MSc thesis in Geomatics for the Built Environment

Locating and quantifying recyclable metal cables

Matthijs Bon

2017

LOCATING AND QUANTIFYING RECYCLABLE METAL CABLES

A thesis proposal submitted to the Delft University of Technology in partial fulfillment
of the requirements for the degree of

Master of Science in Geomatics for the Built Environment

by

Matthijs Bon

January 2017

ISBN 999–99–9999–999–9

The work in this thesis was made in the:

Faculty of Architecture & the Built Environment
Delft University of Technology

Supervisors: Alexander Wandl
Dr. Sisi Zlatanova

Co-reader:

CONTENTS

ACRONYMS

1 INTRODUCTION

1.1 BACKGROUND

If we keep up the current resource usage and waste production for a couple of decades, the earth will not look as it looks today. Fossil fuels and resources are depleting rapidly and more and more waste is produced every year. Our economy is based on a linear process in which we *take* resources from the Earth, *make* a product out of it and *dispose* of the product once the product has reached its end-of-life [Webster and Johnson, 2009]. A shift towards a circular economy in which waste is *reduced*, products are *reused* and *recycled* into new products or materials (3R principle), is needed.

A step towards such a circular economy is the Waste Management Directive 2008/98/EC [EC, 2008], published by the European Committee, which sets concrete goals to improve the efficiency in waste management in the European Union. The directive aims at decreasing packaging and landfill waste and promotes the reuse of municipal waste. In September 2016, the Dutch government released a note that by the year 2050, the whole Dutch economy will have made the transition towards a circular economy [Rijksoverheid, 2016].

On a more local level, the municipality of Amsterdam recently approved of a development strategy of the area 'Haven-Stad' in Amsterdam. The strategy focusses on creating mixed-use buildings for residential as well as office purposes. Additionally, the aim is to reuse and recycle (parts) of existing buildings and infrastructure to stimulate a local circular economy. [Gemeente Amsterdam, 2016]

1.2 SOCIAL RELEVANCE

In recent past, a publication on vacancy of office buildings in The Netherlands shows that 17% of Dutch office floor area is vacant and that figure is only growing [CBS et al., 2015]. Such vacant buildings might contain recyclable materials, but these are almost never reclaimed due to high costs once the building is not in use anymore. The buildings and their surrounding underground infrastructure can be seen as 'Urban Mines' [Zhu, 2014], a quarry that contains high amounts of valuable resources, hidden within the urban landscape. A big problem that arises with these urban mines is the lack of data on quantity and quality of the recyclable resources. Additionally, there is limited quantitative information available on the actual process of demolition [Scheuer et al., 2003], which makes it hard to reuse these resources locally in new buildings.

Furthermore, urban infrastructures such as (waste) water distribution systems, power supply grids, gas pipes and telecommunication cables, which where once part of the above-ground urban landscape are now buried underground [Kaika and Swyngedouw, 2000]. Such urban infrastructures can lose their function once an industrial area is redeveloped. More often than not, this underground infrastructure is not recovered by network operators or waste management companies due to high costs. This results in underground waste, accumulating over time, resulting in high amounts of wasted underground resources. These wasted resources have been termed hibernating stocks [Bergbäck and Lohm, 1997], due to their inoperable nature. Wallsten et al. [2013] did a study on prospecting these urban mines and found that these resources can be spatially located by performing Material Flow Analysis (MFA), looking at the history of infrastructural systems and using current geographical data. This research was conducted in Sweden, but it shows how many recyclable underground resources are available. This might also be the case for the Netherlands.

In the Netherlands, management of the underground infrastructures is strictly monitored by various instances. On a national level, the Kabels en Leidingen Informatie Centrum (KLIC) requires every network operator to register their underground infrastructure. This results in a large database with the underground infrastructure of the Netherlands. Every excavation work is registered to prevent damages to the infrastructure. On a more local level, some municipalities have additional information on underground infrastructure and require additional permits for laying new underground cables. This results in a vast database that contains almost every meter of underground infrastructure. However, contact with the municipality of Amsterdam revealed that there is a high demand for a dataset on (electricity) cables that contains information on the use of these cables.

1.3 SCIENTIFIC RELEVANCE

As [van der Voet and Huele, 2016, p. 4] already put it: "*only if we prospect the urban mine in terms of viability and value, we will be able to include urban mines in our planning for the future materials supply of societies.*" In most cases, being able to prospect depends on data availability. In The Netherlands, almost all data is available, but when this is not the case, data collection is necessary. Jeong and Abraham [2004] developed a decision support tool to be able to determine which techniques are most appropriate for data collection in a certain case study area, but the result is still a combination of techniques that will be utilized. Furthermore, most existing techniques for underground localization rely on someone to be at a physical location to determine the location of electrical cables and thus the quantity. In the literature there are so far no methods that can assess the location of cables and therefore the quantity without going out into the field.

The literature on the subject of indoor localization techniques is somewhat limited. Some of the contemporary buildings are now managed in Building Information Modelling (BIM) software, which means that information on the materials inside the buildings can be easily accessed. This brings great opportunities for assessing the above-ground urban mine. However, many buildings in Amsterdam were built before these models were used, which means BIM models are not available. A study on the dwelling stock in Norway incorporating MFA, shows that many buildings from these decades will soon reach their end-of-life [Bergsdal et al., 2007], which illustrates the necessity for an assessment of the quantity of urban mines in case these buildings are demolished and replaced.

1.4 PROBLEM STATEMENT

When it is unclear if a certain area contains underground infrastructure, underground localization techniques are used to find the underground cables. There are numerous techniques available to do this, e.g. electromagnetic line locators, Ground Penetrating Radar (GPR) and metal detectors, but not one technique is capable of finding all underground infrastructure, since they rely on different technologies that can only detect a specific set of materials. Additionally, most of these techniques require network operators to be at the physical location of the expected underground infrastructure.

In The Netherlands, such localization techniques are used rarely, since most of the underground infrastructure is already localized when they are registered. However, this might not be the case in other countries and to be able to assess the quantity of urban mines, having the location of underground infrastructure is essential. What if there was one method that combines multiple underground localization techniques to be able to directly and easily assess the quantity of an underground urban mine.

Additionally, a large part of urban mines consists of valuable resources inside buildings, such as electrical cables, door and window frames and steel beams. If not only the quantity of the underground urban mine can be assessed, but also the urban mine above ground, one is able to assess a complete city's urban mine. From the scientific and social relevance, it can be concluded that there is not yet one method or technique available that can assess the quality of an urban mine, both above-ground and underground.

2 RESEARCH APPROACH AND METHODS

2.1 RESEARCH QUESTION

This research project is guided by the following research question:

How can we improve existing localization techniques for metal cables, both indoor and underground, to be able to assess the quantity of an urban mine?

The objective of this research is to provide one comprehensible tool that can assess the quantity of an urban mine. The following sub questions for this research are relevant:

1. What data is already available in the case study area?
2. What methods can be used to locate underground metal cables?
3. What methods can be used to locate metal cables in buildings?
4. How can the used methods and the resulting location and quantities be validated?
5. What is the most efficient way to store the resulting data?
6. What visualization methods are available for visualizing the location and quantity of recyclable metals?

The question numbers correspond to parts of the methodology flowchart in figure 2.1.

2.1.1 Scope of research

This thesis aims at locating metal cables in three locations: ***1)*** Underground infrastructure; **2)** Office buildings and; **3)** Residential buildings. These three locations all contain metal (cables) that can possibly be recycled once the building is demolished or an area is redeveloped.

In this research, multiple methods will be assessed, resulting in a combination of methods for the most optimal localization and quantification of *metal*. Other materials will not be considered in this research, since time is a limiting factor. This thesis will not focus on the *quality* of the cables, since this would require to actually examine the metal cables and thus digging up the cables. The economic aspects will only be addressed very briefly.

2.2 METHODOLOGY

Figure 2.1 shows the structure of this thesis and how each of the research sub questions will be answered. The next subsections will elaborate more on each of the steps.

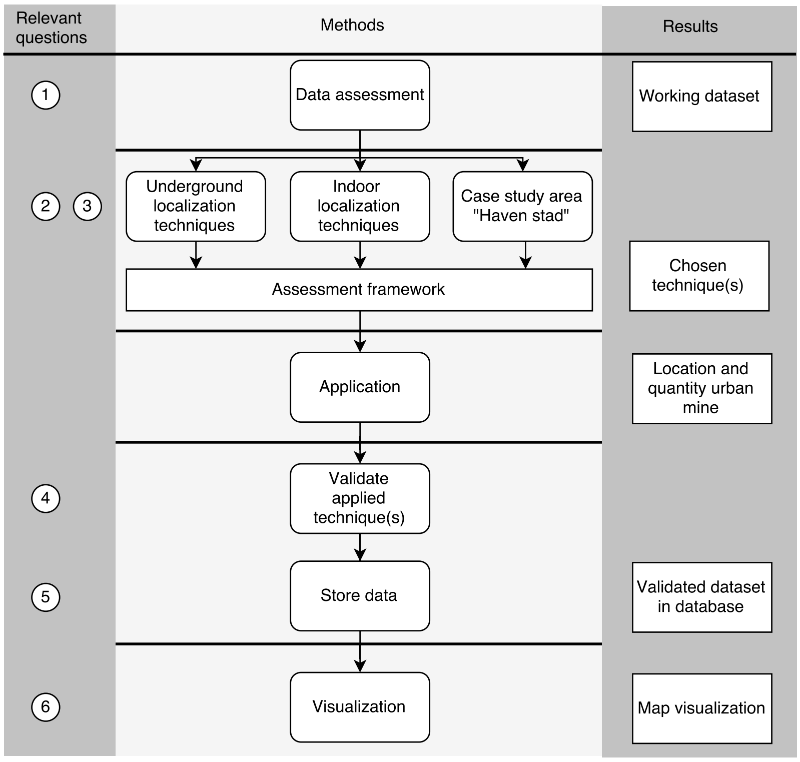

Figure 2.1: Methodology

2.2.1 Data assessment

The first step in this research process is to determine which data is already available in the specific case study area. The municipality of Amsterdam has a lot of datasets, however, not all are openly available. Obtaining the dataset from either the municipality or KLIC takes time, so this has a high priority. Furthermore, it would be very interesting to gain insight in the management of the data. Interviews with municipalities and network companies are necessary to gather knowledge.

When the data is available, the quality of the dataset must be assessed. The accuracy must be determined and it is useful to know if the dataset distinguishes between cables in use and not in use. This is necessary for one of the final steps in the process, validating the developed method.

2.2.2 Underground localization techniques

There are several techniques available for underground localization of metal cables. Such techniques include magnetometers, electromagnetic line locators, metal detectors and GPR. These technique need to be fully described, i.e. what is the necessary input, what are the required operations, is there any preprocessing necessary or a lot of analysis afterwards. Another very important aspect that should not be neglected is the limitations of each technique. Much of these answers can be found in the literature and will be discussed in Chapter 3.

2.2.3 Indoor localization techniques

For indoor localization, the techniques are less clear than for underground. Literature review is required to find and compare techniques. One way to locate and quantify indoor metal cables could be to use BIM models. Additionally, interviewing contracting and demolition companies might be able to provide some information on the process of construction and demolition.

2.2.4 Case study area "Haven stad"

The municipality of Amsterdam has designated the area "Haven-Stad" as a project that is being developed until 2040. The aim is to create job opportunities as well as residential buildings for inhabitants of Amsterdam, now and in the future. This transformation provides extra social relevance for this thesis research. The transformation of Haven-Stad comes with demolishing of buildings and excavating, which makes it interesting to know where and how much recyclable metal resources are available.

For the assessment framework and to find the most suitable techniques, it is very important to know the area of study. Every place has its own 'genius loci', i.e. place specific features, which have to be considered.

2.2.5 Assessment framework

Since usually not one technique applies to all scenarios, it is necessary to assess each technique for both underground and indoor locating and quantification of metal cables and determine which technique is best used in the case study area *and* which techniques can be combined into one single method. An assessment framework should be created to which all techniques can be assessed, to find the most suitable technique. As starting point for the assessment framework, the tool by Jeong and Abraham [2004] in Section 3.2 can be used. The technique that proves to be the most suitable for this particular research has to be applied and validated.

2.2.6 Application

The chosen technique(s) should be applied to the case study area which will result in data on the location and quantity of the urban mine, both aboveground and underground. This will require algorithms to be developed and programmed.

2.2.7 Validate method

The data that is available in The Netherlands can be used to determine the quality of the chosen method. The method is applied and has a certain outcome, which contains the amount of metal cables in that area. These results can be validated with data from the Dutch cadastre or the municipality of Amsterdam. If the method is correct within certain margins, the chosen method is valid enough for this purpose. If not, the method might be adjusted, or other techniques can be used.

2.2.8 Store data

At the end of the process, the results should be stored, this way other projects might benefit from these results. Storing is also very important to be able to visualize the dataset. Depending on the outcome of the method, the result will be vector data, raster data, a combination of vector and raster, or non-spatial. All these data types can be stored in a database, possibly with a spatial extension. PostgreSQL is an open source Database Management System (DBMS) and with the extension PostGIS it has the functionality to store spatial data. Efficiency is usually of great concern when storing (spatial) data, but this is mainly influenced by the size of the data, which is yet unknown.

2.2.9 Visualization

From the database, the results can be retrieved to visualize in a map of some sorts. In the best case scenario, something similar to the Waag Society map, see figure 2.2 will be the final result. In stead of only building, the map will also show underground metal cables and a total amount of metal. Naturally, many ways of visualizations are possible. A review of possible visualizations is necessary, such as deciding to visualize in a 2D or 3D map and the unit of measure, i.e. at which granularity to display the data.

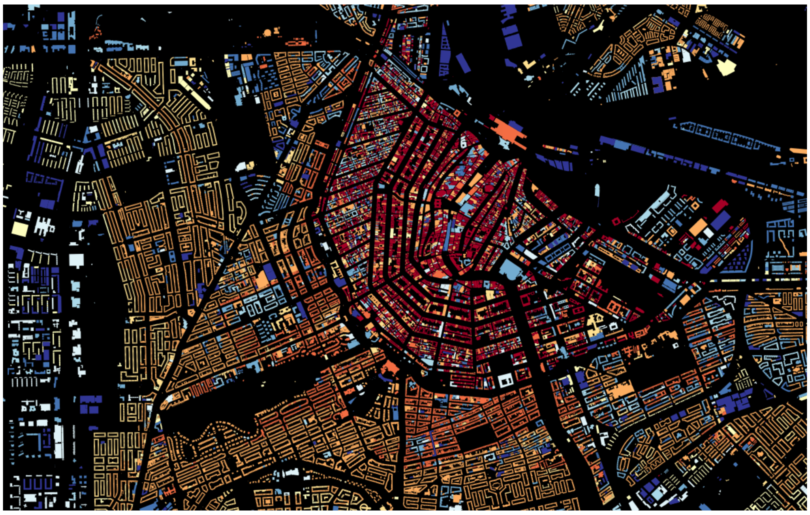

Figure 2.2: Waag Society map, showing building in Amsterdam, coloured according to building age. © Waag Society

2.3 TOOLS AND DATA

The source code for this project will most likely be programmed in Python and additional libraries. Additionally, storing the data in a database requires a DBMS, such as PostgreSQL. Since the data is spatial, use of the PostGIS extension is necessary. Visualizations can be made in a Javascript library called D3.js or with QGIS with the help of Adobe Creative Suite. The Kadaster has data on underground infrastructure, called KLIC-data. This data is most probably very useful for this research, but the main question is if they are willing to share the data. Also, there might be possibilities to contribute to project REPAiR [van Timmeren, 2016], which brings possibilities for obtaining data. Additionally, since the municipality of Amsterdam is transforming the area Haven-Stad, they might have data available that they are willing to share for the purpose of this research project.

2.4 PLANNING

To finish this thesis in time and to guide the process, figure 2.3 shows the planning of activities per week, starting in week 2.9 of the TU Delft academic calendar. Should it be the case that certain activities take longer than expected, activities will run parallel or another activity will start later.

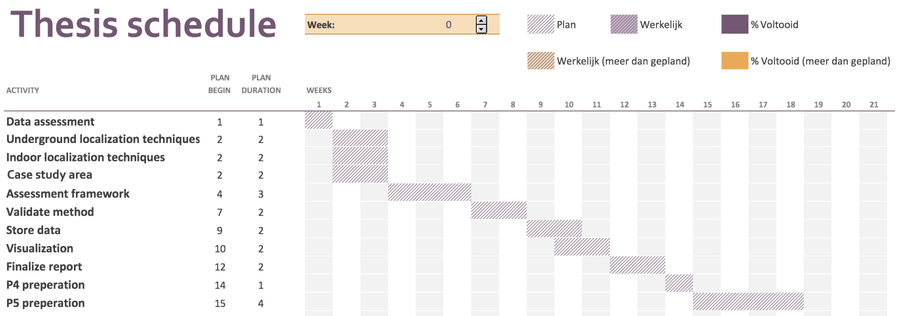

Figure 2.3: Weekly schedule

3 RELATED WORK

In this chapter, the reviewed literature will be discussed. The chapter is structured in the following way:

- Underground urban mining
- Methods for localization of underground cables
- Indoor urban mines
- Methods for localization of cables in buildings

3.1 UNDERGROUND URBAN MINING

Zhu [2014], discusses the concept of Urban Mining, reusing and recycling resources which are dispersed among urban infrastructure, buildings, consumer products and waste. These resources could be reclaimed if the exact location data is available. A Geographical Information System (GIS) could become useful in these environments, to map and visualize the recyclable resources. Blengini [2009] also discuss roughly the same topic. They pose that every building that is demolished could be seen as a quarry. Such a quarry contains valuable materials which can be reused elsewhere. This has proven to be feasible from environmental and energetic perspectives and also profitable and economically interesting. However, data is needed for a GIS to function and this data is often very limited or unavailable.

Wallsten and Krook [2016] did a study on where political decision makers should intervene to stimulate recovery from underground infrastructure. From multiple interviews with respondents, they could classify five interpretations of so-called urks. An urk can be denoted as "infrastructure cables and pipes that remain underground after being disconnected" [Wallsten and Krook, 2016]. Each different interpretation has different aspects and problems that should be resolved to stimulate resource recovery. Such a classification of urks can help build political recognition and stimulate resource recovery. One particular interesting interpretation of urks is that of a mineral resource deposit. Usually the costs of recovery are much higher than the revenue from recycling, which makes it uninteresting. However, in the case of redevelopment of an area, recovery of urks might be feasible, because that site is excavated anyway, which lowers the overall costs [Wallsten and Krook, 2016].

3.2 METHODS FOR LOCALIZATION OF UNDERGROUND CABLES

When investigating urban mines, one of the biggest issues is data on the urban mine. Ideally, network operators have a well-maintained database on all the in-use cables in a certain area. However, sometimes the cables that are not in use anymore have just been removed from the database, but not from the soil. In better situations, network operators can update the cable by saying it is out of use, but unfortunately this is not always what happens in reality.

Therefore, techniques have been used to locate underground metal cables. Jeong and Abraham [2004] developed a decision tool to determine which localization techniques is best fit in a specific situation. This tool can be a starting point for the assessment framework. Several techniques are available, of which the most commonly used techniques will be discussed in the next subsections.

3.2.1 Magnetometers

Magenetometers utilize the magnetic fields radiated by ferrous objects in the earth soil. A deviation in the magnetic field of the earth caused by these ferrous objects can help detecting these ferrous objects. However, for this research the focus lies with electricity cables. This causes two problems when adopting this method for localizing. First, the electricity cables are not ferrous but are mostly made of copper. Secondly, the electricity cables can cause interference with the magnetometer, resulting totally unreliable readings.

3.2.2 Electromagnetic line locators

Several electromagnetic methods exists to localize pipes and cables in subsurface areas. These methods rely on the principles of electromagnetism, in specific the notion that metallic objects can create a magnetic field when a pipe or cable is induced with a magnetic frequency. An example of such a technique is an electromagnetic line locater. The electric cable can be located by introducing a signal to the cable, connected either directly or indirectly to the cable. The resulting magnetic field can be detected by an antenna and can provide information on location and even depth [Costello et al., 2007]. Important to realize here, is that a direct connection or indirect connection is preferred, but not the only way. A more passive method makes use of the background signals that are induced by underground metal cables [Costello et al., 2007]. However, this method is much more unreliable than the direct and indirect methods. The active methods are much more accurate, but they require an access point, which is not always available. The passive method could be used in more larger areas where access points are unavailable to provide an rough estimation of the location and amount.

3.2.3 Metal detectors

Metal detectors can also be used for locating underground metal cables. The detectors work by transmitting magnetic field into the ground and analyzing the resulting field for abnormalities, such as metal cables and pipes. But since the field only reaches so far into the ground, the operating depth of metal detectors is only up to 2-3 meters, depending on the size of the search-coil [Jeong and Abraham, 2004].

3.2.4 Ground penetrating radar.

One of the most used imaging techniques for localization of underground utilities is GPR. This technique makes use of electromagnetic waves as well, but the material of the cable or pipe is not limited to metals. Electromagnetic waves are transmitted into the ground from an antenna and will reflect of underground utilities. The reflection can be detected by a receiving antenna [Costello et al., 2007]. The method works most effective when the antenna is placed perpendicular to the cable or pipe. However, the ability to detect both metallic and non-metallic utilities bring the challenge of identifying the utility after detection, possibly using other localization techniques [Costello et al., 2007]. Moreover, the type of soil also influences the performance of GPR [Jeong and Abraham, 2004]. One major drawback of GPR is the limited operating depth, which has a maximum of 2m [Jeong and Abraham, 2004].

3.2.5 Graph theory

As stated previously, there do exists methods for localizing underground metal cables. However, they are quite expensive or work-intensive while automated methods for localizing recyclable metal cables do not exists yet. Graph theory can be used as a methods for locating the metal cables from a design perspective. Since most metal cables are used for electricity and data transmission, finding the metal cables can be translated to a design process for finding an optimal power network design. If we can estimate the optimal location and amount of electricity cables necessary, we have the minimum available amount of recyclable resources.

An estimation of a power network can be given by using an Steiner Minimal Tree approach. A Steiner Minimal Tree is a graph G in which the total length of the edges is minimized [Kou et al., 1981]. Using this graph and public space as an constraint, it might be possible to derive an accurate location of metal cables available for recycling. Additionally, using methods like medial axes [Lee, 1982] or segmented voronoi can help finding the optimal location of cables in the public space.

3.3 INDOOR URBAN MINES

When we talk about urban mines, we have to consider not only the underground resources that might become available, but also the above ground resources, usually found in buildings. Building construction materials often include reinforced concrete and steel beams and those might be recycled once the building reaches its end-of-life. Furthermore, most building constructed after 1900 contain an electrical system mainly constructed out of copper wires. Since copper is a limited resource on Earth, being able to mine copper from buildings that are not in use anymore could become very useful. However, little is known about the actual process of demolition [Scheuer et al., 2003], which poses a challenge when we want to assess the quantity of the above-ground urban mine. This section and subsections describe some of the techniques for determining the quantity of metal cables in buildings.

3.4 METHODS FOR LOCALIZATION OF CABLES IN BUILDINGS

In 2016, the Amsterdam Institute for Advanced Metropolitan Solutions (AMS) organised a project on 'Prospecting the Urban Mines of Amsterdam [van der Voet and Huele, 2016]. This project was concerned with exploring the potential and limitations of the urban mine of Amsterdam. In this project, they also came across the challenge of data collection. They combined multiple data sources into one map that contains the building information and the amount of metal in that building. This project's calculations were based on a BIM based approach, which will be described in the next section. Additional methods can be used to assess the above-ground (e.g. in buildings) urban mine, such as MFA. Furthermore, interviews with demolition companies can bring valuable insights in the process of demolition and the waste generated by demolition.

3.4.1 Building Information Modelling

The US National BIM Standard is defined in three dimensions [US National Institute of Building Sciences, 2007]:

1. The Building Information Model (a product) is a structured dataset describing a building;
2. Building Information Modeling (a process) is the act of creating a Building Information Model;
3. Building Information Management (a system) comprises the business work and communication structure that increase quality and efficiency.

For this research project, a BIM model can be of great help since it stores all the information on the materials used inside a building. If we define different types of buildings in the case study area and we have the BIM model of each of these types, we can calculate the amount of material (metal cables) available for reuse or recycling.

3.4.2 Material Flow Analysis

MFA is an assessment of an system with regards to its stock and flows. It is often used in waste and resource management because it describes the flow of matter (which by the law of conservation of matter remains the same) from being to end [Brunner and Rechberger, 2004]. One way of looking at MFA, specifically in urban areas, is Urban Metabolism (UM) [Zhang, 2013]. In MFA done in the Urban Pulse project by the AMS, it was found that the UM of Amsterdam is dominated by water flows, which can be explained by the delta location of Amsterdam [Voskamp et al., 2016].

UM and MFA can help in identifying the resource flows of metals in buildings in terms of construction and demolition waste. The results from the MFA in 2012 show that there is 25 kiloton of metal recovered from waste [Voskamp et al., 2016].

BIBLIOGRAPHY

Bergbäck, B. and Lohm, U. (1997). Metals in society. *The Global Environment: Science, Technology and Management*, pages 276–289.

Bergsdal, H., Brattebø, H., Bohne, R. A., and Müller, D. B. (2007). Dynamic material flow analysis for Norway's dwelling stock. *Building Research & Information*, 35(5):557–570.

Blengini, G. A. (2009). Life cycle of buildings, demolition and recycling potential: a case study in Turin, Italy. *Building and Environment*, 44(2):319–330.

Brunner, P. H. and Rechberger, H. (2004). *Practical handbook of material flow analysis*. CRC/Lewis.

CBS, PBL, and Wageningen UR (2015). Leegstand van kantoren, 1991-2015. Technical report, CBS, Den Haag; Planbureau voor de Leefomgeving.

Costello, S., Chapman, D., Rogers, C., and Metje, N. (2007). Underground asset location and condition assessment technologies. *Tunnelling and Underground Space Technology*, 22(5):524–542.

EC (2008). Directive 2008/98/EC of the european parliament and of the council of 19 november 2008 on waste. *Official Journal of the European Union L*, 312(13):22–11.

Gemeente Amsterdam (2016). Startnotitie Ontwikkelstrategie Haven-Stad. Notitie.

Jeong, H. S. and Abraham, D. M. (2004). A decision tool for the selection of imaging technologies to detect underground infrastructure. *Tunnelling and underground space technology*, 19(2):175–191.

Kaika, M. and Swyngedouw, E. (2000). Fetishizing the modern city: the phantasmagoria of urban technological networks. *International Journal of Urban and Regional Research*, 24(1):120–138.

Kou, L., Markowsky, G., and Berman, L. (1981). A fast algorithm for steiner trees. *Acta informatica*, 15(2):141–145.

Lee, D.-T. (1982). Medial axis transformation of a planar shape. *IEEE Transactions on pattern analysis and machine intelligence*, (4):363–369.

Rijksoverheid (2016). Nederland Circulair in 2050. In het kort. Brochure.

Scheuer, C., Keoleian, G. A., and Reppe, P. (2003). Life cycle energy and environmental performance of a new university building: modeling challenges and design implications. *Energy and buildings*, 35(10):1049–1064.

US National Institute of Building Sciences (2007). United States National Building Information Modeling Standard, Version 1 – Part 1: Overview, Principles and Methodologies. Standard, Facilities Information Council, USA.

van der Voet, E. and Huele, R. (2016). Prospecting the urban mines of amsterdam. Deliverable 1, Leiden University, Waag Society and AMS.

van Timmeren, A. (2016). REPAiR - REsource Management in Peri-urban Areas: Going Beyond Urban Metabolism. Technical report, TU Delft, Ghent University.

Voskamp, I. M., Stremke, S., Spiller, M., Perrotti, D., der Hoek, J. P., and Rijnaarts, H. H. (2016). Enhanced performance of the eurostat method for comprehensive assessment of urban metabolism: a material flow analysis of amsterdam. *Journal of Industrial Ecology*.

Wallsten, B., Carlsson, A., Frändegård, P., Krook, J., and Svanström, S. (2013). To prospect an urban mine–assessing the metal recovery potential of infrastructure "cold spots" in Norrköping, Sweden. *Journal of Cleaner Production*, 55:103–111.

Wallsten, B. and Krook, J. (2016). Urks and the urban subsurface as geosocial formation. *Science, Technology & Human Values*, pages 827–848.

Webster, K. and Johnson, C. (2009). Sense & sustainability. *Educating for a low carbon world*.

Zhang, Y. (2013). Urban metabolism: a review of research methodologies. *Environmental pollution*, 178:463–473.

Zhu, X. (2014). GIS and urban mining. *Resources*, 3(1):235–247.