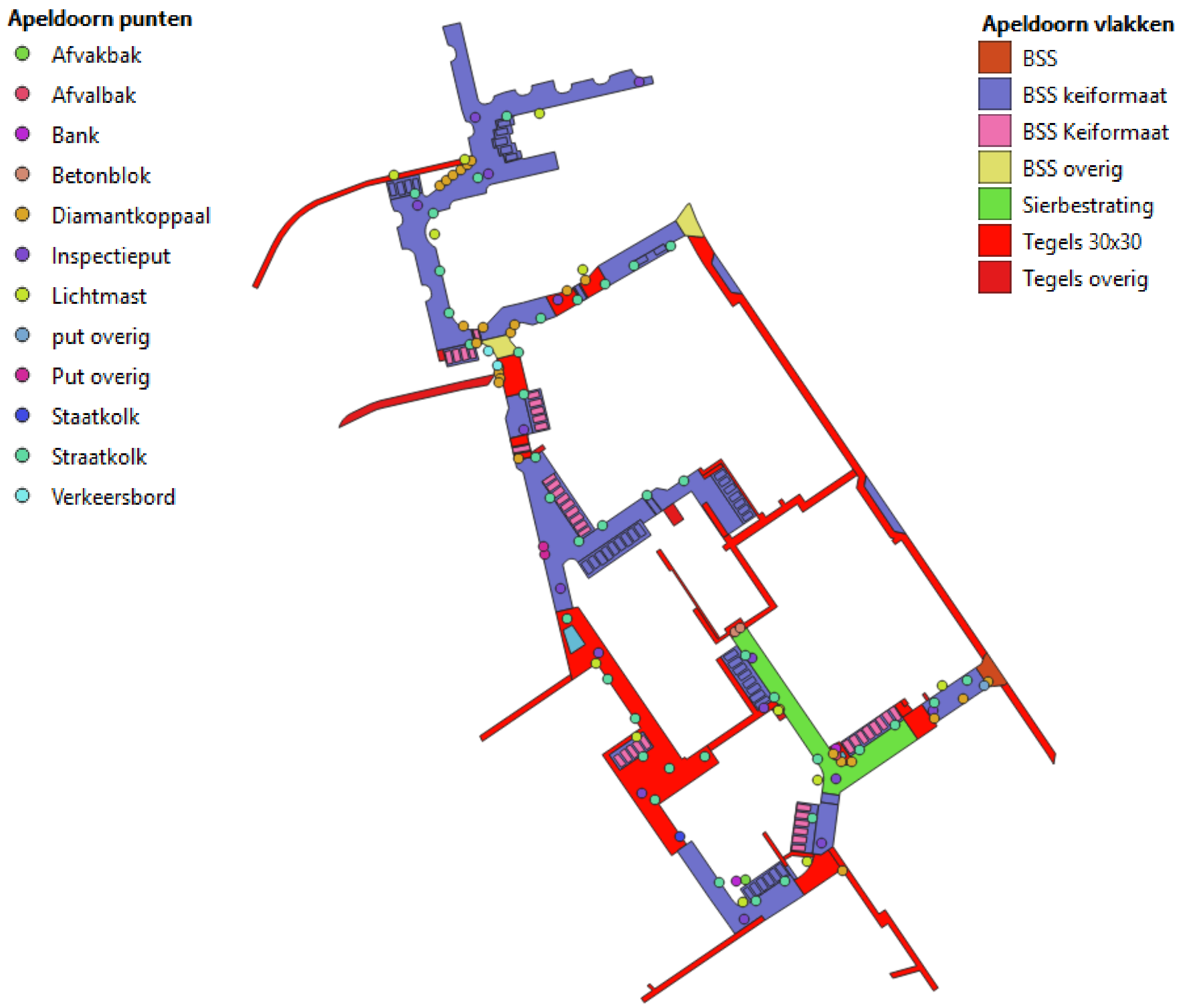

Figure 4. *Results of scanning Griffiersveld through collecting images, radar and laser data.*

5. Analysis

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 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 consists indeed 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 for the applied sensors. Although the quality of soil and sand is assessed at projects, soil and sand sites or depots, the origin and quality of this sand are not registered in GBI.

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, 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 stayed unnoticed by the sensors around two speed bumps consisting of bricks instead of tiles. Also multiple footpaths stayed 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 laid down in GBI (see Figure 5). The asset management system mentioned the presence of concrete tiles here, but in fact concrete bricks are in place. Probably, these were placed after some repairs took place.

Figure 5. *Although the purple surfaces indicated no change in pavement in the asset management system; the colour difference in the scanning routes did give the indication that different sorts of pavement were applied, namely concrete pavers and tiles (by courtesy of Pieter Ausema).*

The second set of scans resulted in point and surface data, where the collected images have been manually inspected, so that the products present could be assessed. Comparing the collected information with the information stored in the asset management system, it was noticed that at multiple locations in the street the collected data could be used to complete or update the information in the asset management system. Two locations of approximately 1 m^2 and 10 m^2 have been paved using concrete tiles, while this was not stored as such in GBI (see Figure 6). Also a small foot path consisting of concrete bricks 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 sidewalk planter, which form was not properly assessed in GBI. At one location, a bicycle path stored in the asset management system and consisting of asphalt, stayed unnoticed by the sensors. At some locations it seems that the appropriate nomenclature is not familiar or at least not clear to all users of the asset management system (see Figure 7).

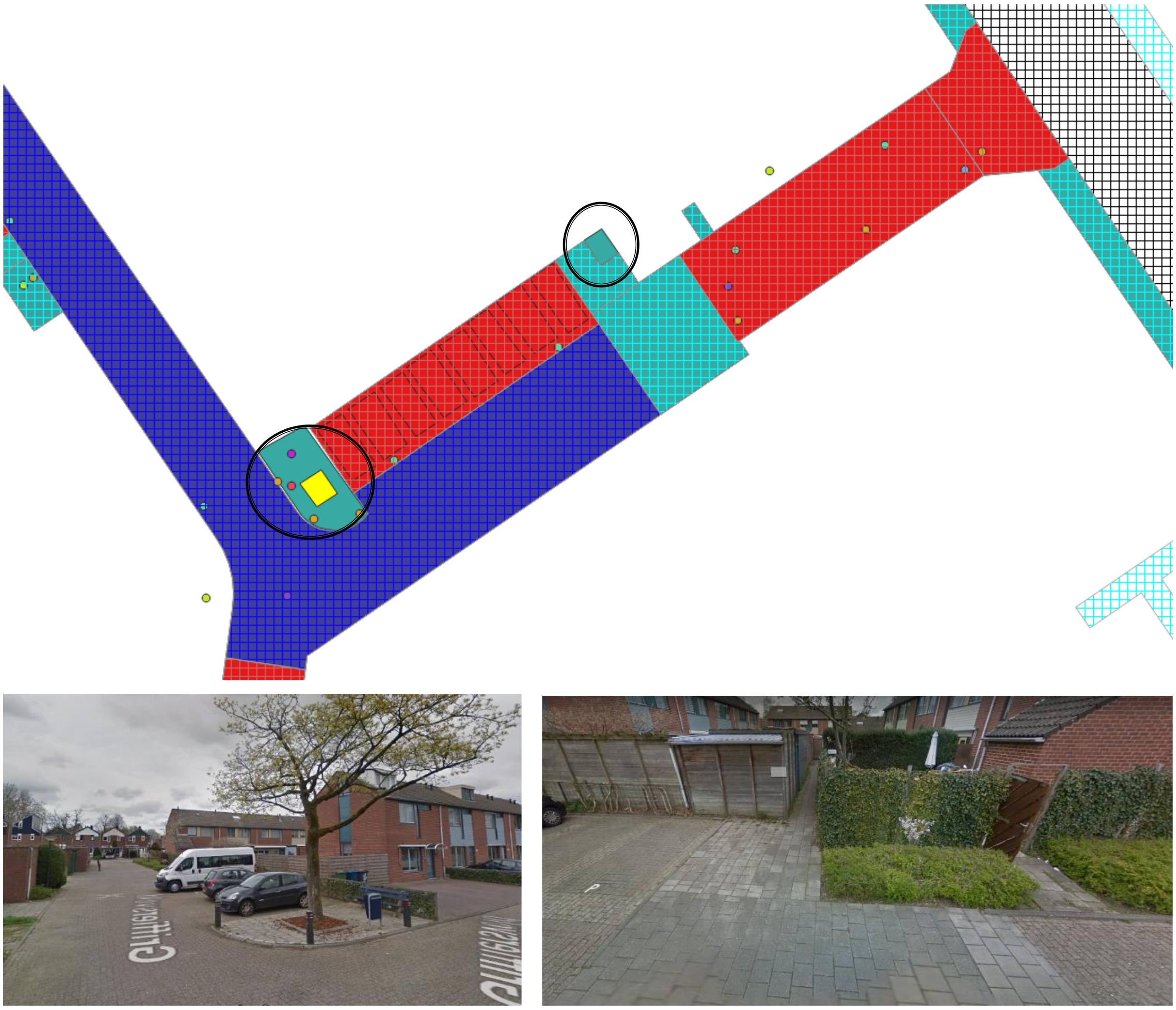

Figure 6. *Two examples of missing paved surfaces in the asset management system (by courtesy of Pieter Ausema).*

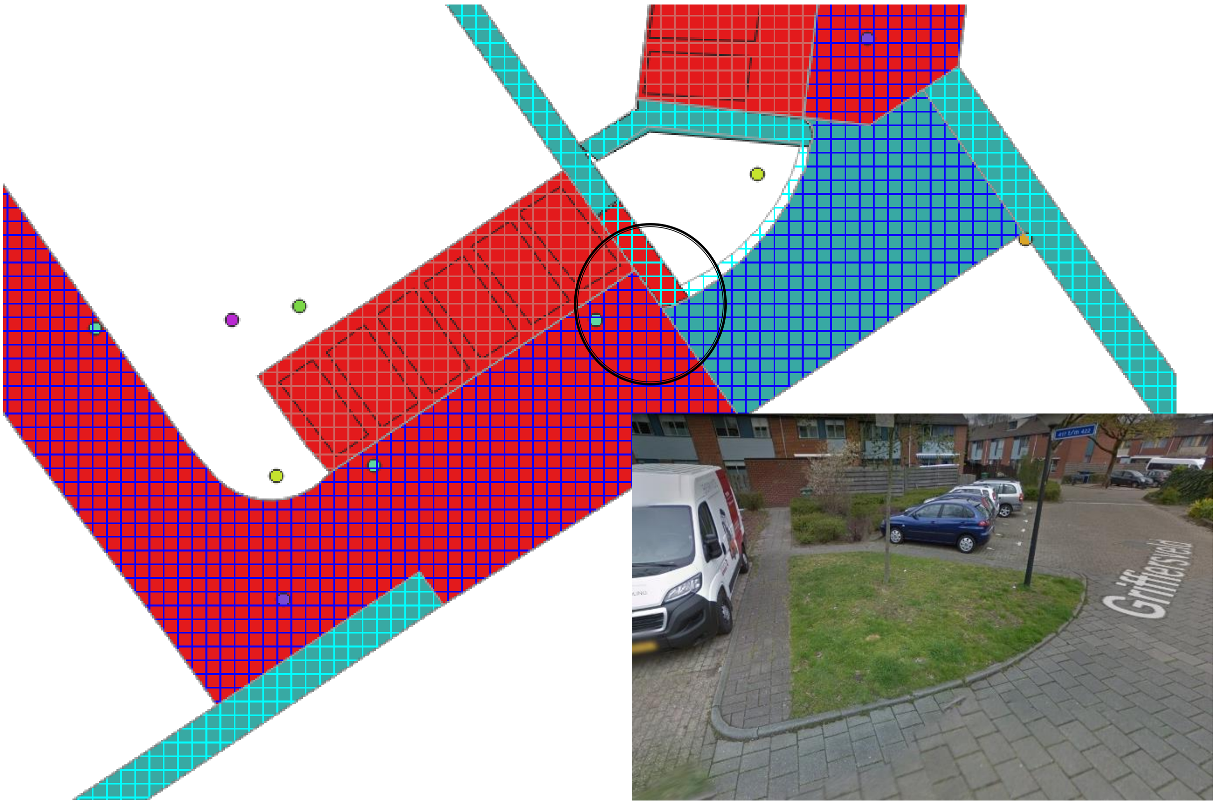

Figure 7. *An example of a paved area, that was wrongfully stored in the asset management system as ornamental pavement (by courtesy of Pieter Ausema).*

Lastly, nor the asset management system, nor the scans noticed a basketball court in Griffiersveld (see Figure 8). The road, parking space and foot paths surrounding it were scanned and are part of the GBI data, but the municipality is not familiar with the court itself and therefore the materials in place.

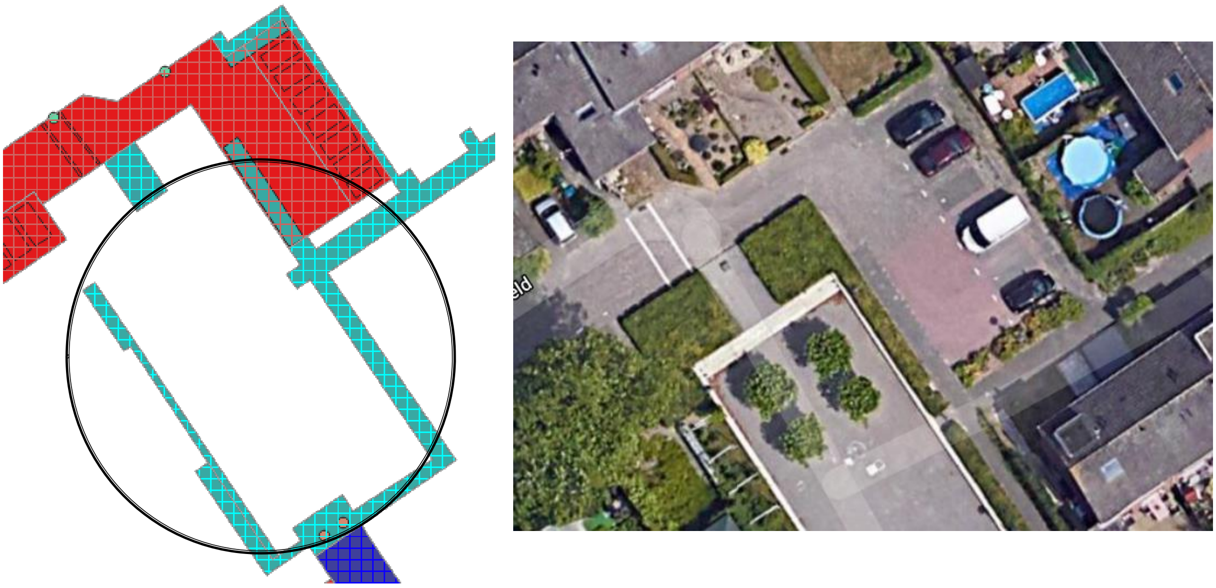

Figure 8. *A basketball court in Griffiersveld that was missing in the asset management system (by courtesy of Pieter Ausema)*

Multiple reasons exist that can explain these differences between the real life situation and the digitized model. One reason is that the original situation was not properly studied and stored, for example by only considering the original plans and not the work as executed by the contractor. A second reason is that during usage of the road on site activities as repairs and other changes by professionals or residents were not properly documented and stored in the database. A third reason is simply the time gap between the last inspection and current situation, whereby through usage a road section changed or even disintegrated. One needs to be aware that the whole trajectory of noticing, measuring, communicating, and incorporating data in the asset management system consists of many links, to which the rule of the weakest link unfortunately also applies.

6. Conclusion

In a circular economy material loops are closed and materials are being 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, as well as the sizes, sorts and qualities of incoming and outgoing material flows. To prepare materials for future life cycles, it is necessary to have the data addressing their quantities and qualities available. In this research project the municipality of Apeldoorn was from a circular point of view able to experience, to what extent the available and newly collected information on her asset Griffiersveld are already futureproof.

In the asset management system data addressing the quality of roads can be stored by means of a long list of different indicators. Currently, up to 53 indicators are linked to any road section in Apeldoorn, however not all data is already collected to specify these indicators. An experiment was conducted using two different road scanning processes on a road consisting mainly out of concrete. This experiment showed that differences exist between stored and actual data. At Griffiersveld these differences were in general relatively small, but not insignificant. One also needs to bear in mind, that this was only one street in which multiple areas were paved differently than expected, and a basketball court seemed to have been overlooked.

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

The research also showed that although a ground penetrating radar system and a gamma spectrometer can add to the insights an asset manager has derived from visual inspections at site. The LiDaR system with high resolution imaging currently seems to be able to provide data that is closer to the traditional process of a visual inspection on site. Therefore this process tends to be favoured by the respondents interviewed. The usage of an UAV equipped with a high-resolution camera does, when legally acceptable, also appeals to multiple interviewees. It might, however and as a topic for further research, wishful to back up these visual inspections with inspections conducted by experienced paving workers. By seeing and feeling the pavers a skilled paving worker might be able to assess their technical lifetime and opportunities for reuse accurately in no time.

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CityLoops is an EU-funded project focusing on construction and demolition waste (CDW), including soil, and organic waste (OW), where seven European cities are piloting solutions to be more circular.

Høje-Taastrup and Roskilde (Denmark), Mikkeli (Finland), Apeldoorn (the Netherlands), Bodø (Norway), Porto (Portugal) and Seville (Spain) are the seven cities implementing a series of demonstration actions on CDW and OW, and developing and testing over 30 new tools and processes.

Alongside these, a sector-wide circularity assessment and an urban circularity assessment are to be carried out in each of the cities. The former, to optimise the demonstration activities, whereas the latter to enable cities to effectively integrate circularity into planning and decision making. Another two key aspect of CityLoops are stakeholder engagement and circular procurement.

CityLoops runs from October 2019 until September 2023.

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