Underneath Norrköping – An Urban Mine of Abandoned Infrastructure

Abstract

Appended Papers and My Contribution

Paper #1: To Prospect an Urban Mine: Assessing the Metal Recovery Potential of Infrastructure "Cold Spots" in Norrköping, Sweden.

Journal: Journal of Cleaner Production 55, 2012, pp. 103-111.

Co-authors: Annica Carlsson, Joakim Krook, Per Frändegård, Stefan Svanström

Status: Published

Overview Interviews and Spatial Data Collection: We did informal interviews with a set of different people at different infrastructure related organisations in Norrköping to get an initial understanding of the topic and the amount of available data. I was in contact with/interviewed all of the fourteen respondents listed in the acknowledgement in the article, except for the conversations with Mats Schillerström at Skanova and Bo Rasmussen at Ericsson Cable Technology, which were performed by Joakim Krook. None of these conversations were recorded.

The empiric material was gathered from a lot of different sources. All the written sources and historical maps at Norrköping City Archive used to assemble spatial statistics were collected and assessed by me. To the extent that digitalized system data already existed for disconnected parts, we got hold of the GIS-files directly from the system providers. The disconnected parts of the electric grid were digitalized manually by myself together with the Environmental Science Program students Simon Andersson and Johan Pettersson. All the authors participated with Stefan Svanström in his office at Statistics Sweden to arrive at reasonable assumptions on the spatial distribution of the DC Power Grid and town gas grid, for which we could not get hold of coherent maps. The calculations of metal content per meter in cables and pipes were done by Joakim Krook, while I performed all of the work done in the GIS-software.

Writing and Graphics: Chapter one was written by me and Joakim Krook, I wrote the infrastructure parts and he the industrial ecology-parts. I wrote chapter 2 and 3 while Annica Carlsson wrote chapter 4. Myself, Annica Carlsson and Joakim Krook together co-wrote chapter five while I wrote the conclusions. I went through, re-worked and edited the entire text before submitting, and was solely responsible for all alterations made during the review process. The maps were developed by Stefan Svanström at Statistics Sweden.

Presenting: The material has been presented at the following conferences:

- ISIE @ UC Berkeley, CA, USA, in june 2011 by co-author Per Frändegård.
- Sym City @ Kåkenhus, Norrköping, in november 2011 by me.
- 4S @ Cleveland City Center Hotel, Cleveland, OH, USA, november 2011 by me.
- ConAccount @ Darmstadt, Germany, september 2012 by co-author Annica Carlsson.

Paper #2: A Cable Laid Is a Cable Played: On the Hibernation Logic Behind Urban Infrastructure Mines
Academic journal: Journal of Urban Technology 21:3, 2013.
Co-authors: Nils Johansson, Joakim Krook.
Status: Published.
Interviews and transcription: The empiric material was gathered in nine interviews. I was present at all of these occasions exept one, when the interview was done by co-author Nils Johansson alone. The following table outlines who were present at which interviews and who transcribed them. I did all of the transcriptions but three, out of which two were made by co-author Nils Johansson and one made by a student hired through a staffing company.

	#1	#2	#3	#4	#5	#6	#7	#8	#9
Björn	I + T	I + T	I + T		I + T	I	I + T	I + T	I
Joakim	I				I		I		
Nils	I		I	I + T	I	I	I	I	I + T

Writing and Graphics: I wrote all of the chapters in the article from the ground up except for the paralysis and dormant cells-chapters (see Wallsten et al. 2013, pp.XXX), whose first drafts was written by co-authors Joakim Krook and Nils Johansson respectively. Just like in the first article: I went through, re-worked and edited both these sections to streamline them language-wise before the submission. All the editorial and review comments were thereafter addressed by me. The map graphics was done by my brother Erik Berglund.

Presenting: The material has been presented at the following occasions:

- 4S @ Cleveland City Center Hotel, Cleveland, OH, USA, november 2011 by me.
- The Swedish Ministry of Environment @ Centralpalatset, Stockholm, march 2012 by me.
- GRC in Industrial Ecology @ Les Diablerets, Switzerland, june 2012 by me.

Table of Contents

”Metals are gifts from the stars that were generated over billions of years; we should treat them with the awe and respect they deserve and devise ways to recycle them over and over.” – Thomas Graedel, 2011

1. Introduction: Mining in the Anthropocene

Since pre-historic times, mankind has physically modified the landscape. Us humans have deliberately excavated rock and soil and created different kinds of artificial grounds, built structures and waste material. We are geological agents that affect the composition of rock formations and thus the geological configuration of planet Earth (Szerszynski, 2012).

Since the industrial revolution in the 1750's, both the impact and rate of the material transfer process from the Earth's crust to our built environments have changed dramatically. The widespread industrial activity and far-reaching urbanization have increased the material needs of human society and thereby also the scale, magnitude and significance of mankind's geological activity (Price et al, 2011). The modern process of mining, blasting, dumping, crushing, extracting and exhausting (Mumford, 1934), goes on with increased frequency, as we carve out a gigantic ”hole world” underneath the planets surface (Bridge, 2009). Natural wealth is excavated from the planet's depths and piled up on its surface in ”inverted mines” like skyscrapers (Brechin, 1999), ”ores” of infrastructure systems (Wallsten et al, 2013/this volume) and sedimentary layers such as landfills. It has been noted that the earth would have had a completely different geological self were it not for the geological activity of us humans (Ellsworth & Kruse, 2012).

Regardless of whether one determines the magnitude of this material transfer in terms of impact (quantity of material moved) or rate (the time over which this occurs), it has been argued that the planet has entered into a new geological era; the Anthropocene (cf. Robin & Steffen, 2007; Zalasiewicz et al., 2011; Palsson et al., 2012). In the anthropocene, mankind is regarded as the most prominent global force of geological change (cf. Steffen et al., 2007). (kanske ska själva definitionen in här nånstans, i bredare termer än den strikt geologiska?) There are plenty of indices that suggest the planetary shift towards the anthropocene and a few of them are worth mentioning to exemplify the material impact that we've had on the Earth's crust:

The worldwide deliberate annual shift of material by human activity has been estimated to 57000 million tonnes, which is three times larger than the amounts of water transported to the oceans by all the world's rivers (Douglas & Lawson, 2001). Over the past 200 years, the people of Great Britain have alone excavated, moved and built up at least six times the equivalent volume of its highest mountain; the 1344 meter high Ben Nevis (Price et al, 2011). For some metals, i.e. copper, the total extracted amount that has been transferred to the world's built environments is globally comparable in size to the amount remaining in known geological ores (Kapur & Graedel, 2006). The city of Paris, as a last example, has in a metaphorical sense become a major lead mine in France due to its material build-up process since the Roman antiquity. There is now more lead in Paris than there is in the ores bodies of all the french lead mines summed up together (Barles, 2010).

Most of the raw material that we extract from the Earth's crust end up in cities. It has been estimated that the accumulation of metals in urban areas might be more than a hundred times higher than in rural areas (van Beers & Graedel, 2007). Cities form the basis of our civilization and summed up together they are the heaviest things that we have ever built. This is understandable in terms of that the in-flow of materials into most cities outweigh their outflows (Bergbäck et al., 2001), and cities can therefore be described as linear entities since they constitute the end station for many materials that are continously stocked therein (Girardet, 1992). The possibility to regard the material build-up of cities as a resource base for materials was in the late sixties realized by the urban theorist Jane Jacobs, who argued that cities would be the mines of the future (1968). Her claims were made from an understanding that cities are and always will be inefficient due to their chaotic density of people and material flows. As long as cities continue to exist, she argued, these inefficiencies will generate material surpluses and overflows such as waste paper and restaurant garbage which can be continuously recycled. Unlike mineral veins found in mountains that will be worked out at some point, these urban overflows could in Jacobs view "be retrieved over and over again", as new and formerly overlooked veins, are continually opened (p.111).

Since Jacobs days, the term "urban mining" has been increasingly used in reference to her work, both in the scientific community and elsewhere. Several researchers have taken the "mining" side of the term literally and made intense efforts to explore how metals are transferred through society (cf. Baccini and Brunner, 1991; Bergbäck and Lohm, 1997; Graedel, 2011; Tanikawa and Hashimoto, 2009). Researchers in this academic field have found that approximately half of the amounts of base metals such as iron and copper that has been extracted to date is no longer in use (Spatari et al, 2005; Müller et al, 2006). In to most often unknown quantities and concentrations, these metals are either found in different kinds of waste deposits or have dissipated into water and air (Brunner, 2007). Significant amounts are also assumed to be found in other kinds of sinks in the built environment. Accumulated over time, such sinks constitute what researchers in the field describe as "hibernating stocks" (Bergbäck & Lohm, 1997). This term describes entities with material content that have been removed from service but not collected by a waste management solution. They can for example be obsolete TVs (Milovantseva & Saphores, 2012) or disused mobile phones (Murakami et al, 2009) in households' closets and drawers that contain highly sought after rare earth-metals. Hibernating stocks are interesting from an urban mining perspective because their state of not being in-use, which makes them potentially available for recycling. This does not at all however mean that this would be a profitable endeavor (UNEP, 2010).

The object of inquiry of this licentiate thesis is an example of such a hibernating stock; the abandoned parts of the urban infrastructure in the Swedish city of Norrköping. Often called "the Manchester of Sweden", Norrköping like all other industrialized cities, contain significant amounts of cables and pipes that remain under the streetscape also after having been taken out of use (cf. Hashimoto, 2007; Krook et al, 2011). Because of the highly concentrated bulk metal contents in such cables and pipes, they could be dug up and recycled. Both the parts that already are already "hibernating", but also the ones that become so in the future. This has lead the UN to target hibernating stocks of urban infrastructure as a resource base for the secondary extraction of metals (UNEP, 2010).

Since infrastructure is the end destination of a small but significant share of the world's yearly production of bulk metals, improved recycling schemes for urban infrastructure waste could make a difference in avoiding the environmental degradation caused by traditional mining activities[1]. Depending on the kind of metal, several tonnes of mined and processed ore are avoided for every ton of metal that is recovered and reused[2].

The justification for traditional mining activities is furthermore decreasing as high grade deposits are exhausted[3] and the energy requirements for mining will continue to rise accordingly. The longer term prospects for the traditional mining sector has been deemed a steady decline (Ayres, 1997), and so in this respect, urban mining should be understood as a responsive strategy to the altering state of the planet's geologic configuration.

This is especially relevant in the anthropocene, where extractive processes must sooner rather than later become redirected towards resources found in the built environment instead of the traditional ones in for example mountainous ores.

In a not too distant future, there will come a time when "the value of the energy embodied in low grade ores or mineral fuel deposits in the earth's crust will no longer economically justify the expenditure of solar energy needed to extract and refine them" (Ayers, 1997). When that happens, urban mining strategies should preferably already be applied at a grand scale, or at least be shovel-ready.

This is the rationale for the present thesis.

[1] For well-written accounts on the immense environmental implications of traditional mining, see Bridge (2004) or Diamond (2005, pp. 462-478). Processual matters such as industrial pollution, energy and water consumption, waste and tailings production are highlighted in these texts, together with the inexcusable strategies used by mining companies to deny their environmental responsibility, hire lobbyists to press for weakened environmental legislation and file for bankruptcy to avoid paying clean up-costs.

[2] For detailed information on the exact quantities, see the Delimitations-section (p.XXX).

[3] This is a given for any mined mineral deposit, in which mineral production today will always reduce the opportunity for production tomorrow (Mumford, 1934). Over time, ore grades will therefore inevitably decline. As an example, the average ore grade in mined copper deposits in the US today is 0,5% (Bridge, 2000). This is to be compared to the 19th century when the worldwide ore grades were twenty times higher, equaling 10% (Ayers, 1997).

2. Aim and Research Questions

The aim of this licentiate thesis is to explore the potential of urban mining in the infrastructure sector. The locus of the study is the Swedish city of Norrköping and the focus lies on the phenomenon of hibernating stocks of metals in that city's infrastructure systems. These stocks consists of cables and pipes that have been disconnected but remain in their subsurface location since they have not been taken care of by a waste management solution. I address this topic from two distinctly separate angles, as I aim to achieve two kinds of knowledge needed to implement mining of urban ore on a larger scale.

The first angle is quantitative and spatial, and I use it to ask "How many?" and "Where?"-questions concerning hibernating stocks. The need for answers to both of these questions has been argued to justification urban mining (Brunner, 2007; Graedel & Allenby, 2010). It is not only the sum of hibernating tons that are important, but equally so the spatial location of these tons. This motivates the following research questions:
RQ #1: How many tonnes of hibernating stocks are there in urban infrastructure?
RQ #2: Where are these tons located?

The second angle is processual and address how human actions entangled in a highly technological urban environment are involved in the accumulation of hibernating stocks. From this angle I ask the "How come?"-question concerning hibernating stocks. Just like knowledge on household behaviour has been shown as needed to implement appropriate recycling schemes (Bulkeley & Gregson, 2009), knowledge on the socially embedded processes in which hibernating stocks of urban infrastructure accumulate are here considered as necessary for the implementation of urban mining. This motivates the following research question:
RQ #3: How do hibernating stocks of urban infrastructure come into existence?

The answers to these research questions are separately found in the appended articles one after the other. The first article is of a more quantitative nature and thus concerns RQ:s #1 & #2, while the second one concerns RQ#3. Given this, and that the two angles are explained as such above, it may seem as if my research consists of two parallel tracks. In practice, this is however not how things occurred. Instead, the process was from the beginning characterized by the intertwining of two distinctly separate research approaches found in the academic fields chosen for the assessment. I chose to apply Material Flow Analysis (MFA) from the field of urban metabolism as my quantitative approach and infrastructure studies as my qualitative one[4]. My ambition to combine these two leads us to the fourth and methodological research question:
RQ #4: How and with what consequences can MFA and infrastructure studies be combined into a coherent research approach?

[4] Infrastructure studies is my own term for infrastructure related research found in the academic fields of history of technology, urban history and science and technology studies. See p.22 for further arguments on this matter.

Last, and as a consequence of this combined methodological approach, a fifth and final research question can be posed regarding the theoretical contribution of this licentiate thesis:

RQ #5: How does the increased awareness of hibernating stocks change the way that urban infrastructure is perceived?

The answers to all of these questions are found throughout the cover essay. The full-length answers to **RQ:s #1-3** are found in the two appended articles but are also outlined in the Results-section. The answer to **RQ #4** is found in the end of the Combining the Perspectives-chaper while the answer to **RQ #5** is the main topic of the Conclusions-section.

In the following, I will describe the delimitations of the thesis.

3. Delimitations

Due to my ambition of combining research perspectives there is a plethora of delimitations that needs to be clearified before it is possible to write the theoretical framework and methodological chapters in a precise enough way. These are all lined up and explained under a series of why?-headlines in the following.

3.1 Why the city of Norrköping?

The spatial limitation of this licentiate thesis is the city of Norrköping. For Swedish standards, Norrköping has a particular industrial history and is a very infrastructural in the sense that infrastructure is prominently present in the central cityscape. The infrastructural configuration of Norrköping thus enriched the study with empirical topics as it became possible to include infrastructural dynamics related to tram operations, the derelict towngas grid which in some areas carry fiberoptics and the obsolete grid extensions that once provided the textile industries with infrastructure system services in the city center. These are all systems that are unique for Norrköping in the broader Swedish picture. We could furthermore delineate some of the differences between public and private infrastructure provision, since Norrköping sold the electricity and district heating networks in the early 1990's.

Because of all of this, Norrköping is a special rather than a representative case in the sense that hibernating stock approximations can not swiftly be aggregated to apply also for other Swedish cities, since these do not share Norrköpings infrastructural history.[5] Anyone interested doing a comparative analysis must instead pick and choose among the systems presented in our study to match the configuration of the city that s/he is interested in comparing Norrköping with. Having many systems to pick form is considered a strength for anyone interested in such comparative quantitative endeavours.

It would be too much of an after the fact reconstruction to say that Norrköping was chosen on the basis of previous research done on the city's infrastructure. But nevertheless this body of work, constituent mainly of two empirically thick dissertations on water and sewerage (Hallström, 2002) and gas and electricity (Kaijser, 1986), has played an important role in how my project has developed and directed the research in its particular direction. The delimitation of looking at Norrköping only, has made these two books central to my thesis.

While the above meantioned reasons for why Norrköping was chosen are all academic ones, there were practical one as well. In so far as the group at the University where I work has good connections with both city officials and private actors there, Norrköping was a convenient study object. Access to both data and informants were therefore known and/or established from the beginning of the project. Like all other Swedish cities, Norrköping has kept track of their municipal statistics on their utility services, together with all the

[5] This postulate has got to remain the assumption for now, as we have yet to perform a comparative study also of other Swedish cities.

infrastructure systems installed and used. Together with all the relevant maps, these volumes are all stored in the city archive and thus relatively easy to access.

Lastly, the funding of my PhD Candidacy comes from a research program called Sustainable Norrköping, which is formulated to explicitly deal with sustainability and urban development matters in relation to this Swedish city.

3.2 Why infrastructure as a bundle?

The reader of the two articles will soon discover that my assessment is not aimed at one specific infrastructure system. Instead, we follow the lead of Graham & Marvin (2001), who emphasise the importance to get away from the ”network specialism” often found in research on urban infrastructure (p.34), and instead emphasise how these systems ”rely on each other and co-evolve closely in their interrelationships with urban development and with urban space” (p.8). Graham & Marvin argue that exploring the bundle of infrastructure systems together makes it possible to study the interdependencies between different infrastructure systems and also identify similar trends found in each of them. In this case, studying infrastructure as a bundle was especially valid in the second article where both interdependencies and trend similarities are scrutinized regarding hibernating stocks. The broad and bundled delimitation was also necessary because of the decision to include three different metals, since these come in different amounts and concentrations in different systems and are not at all found in some of them.

3.3. Why iron, copper and aluminium?

In the introduction, I outlined the objectionable aspects of metal extraction activities in general. While all of those are reasons enough to argue for increased urban mining, it must be further explained why iron, copper and aluminium was chosen as particular metals of study. The arguments for increased recycling varies slightly between them but are all related to their magnitude of societal use.

Iron, copper and aluminium are all omnipresent in the built environment of our societies. Iron in the form of steel is necessary for the construction of built structures, copper transmits most of the world’s electric power, while the transport sector is heavily dependent on aluminium (UNEP, 2010). All of the three metals are existant in high concentrations in infrastructure systems.

The planetary reserves of bauxite and iron ore with which you make aluminium and steel are vast, meaning that they can be produced cheaply (Alwood & Cullen, 2012), and from ores of relatively high grade (Ayers, 1997). The problem with these metals is therefor not their absolute lack of supply, but rather their total shares of the world’s energy consumption. Steel is the engineering material that accounts for the most CO_2-emissions in the world, while aluminium comes in fifth place[6]. This means that both of these metals show a significant potential for climate account savings.

Compared to primary production, the recycling of steel and aluminium is of course significantly less energy intensive and thus also cheaper (Allwood et al., 2011). An existing barrier to increased recycling rates of steel and aluminium is the wide variety of minuscule uses of these two metals: bottle caps, wire, foil, nails and so forth are difficult to recover not the least economically. In comparison, pipelines and cables found in infrastructure systems are large objects with significant concentrations and therefor easily aggregated for the sake of recycling (Ayers, 1997).

The recycling case for copper follow slightly different logics, since the average ore grades from which copper is mined is significantly smaller: 0,8% (Crawson, 2012), than the average for steel: 59% (Polinares, 2012), and aluminium: 19% (OECD, 2010). In magnitude, this means that to produce a ton of copper you need to mine 125 tons of copper ore, whereas the corresponding numbers for steel and aluminium are only 1,7 and 5 tons. The difference between these ratios can of course be seen also in the highly different resource requirements of these processes and so is the energy intensity of copper production that becomes the focal point of potential energy savings rather than the potentials related to the total energy use of copper's worldwide production.[OKLART} Copper is furthermore produced in smaller quantities than steel and aluminium globally. For these reasons, copper is more expensive than steel and aluminium, making the economic case for the recycling of copper stronger. The arguments for recycling copper are thus more clearly associated with the resource scarcity perspective, also since the ore grades are steadily declining (Bridge, 2000) and given the estimate that half of the world's reserves have already been exploited (Kapur and Graedel, 2006).

[6] Steel accounts for 25% of all CO2-emissions from the worlds entire industrial sector, the share for aluminium is 3%. Cement, plastics and paper ends up in places two to four. Engineering materials are the ones used to create goods, infrastructure and buildings. This does not include hydrocarbons like oil and coal which are used as fuel (Alwood et al., 2011).

4. Definitions

Hibernation

Sociotechnical

Urban mining

Infrastructure studies

Material flow analysis

Waste

Resource perspective

Reuse/Recycling/Recovery

Urban Metabolism

5. Theoretical Framework, part I: Urban Metabolism and Material Flow Analysis

I will launch the theoretical framework of this licentiate thesis from the understanding of urban metabolism found in the academic field of industrial ecology[7]. The core of this field consists of a belief that industrial and ecological systems share certain traits, and that nature and ecology can function as key inspirations when improving the environmental performance of industrial as well as urban processes (Lifset and Graedel, 2002). Industrial ecology has developed into a toolbox full of research approaches for different kinds of environmental engineering assessments, within which urban metabolism is one but many. It is from here that I've brought the core of my approach to answer research questions #1 and #2.

Urban metabolism is a diverse and broadly applied concept dealing with how cities transform and integrate raw materials, including energy and water, into the built environment (Decker et al., 2000). Narrowed down to quantitative terms, it is understood as "the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste" (Kennedy et al., 2007, p.44). From the urban metabolist perspective, the city is mainly interesting because of its material composition, which is divided into two separate spheres: the urban biosphere consisting of all the materials that people and other urban organisms consume (Douglas and Lawson in Ayres and Ayres, ed. 2002), and the buildings and infrastructure of the urban fabric (Douglas, 1983). It is the urban fabric that is of interest here. Within urban metabolism, the renewal of this urban fabric result in material wastes which over time tend to remain in the city as they are used to level original building sites for new construction. Cities thus rise over the residues of past structures, and these residues continually become part of the 'urban deposit' (Wilburn and Goonan, 1998). Dumps of waste and residue from industrial transformation are also part of this urban deposit: "The urban fabric, and all the materials housed and stored within it, and the underlying and surrounding urban deposit make up the urban materials stock." (Douglas and Lawson in Ayres and Ayres, ed. 2002)[8].

Given these descriptions, the city is from the urban metabolism perspective thus first and foremost understood as a biophysical entity, while much less emphasis is given to the social and political aspects of the urban material flows studied. This is a limitation that has been recognized by researchers from insiders of the industrial ecology field (cf. Anderberg, 1998; Newman, 1999; Barles, 2010; Minx et al., 2011) as well as outsiders (cf. Gandy, 2004; Swyngedouw, 2006; Monstadt, 2009; Castán Broto et al, 2012; Hodson et al., 2012). In the methodology section we shall return to this issue more in-depth.

There are four methodological approaches commonly used within industrial ecology for the study of urban metabolism. These are all quantitative but fulfil different purposes

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[7] It should be noted that also other scholars than industrial ecologists have shown an interest in understanding cities as spaces of metabolic flows (cf. Castells, 1985; Odum, 1989; Harvey, 1996; Tarr, 2002; Gandy, 2002; Kaika, 2004).

[8] For a literature review of urban metabolism studies, see Kennedy et al. (2011).

dependent on whether the interest lies in a city's ecological footprint or its dependence on flows of materials, substances or energy (Barles, 2010 p.444). In this licentiate thesis the focus is on materials, and I therefor use material flow analysis (MFA) as my quantitative approach.[9]

5.1 No Flow Left Behind: The Lynchpins of Material Flow Analysis

MFA is to a large extent an accounting exercise aimed at quantifying the stocks and flows of a certain material in a certain geographically defined context (Kennedy et al., 2011). The geographical context is not necessarily a city; it can be a region, a nation or even the entire planet. MFA is an analysis of the throughput of matter in the processes of industrial society[10]. One such process is for example the material transfer in and out from the urban fabric. The entities of accounting can be either chemically defined substances, natural or technical compounds or bulk materials (e.g. Bringezu and Moriguchi in Ayres and Ayres, 2002; Graedel and Allenby, 2010). A central aspect of an MFA is the coupling of the very small; "in an elemental analysis, the emphasis is on the atom" (Graedel & Allenby 2002, p.245), and the large aggregated flow chosen as the scale of inquiry. An MFA can for example calculate the global flows of nickel (Reck et al, 2008), the flows of steel and copper in Japan (Daigo et al, 2007) a set of different metal flows in a particular city such as Stockholm (Bergbäck et al, 2001) or the flows of steel through the construction sector at large (Moynihan & Allwood, 2011)[11]. It was through the means of MFA that researchers could highlight the significant amounts of metals that had been taken out of use over time but had not been collected by waste management (cf. Hedbrant, 2003), so called "hibernating stocks" (Bergbäck and Lohm, 1997).

Even though hibernating stocks is a concept that originates from within the MFA community, "amazingly little" is known about where and how large they actually are (Brunner, 2004 p.5). For example, previous research that mentions hibernating stocks of urban infrastructure does so without specific details on the matter (Alwood and Cullen, 2012 p.267; Graedel, 2011 p.48). While this gap of knowledge serves as a the perfect motivation for this licentiate thesis at large, I shall describe the most often used approaches within material flow analysis in an attempt to explain why it exists. My ambition with this is not so much to describe the previous research, as it is to outline some general methodological deficiencies of MFA. I believe this to be more a fruitful way of contextualizing my research in this cover essay; since I want to suggest ways of methodological improvement rather than just position my research in relation to other works in the field.

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[9] Apart from MFA, the other urban metabolism-approaches are Substance Flow Analysis (SFA), Energy Flow Analysis (EFA) and Environmental Footprinting (ibid.).

[10] Material Flow Analysis is typically based on a differentiation between human and natural resource cycles and so they separate between anthropogenic and biogeochemical or biophysical stocks and flows. There are examples where both of these cycles are analysed within the same study (e.g. Rauch and Graedel, 2007), but the entities remain differentiated and is thus fully compatible with a dualistic view of the world.

[11] For a literature review of all anthropogenic material cycles that so far has been assessed by the MFA-approach, see Chen and Graedel (2012).

5.2 Top-Down or Bottom-Up? MFA and Missing Masses

Data collection for MFA can be done in two major methodological ways: using a top-down or a bottom-up approach[12], which in different ways simplify the highly complex material flows of reality into manageable and computable representations.

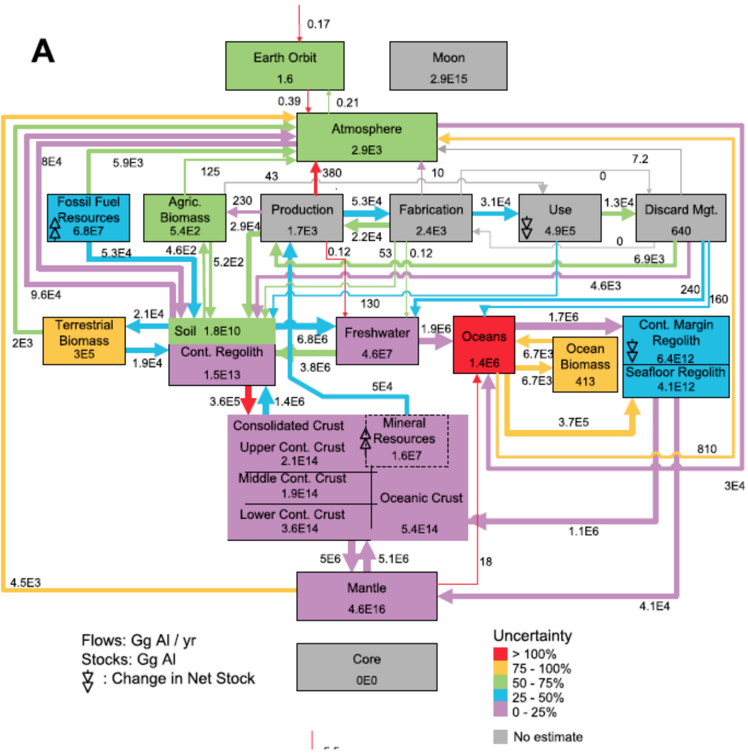

Figure 1. The global flows of aluminium, in gigagrams (Rauch & Graedel, 2007).

At the core of the top-down MFA approach lies the simple principle of ”inflows equals outflows”, which provide the basis for comparing the input flows of natural resources, the internal flows of materials inside the chosen geographical context and the output flows of waste and emissions (Kleijn, 2000). The spatial scale and the amount of stocks may differ but typically, the flowcharts are used to describe the process of extraction, transformation, manufacturing, consumption, recycling and disposal of the chosen material (see figure 1). MFA is a lot about finding the right data, or ”to generate self-consistent quantitative flow numbers for all the arrows on the diagram” (Chen and Graedel, 2012). Data that is not directly available in trade statistics or other data sources, must be approximated by mathematical calculation. This is often the case for the material amounts that end up in waste repositories as well as for hibernating stocks, which are most often indirectly assessed. Mathematically, estimatations on hibernating stocks are achieved by integrating the rates of discard and recycling over the time period of your study.

[12] The top-down and bottom-up-methods described here are archetypes found in industrial ecology handbooks (cf. Graedel & Allenby, 2002; Brunner & Rechberger, 2004). In practice, and because of different purposes and data availability, the MFA:s often show significant differences (Chen & Graedel, 2012). Possible combinations of the two approaches can be rewarding for triangulation purposes to check the accuracy of ones results (cf. Zeltner, 1999; Wang, 2009).

Principal copper stocks in New Haven

	kg/c	Cumulative sum
Power generation and transmission	42	42
Plumbing	28	70
Wiring	25	95
Cars	8	103
A/C and equipment	12	115
Ships	7	122
Telecommunication	5	127
House E&E	6	133
House white	3	136
Commercial E&E	1	137
Industrial machinery	3	140
Trucks and buses	3	143
Architectural	1	144

Table 1. A typical inventory of stocks in a bottom-up MFA, where the stock calculations are based on their kg/capita (c) content. (Drakonakis et al., 2007).

The bottom-up MFA approach does not rely on flowcharts, but consists instead of inventories of different entities that contain the material in question. Buildings, infrastructure and electronic gadgets are examples of such entities. The material contents of a certain entity is found using engineering product data and then multiplied with the number of units of that entity that is estimated to be in use inside the geographic context to arrive at estimated metal content per capita (see Table 1). Census data is often the basis of such estimations (Graedel and Allenby, 2002, p.245). The number of buildings, cars, electric grids etc. can be determined by using a GIS-based census information, and then multiplied with the typical copper concentrations of these entities to arrive at estimates of the total stocks and their location (van Beers and Graedel, 2007). Used in this way, the bottom-up approach enables an approximation of the spatial distribution of stocks, which is relevant if you want to know where within a certain city a certain material is located[13]. A weakness that has been found using the bottom-up approach in practice, is that it yields less useful data on wastes, because of the lacking availability of trustful information on the content and extent of such repositories (Graedel and Allenby, 2002, p.245). This lack of information naturally also include hibernating stocks and unlike the top-down approach, there are no flow data that can function as the basis of mathematical estimations of these stocks.

5.3 MFA and the Black Boxes (Vet vi vad en black box är när vi kommer hit?)

After this introduction of the two MFA approaches we now know that the top-down approach can estimate the stocked amounts of hibernating materials but not where in society these are located. The bottom-up approach can estimate where in society the in-use material stocks are located, but not where or how big the hibernating ones are. Due to this

[13] This can for example be used with the purpose to inform the collection and re-use a certain material, or to spatially anticipate environmental problems if the material studied is a hazardous or toxic (Graedel and Allenby, 2002, p.298). Not all bottom-up MFA:s are spatial. When writing this, the number of spatially informed MFA:s are easily counted (see p. xx).

loophole which persist also when the two MFA methods are combined, *a spatially informed MFA that specifically focus on materials which are not in use* has not been done. MFA as it has been used up until this point, [insert something about the results of the first article here] seems to lack the adequate approaches to come up with the information needed. Or to reverse the angle; the sufficient data to determine these stocks are seemingly not to be found. If however, and as Graedel and Allenby (2002, p. 301-302) point out, the desired outcome of MFA is to improve the conditions for the practical implementation of urban mining, then the accurate determination of both the size and spatial distribution of the stocks assessed is necessary.

For reasons that will be further explained in the methodology chapter, I believe that the key to achieve this lies in how MFA researchers use black boxes to arrive at their results. To perform the calculations in an MFA, as well as many other engineering sciences, the huge amounts of data must be broken down into manageable sizes in some way. For MFA, black boxes provide a tool for simplification and function as allocation devices for quantitative information. A black box in MFA is only interesting in terms of its input, output and transfer characteristics in numbers, its inner workings is purposefully neglected[14]. Black boxes is thus the core enabler for MFA:s quantitative assessment and are deemed as essential to make MFA knowledge claims about the world (cf. Bringezu & Moriguchi in Ayres and Ayres, 2002; Brunner & Rechberger, 2004).

Depending on the chosen level of analysis and what compound's flow to assess, MFA:s can black box plumbing, cars and houses (Drakonakis, 2007, assessing metals, see Table 1), mines, smelters, scrapyards and landfills (Reck et al, 2008 assessing nickel), countries and continents (Johnson et al., 2006 assessing chromium) or the Earth's orbit, the Moon and the Universe (Rauch & Graedel, 2007 assessing copper, see Figure 1). They are devices found in both the top-down and the bottom-up MFA approach, but they are built up and used in different ways.

In the top-down approach, the black boxes are found in the flowcharts, which break down complex processes of the real world into a sequence of subprocesses (see Figure 1). Arrows are used to represent the flows into, between and out from black boxes, which are thus only interesting in relation to their inputs and outputs. What happens inside the box is not taken into account. The number of black boxes used vary according to the level of detail desired and the data available (Brunner & Rechberger, 2004, p.38-39).

In the bottom-up MFA:s we find the black boxes in the so-called stock inventories with lists of different product categories (see Table 1). Just like with the top-down approach, the black boxes can vary according to the desired level of detail and data availability. Since detailed product information is more readily available than larger set of trade statistics and the like, the black boxes of bottom-up MFA:s are generally more detailed than top-down ones,

[14] Black boxes are thus the core device to achieve simplification and models of the world within MFA.

whose scope and geographical boundaries are generally bigger (Graedel & Allenby, 2010, p.245).

In the methodology chapter, I shall argue that how one constructs the black box(-es) is critical to whether the results of an MFA can match a social science counterpart and thus be of relevance to develop strategies for increased urban mining. The devil is indeed in the chosen scope and level of detail. Before doing so, we need to dig deeper into the second area of research literature used within this thesis; infrastructure studies. Black boxes are central devices also within this field, but they are as we shall see understood and approached from a fundamentally different viewpoint.

6. Theoretical Framework, part II: sociotechnical studies of urban infrastructure

The second approach that I have used to assess the hibernating stocks of Norrköping's urban infrastructure is a body of literature that I for the sake of convenience would like to call infrastructure studies. Under this umbrella term I include a set of social and humanistic sciences scholars that share an interest in infrastructure, primarily from the fields of history of technology and technology studies[15]. From my point of view, and in accordance with the transdisciplinary approach favoured by the infrastructure scholars Graham and Marvin (2001), there is more that connects than separates these fields epistemologically. I shall in the following focus on two of these epistemological aspects; the understanding of infrastructure systems as sociotechnical and the use that these researchers make of black boxes in their studies.

The ambition is to describe infrastructure studies so that the reader can understand the commonalities as well as differences between this field and material flow analysis, together with which it will be combined in the next section. Primarily but not exclusively I will focus on studies of *urban* infrastructure, since these constitute the majority of the referenced work that I make use of in my approach to answer research question #3. Thereafter, I shall outline why infrastructure studies has so far missed the hibernating masses of disconnected cables and pipes remaining in their subsurface location.

6.1 A Sociotechnical Understanding of Urban Infrastructure

At the heart of a sociotechnical worldview, is an understanding that everything that appears to be purely technical is also social and vice versa. The social and the technical aspects of a phenomenon should be viewed as an integrated whole. A sociotechnical understanding of an infrastructure system is thus not possible without taking into regard infrastructure's context of politics, organisations, regulations etc. (Hughes, 1983). If one is interested in the people responsible for the management of an infrastructure system's development, they must as a consequence be understood as more or less heterogenous; i.e. he[16] had to work not only with technology as such, "but on and through people, texts, devices, city councils, architectures, economics and all the rest" (Law, 1991).

The ways in which infrastructure systems explicitly reconfigure and is reconfigured by the different ways that responsibles and citizens engage with the urban built environment is central to studies of urban infrastructure (cf. Coutard, 1996, p.47, Graham & Marvin, 2001, p.184). From such a perspective, infrastructures must be understood in their socially embedded but also urban context, in which a large set of actors can shape and become affected by their development (Tarr & Dupuy, 1989; Aibar & Bijker, 1997). Several studies on how technologies commingle with the urban condition can be found[17], within which cities

[15] Technology studies is one of the two major strands of Science and Technology Studies (STS). Like researchers within this field have studies cities and urban infrastructure before me (cf. Hommels, 2005), I do not cover the whole of this academic field but focus mainly on the technology rather than science part.

[16] Always a white middle-aged male engineer.

[17] See Guy & Karvonen (2012), for an introduction on the four themes of contextuality, contingency, obduracy and unevenness, that permeate many sociotechnical studies of cities.

are described as saturated with a large variety of old and new technologies, and how they function on the basis of a dense palimpsest of infrastructure systems (cf. Latour & Hernant, 1998; Graham & Marvin, 2001; Hommels, 2005)[18].

In giving the technological backbone of cities a central position in their assessment, sociotechnically informed studies of urban infrastructure differ from research fields such as urban sociology, Marxist urban studies and cultural theory, who traditionally have relegated materiality to a position of passive bystander or contextual frame (Otter, 2010, p.53)[19]. A sociotechnical perspective instead allows the researcher to ”embrace the messiness of contemporary cities” in describing and disclosing the processes explicitly relating the citizens to their material surroundings. (Guy & Karvonen, 2012, p.121). With a sociotechnical view, the city becomes an enormous artifact, in which the ”size and distribution of its streets, sidewalks, buildings, squares, parks, sewers and so on can be interpreted as remarkable physical records of the sociotechnical world in which the city was developed and conceived” (Aibar & Bijker, 1997).

An example of how such research is carried out is the article ”City-Building Regimes in Post-War Stockholm” by Gullberg and Kaijser (2004). In their view, urban transformations are understood as the result of ”interrelated dynamics of the landscape of buildings and the landscape of networks” (p.15). Buildings and infrastructure are necessary material components to understand urban development and the authors emphasise how different human actors and mechanisms of coordination between these actors are needed to create changes in the urban fabric (p.34). Depending on how a heterogenous set of public and private actors have altered core and peripheral functions over time, their case study on Stockholm shows how the urban fabric and actor constellations allow for different kinds of decision making concerning the city’s infrastructure and built environment in different eras after the second worldwar.

Sociotechnically informed researchers disregard any notion of technological development as a socially exogenous force or the end-product or outcome of a certain sequence of events. Rather, technology is part of a continuous and co-constructive process between humans and their material surroundings, and the task of the sociotechnically interested researcher is to scrutinize this process as such. The methodological approach is often described in terms of opening the black box of technology, and thereby (re-)problematizing it in relation to the surrounding objects and social context (Sismondo, 2004; Hackett et al., 2008). The ambition is to arrive at an understanding of the technological development where the technology’s origins, dynamics and consequences are all exposed (Guy & Karvonen, 2012), and the means to get there is a carefully analyzed dissection of the technological black box’ inner workings. [otydligt]

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[18] The introduction chapter of ”Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition” (Graham & Marvin, 2001), provides an exhaustive survey of how the networked conditions of urban life is understood from a thoroughly STS-informed perspective.

[19] For a refined discussion on the emphasis given to materiality in different perspectives of urban geography, see Latham & McCormack (2004).

Hopefully, it is by now clear how infrastructure studies and material flow analysis make use of black boxes in almost polar opposite ways. Material flow analysis purposefully keep the black boxes shut to make use of them as accounting devices, while infrastructure studies purposefully open them for the scrutiny of sociotechnical processes. I shall get back to how a careful research design can make a single black box work from both of these fields perspectives in the next chapter. In the following, I shall instead elaborate on the reasons for why I have found no infrastructure study that explicitly deal with my object of inquiry; hibernating stocks of urban infrastructure. Under three short sections, I shall present some relevant discussions and lifted criticism from within the infrastructure studies field that I think relate to this question. Thereafter, I conclude this chapter outlining those studies and infrastructure studies concepts that I have made use of in my research and that come closest to my object of inquiry.

6.2 The Neglect of Infrastructure Systems as Material Mediators

The first aspect in the sociotechnical literature on urban infrastructure I want to stress, is that it despite its explicit ambitions to take materiality in full consideration, neglects the infrastructure systems' roles as material intermediaries. Monstadt argues (2009, p.1935), and I agree, that sociotechnical studies mostly omit how ”infrastructures constitute a – if, not *the* – central interface between nature and society” (original emphasis). In the same article, Monstadt goes on stressing how the unintended and negative side effects of infrastructure services such as emissions, waste and landuse are rarely commented upon. A simple and tentative explanation for this lack of scope, is that a sociotechnical focus puts the human-technology relationship at the center (this is after all the emphasis of the sociotechnical), while the human-nature dimension is treated as more peripheral (which instead is the central matter of concern for socio-ecologically oriented researchers)[20]. But even so, I would argue that to include the technological when describing a city must also be to include the natural, since natural resources are vital for the construction of technologies. All of these entities, the social, technical and natural, are in fact entangled and not seperable; the nuts and bolts needed to actually build and construct the grids and systems are in themselves material resources. And they do not only take part in facilitating the material transfer processes of the systems' flows but are part of material transfer processes in themselves as metal products transformed from mineral ore (dug out by the hands and sweat of men). In this sense and to follow Monstadts lead, the ”mineral” materiality of the nuts and bolts of infrastructure systems and thow these are constituent of flows of natural resources[21] is neglected by sociotechnically oriented scholars of urban infrastructure despite their explicit intention to take materiality into consideration.

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[20] For an in-depth discussion on the contrasts and tensions between the sociotechnical and socio-ecological systems literature, please see Smith & Sterling (2008).

[21] It has been estimated that 3,5% of all the world's steel production is used in the infrastructure sector as water and gas pipes. For aluminium, the same number is something like 1% if all kinds of wiring are included (Allen and Cullen 2012, p. 32, 35, 52, 53). For copper, the specific Swedish figure is 28%, mainly in the form of electric cables (Landner and Lindeström, 1999, Figure 5.5, p.76).

6.3 A Bias Towards Development Oriented Narratives and the Workforce Responsible for These

Second, infrastructure studies tend to have a too-narrowed focus on the supply-side of infrastructure provision and the responsible people managing this supply. The disconnected parts of infrastructure that the hibernating stocks consist of are most often part of another and neglected narrative; one of reactive actions in response to declining demand.

Graham and Thrift argue that this neglect stems from a predominant interest in social theory to engage in matters of connection and assembly, rather than disconnection and disassembly (2007, p.7). Moss (2008), echoes this plea in his observation that the focus of infrastructure studies has remained on the extend-and-supply logic of system flows, and that there still exists a knowledge gap regarding underutilized network spaces (p.439). His argument continues a criticism that was articulated against early infrastructure research in the field of history of technology for being too much oriented towards development biased descriptions (Bijker & Law, 1992), and place too much emphasis on the workforce responsible for this development; the manager or so-called system builders (cf. Law, 1991, p.12, Graham & Marvin, 2001, p.183)[22].

The supply-oriented planning is naturally a central task for the management workforce of any infrastructure system. And so perhaps, it is the legacy of a too-narrow and largely managerial focus on system providers and the emphasis extend-and-supply of system flows that has invibilised disconnection and disassembly from the view of urban infrastructure scholars.

Since the system builders or managers in all likelihood prefer to talk about how they extend their networks and supply new users in response to increased demand, the over-emphasized focus on them is likely also the reason for why relatively little is known about infrastructure system decline in general (Gandy, 2005), and why we are seldom if never served explicit accounts on how infrastructure systems are discontinued or un-made (Weber, 2012). Perhaps tellingly, the most often referenced article on system decline describes how stagnation must not lead to inevitable system obsolescence. Rather, systems might instead stabilize and even and again prosper anew (Gökalp, 1992). Infrastructures seldom seem to die off in urban infrastructure research[23].

6.4 The General Invisibility of Waste

The last aspect that I want to emphasize is the levels of invisibility that keep hibernating stocks from view. Although static in and of themselves, infrastructure systems and their components mediate the flows of system services between producer and consumer in true

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[22] This argument has especially been put forward for in relation to the weight given to the users of infrastructure services (cf. Akrich, 1992; Summerton, 1995, 1998), a scewness seems to have levelled out in later years as there are by now plenty of user-centered infrastructure studies (insert refs.)

[23] Studies that explicitly deal with infrastructure decline are easily counted, and only some elaborate on the topic (cf. Hughes, 1987; Gökalp, 1992; Kaijser, 1994; Ekman, 2003).

silence. Many are the scholars that have asserted that as long as infrastructure systems work they are the least visible, and this is often acknowledged by scholars engaged in infrastructure studies. Catastrophies, interruptions and breakdowns seems needed in order to render them attention (cf. LaPorte, 1994; Guy et al., 1997; Star, 1999; Mau, 2004; Graham, 2009; Nye, 2010). But invisibility is equally present in relation to wastes and other surplus materials that our technological societies produce. Like many other kinds of waste materials[24], hibernating stocks of urban infrastructure are hidden from view in nether societal regions (Goffman, 1971, quoted in Chappells and Shove, 1999). Not being part of economic processes any longer, wastes furthermore tend to not only be neglected in a direct and real sense, but equally so in statistics and account ledgers were information is rare if at all existant (Brunner, 2007). And so, while scholars of infrastructure studies might recognize their object of inquiry's invisible characteristics, this does not automatically mean that they are sensible to the material wastes that the provision of that very same object result in. One factor that is contributing to this negligence is the abscence of the maintenance and repair workforce in infrastructure studies (Graham & Thrift, 2007). Like all material wastes, disconnected infrastructure must be collected from, or in my case left at, their points of production by people (Jacobs, 1969 p.111), and this workforce is thus far almost completely left out of the academic research. They perform a kind of technical backstage work that is rarely recognized and/or commented upon (cf. Goffman, 1969; Shapin, 1989; Graham and Thrift, 2007)[25]. We shall return to this matter in the next chapter, when discussing the methodological consequences of using hibernating stocks as an object of inquiry in infrastructure studies.

6.5 The Close but no Cigar of Infrastructure Cold Spots

Before concluding this chapter, a brief mentioning of the concept developed within infrastructure studies that has come the closest to assess hibernating stocks so far is necessary; infrastructure 'cold spots' (Guy et al., 1997; Moss, 2003, 2008; Naumann and Bernt, 2009). 'Cold spots' are defined as "parts of infrastructure systems where demand is weak and/or declining" (Moss, 2008, p.438), and they might for example be the result of underutilization of system services that follows from shutdowns in industrial areas. The increased prevalence of cold spots challenge the certainty that infrastructure systems must indeed always be planned for continous growth.

While 'cold spots' signify locations with weak or declining demand for infrastructure services, the disconnected parts of infrastructure that I am interested in here are most often a consequence of ceased or *non-existant* demand. And so, for the infrastructure studies

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[24] One can of course provide a lot of arguments about whether hibernating stocks are waste or not or something in-between. I'm putting that discussion aside for the moment, and am here content with using the term unreflectively.

[25] Graham and Thrift (2007), point out that while infrastructure maintenance and repair work can constitute as much as 10% of a city's economy, it has to a large extent been excluded from contemporary research. In reference to a series of ethnographic research on technical workers (Orr, 1996; Downey, 1998; Henke, 2000), they argue that maintenance and repair work is represented as subordinate in most bureaucracies and thus actively hidden from view (p.4). Therefor, in invoking Susan Leigh-Star (1999), they highlight the surfacing of invisible work as a major research challenge in the social sciences.

approach to be useful for my purpose, the concept of ’cold spots’ had to be theoretically developed to also include what could called ”frozen spots” that come in three different spatial patterns. This observation constituted the results of my second article (Wallsten et al., 2013), and provides the answer to RQ#2. I shall dive further into the matter in the results chapter of this cover essay.

In the following chapter, it is finally time to explain how the methodological intertwining of material flow analysis and infrastructure studies was realized and the consequences that this amalgamation had for the research done. Without the cross-fertilization between these research approaches, I would argue that the results would have been a lot more meagre. We are thus approaching the discussion that provides the answer of research question #4: how and with what consequences can MFA and infrastructure studies be combined into a research approach?

7. Combining the Perspectives: The Methodological Implications of launching a Boundary Object

Up until this point, I have described how urban metabolists and researchers studying urban infrastructure from a sociotechnical perspective share the interest in the material configuration or urban fabric of cities (cf. Brunner & Rechberger, Otter). This common interest points at the possibility of finding a kind of ”trading zone” between them in which both can benefit. But I have also highlighted that they analyse the material configuration of cities with different tools and perspectives.

Urban metabolists such as Douglas (1983) and Wilburn and Goonan (1998), understand the city as a purely biophysical entity in which material flows over time accumulate into an urban fabric of buildings and infrastructure (see p.xx). Infrastructure scholars such as Gullberg and Kaijser (2004) on the other hand, emphasise the process behind the particular sociotechnical configuration of the urban fabric they study and therefore give actors, politics, standards and coordinating mechanisms etc., a central position (p.18). The differences become especially clear if you consider the different ways that the approaches make use of the black box-concept in relation to the urban

The urban metabolism approach purposefully black box the urban fabric (buildings and infrastructure) into a device for the accounting of material accumulation. This urban fabric is only interesting in terms of in-flows, stocks and out-flows, while its existence as a result of actors engaged in a sociotechnical process is not. By whom and according to what mechanisms the urban fabric accumulates is left outside of the research assessment.

This inherently sociotechnical process is, on the other hand, the explicit focus from the infrastructure studies perspective. The urban fabric-black box (again, the city’s buildings and infrastructure), should from this view purposefully be opened and thereby understood, not as the end result of a set of social mechanisms, but as a continous and ever-changing process within which the technological aspects of the urban environment play a constitutive part.

It is clear that the fields operate in different conceptual territories and that black boxes perform different academic functions in them respectively. The central methodological argument for this cover essay is not that these two disparate understandings shall merge into a consensus. Rather, they must be set to cooperate and create a mutual modus operandi that make use of rather than obliterate their internal diversity.

Sociologist Susan Leigh Star have formulated the analytic concept of boundary objects (1989) to define the kind of heterogenous scientific work that this licentiate thesis is an example of. Adaptable to different scientific viewpoints, boundary objects can ”inhabit several intersecting social worlds” and ”satisfy the informational requirements of each of them. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable” (p.393). In the case of this licentiate thesis, the MFA- and STS-community of researchers can be seen as examples of such social worlds with different viewpoints, while the black box they both make use of to study the urban fabric can be thought of as a potentially unifying boundary object.

Following Stars observation that boundary objects might very well be abstract and concrete at the same time (p.408); I regard the hibernating stocks of urban infrastructure in Norrköping together with the academic construct of the black box that I have used to study them, as one and the same boundary object. The concrete cables and pipes are in my research represented by an abstract black box set to function in both of the two fields, and the boundary object is then assessed quantitatively from the flow-perspective of urban metabolism (in article #1) and recontextualized in qualitative process-terms with an sociotechnically informed perspective (in article #2). It is in this pivotal point, where the hibernating stocks and their functioning as a black box ”form a common boundary between worlds by inhabiting them both simultaneously” (Star, 1989 p.412), that the modus operandi of this licentiate thesis is found. The boundary object of hibernating stocks is an arrangement that allows the two different viewpoints found in urban metabolism and infrastructure studies ”to work together without consensus” (Star, 2010 p.602).

An implication of designing my research approach in this way, was that the conventional MFA and infrastructure study approaches had to be reconfigured and apply slightly new means to assess the up until now peripheral research topic of hibernating stocks of urban infrastructure. The approaches furthermore and to some extent influenced eachother to cover aspects that would have been unreachable by applying the perspectives separately and one at a time. The description of how this was done and the consequences it had for both the approaches is found in the following. In other words; we now turn to the licentiate thesis' methodology.

7.1 Research Methodology: A Case Study Approach

[Insert here: short on what a case study is?] While the tools used to assess the chosen case might differ depending on the academic context, a central aspect of case studies is the careful outlining of the boundaries chosen to delimit the object of study. There is a clear need to define the object and relate to it as a system with boundaries. Regardless of the empirics, it has been noted that it is the unit that is central to a case study analysis, and not the topic (Merriam, 2009).

Given this, I had to carefully delimit the case study boundaries so that it would constitute a boundary object and black box that made sense to analyse both from the MFA and infrastructure studies perspective. While sociotechnical studies of urban infrastructure are often rigged as case studies as a means of analyzing it as a co-constitutive processes involving both social and technological mechanisms (Guy & Karvonen, 2012). Thus, such studies begin with choosing the object to assess and the careful delimitation of this. MFA:s on the other hand, most often starts in choosing the material to assess rather than the object. As a consequence of this, choosing a case study approach had implications for how the MFA was performed.

7.2 The methodological consequences for MFA

Instead of being used as a general material accounting methodology for a certain geographical scale, MFA is in this thesis used as a case study tool[26]. In two ways, this is different from how MFA:s are generally carried out.

As previously stated, MFA:s are most often rigged on the basis of two parameters: the material chosen for the assessment and the geographical unit within which this material is to be accounted for. In MFA so to speak, the objects arrive late as the material and the geographical area to assess is chosen first and only therafter and as a consequence of the material and geographical choice, is the inventory of the objects that contain the chosen material performed. The rig in this licentiate thesis is an example of a reversed perspective; first the object of study and the geographical area was chosen (deliberately to also function as a boundary object for both MFA and infrastructure studies assessment), and only thereafter were the materials taken into consideration. Iron, copper and aluminium were determined as a consequence of the chosen object of inquiry and not vice versa. In this licentiate thesis and unlike most other MFA:s, it is thus the materials that arrive late, and not the objects. This is the first major difference.

The second major difference is related to the scope. Conventional MFA:s most often operate at the regional/global scale (Chertow, 2000), which means an enormous amount of objects to take into account. Circling in on ”one” empirical object; hibernating stocks of urban infrastructure, is thus a significant simplification. In conventional top down-MFA:s, infrastructure can be represented as one black box in a set of many or be hidden away inside a black box together with many different others usages of the material (see Figure 1 for an example on how infrastructure is hidden in an ”in-use”-black box). In conventional bottom up-studies, infrastructure often get one row in a set of many in the inventory (see Table 1). In this licentitate thesis, the scale is shifted downwards and the scope thereby limited allowing for an increased level of detailed scrutiny. Instead of having only one row designated for infrastructure, my inventory for infrastructure details numbers of seven different infrastructure systems (see Tables 1 and 2 in Article #1). The limited scope furthermore allowed for time-consuming data collection to retrieve statistics, maps and archive material.

In this way, the MFA could be made to rely exclusively on the use of local data that corresponds with the local scope, which is a strength in terms of reliability and validity in comparison to other MFA:s that often rely on whatever data that could be found regardless of it's geographical origin. All the used data in my assessment stem from within the boundaries of the case study. Municipal statistics and historical maps dating back to the

[26] It should be mentioned here that there are MFA-researchers that relate to their work as case studies (cf. Hendriks et al., 2000; Kleijn, 2000; Barles, 2010;). Regardless of this, the typical focus of MFA:s tend to be on the flows across the chosen geographical entity's boundaries (Ramaswami, et al., 2012) rather than the internal ones, and they thereby treat the delimited geographical area as a kind of ”limited summation unit” (Anderberg, 1997). This is quite different to what is typical for case studies, where the internal dynamics inside the case study boundaries are of highest interest. What is significantly different between the case study performed here and conventional MFA ones (regardless of whether these are labeled as case studies or not), is that the delimitation is centered around an object in a geographical area and not a certain material in a geographical area.

1850's was used for the systems that were disconnected in their entirety, and image-files and GIS-data of maps was used for still operating systems that also had disconnected parts and zones. No regional or (inter-)national numbers had to be downsized and assumed to be representable also for Norrköping. Neither did we, with one exception alone, make use of any kilograms per capita-assumptions to extrapolate findings that were relevant for one part of the city to hold for the city as a whole.

There is a downside using data with this level of detail and specificness that should be mentioned; the results are difficult to abstract from their local context. This relates to how clearly defined boundaries of a case study approach result in difficulties of generalizing. As the data is specific for the case study and dependent on the particularities of Norrköping's infrastructural history, I purposefully avoided generalizations about whether the quantitative results were valid also for other cities[27]. Instead, and in line with how case studies tend to afford the opportunity for theoretical generalizations rather than statistical ones (Yin, 2003 pp.10), I expanded qualitative theories of urban infrastructure studies in the second study (see the results-section).

Summing up, the consequences of framing MFA as a case study that also correspond well also to sociotechnically informed scrutiny, is thus a compromise in terms of scope and possibilities of generalization. First, conventional MFA:s are used to paint the whole picture of the geographical area of study. Assessing only the hibernating stocks of urban infrastructure limits the scope since the MFA does not aim for the total amounts of hibernating iron, copper and aluminium in Norrköping as a whole. Second, and given the enabled level of empiric detail that the case study approach allows and is primarily used for (Merriam, 2009), the ability to generalize from the MFA results is instead handed over to the qualitative realm of infrastructure studies.

Unlike most other MFA:s however, the limited scope means that the object of inquiry is not lost in flowcharts or inventories. The MFA can instead and with reliable local estimates on how much the hibernating stocks weigh and where they are located, hand them over to the department of process related assessment; the sociotechnically informed inquiry. This is what I believe is gained here; an MFA that instead of aiming at the generalization of data to account also for other scales, can inform the local context and the different processes that move materials around there[28]. Such processes require human agency and so that is what I turn into next.

[27] Support for avoiding such generalizations is found in the work of Weisz and Steinberger (2010), who have shown that the unique configuration of cities can result in very different material consumption per capita although there are similarities. As an example, the material turnover per capita and year is five times higher in Lisbon, Portugal than in London, England, suggesting that one should be careful in letting statistics travel over case study boundaries.

[28] It should be noted that this licentiate thesis is not the first attempt at including social aspects into studies of urban metabolism. Castán Broto et al. (2012) even claims that urban metabolist scholars often work to push the boundaries of their own discipline. However, and in relation to this work, an interesting difference is worth noting in that such attempts often suggest an extension of the urban metabolism model to also include social aspects rather than delimit it to make a better match for social science scrutiny (cf. Newman, 1999; Hodson et al., 2012; Ramaswami et al., 2012). An interesting case of the opposite is Anderberg (1998), who states that the ambition of

7.3 The Methodological Consequences for Infrastructure Studies

It is perhaps not surprising that the existence of hibernating stocks of infrastructure is a discovery made using a MFA research approach rather than within infrastructure studies. After all, the sensitivity to waste matters is much more clearly emphasized with the urban metabolist set of mind where residues of past structures are a component in the so called 'urban deposit' (Wilburn and Goonan, 1998).

No direct assessment of hibernating stocks of urban infrastructure had been made before the research in article #1 was conducted. Since every fourth kilo of infrastructure was found to be disconnected (Wallsten et al., 2013, see also: the Results-section), the results suggested that without taking hibernating stocks of disconnected cables and pipes into consideration, the complete characteristics of urban infrastructure would remain unknown. A closer scrutiny of the systems' nuts and bolts seemed indeed to be an interesting object of inquiry, but the question arose on how to perform academic assessment of these cables and pipes?

We knew that a micro-level practice perspective is key to arrive at knowledge on the advent of surplus material (Bulkeley and Gregson, 2009), and that all such surplus material must related to somebody's everyday tasks at work (Jacobs, 1969). That somebody would be a perfect informant for the study, but who could that somebody be?

The answer in this licentiate thesis resulted in a methodological extension for infrastructure studies that has been inspired by what Bowker (1994, quoted in Star 1999) has termed an "infrastructure inversion". In such an inversion, the backstage elements of work practice are purposefully foregrounded to reveal hidden characteristics of the case at hand. Our inversion was realized through the positioning of the so often excluded maintenance and repair workforce as a link to the material underworld of urban infrastructure. Inspired by Graham and Thrift (2007), the maintenance and repair workforce was given a pivotal position in the study and could thus become "one of our chief means of seeing and understanding the world" (p.XXX)[29]. Since the maintenance and repair workers are ones who actually see and touch the disconnected infrastructure before it is reburied, making them key informants in our study got us as close as possible to the sequence of events that occurs whenever infrastructure is taken out-of-use[30]. The inclusion of this workforce as key informants had a set of interesting consequences that all relate to the previously outlined reasons for why infrastructure studies scholars until now have neglected hibernating stocks (see chapters 6.2-4).

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getting closer to human actions, as well as temporal and spatial aspects, is more reasonable with a limited empirical object instead of making extensions to the conventional flow approach.

[29] The inversion is described in greater detail in the methodology-chapter in article #2, which also outline why certain respondents were selected and not others.

[30] I'm focusing here on the methodological addition to include this workforce in the study. These were however not the only ones that we interviewed as we also had the system providers for all the studied infrastructure systems as informants as well. While these informants gave us a lot of input to infrastructure provision matters they, like most project managers, keep a certain distance to the technological object that they are set to manage (Czarniawska, 2000). Due to this fact, it was absolute key to include the maintenance and repair workers as well, especially to get to the micro-level practice perspective.

7.4 Maintenance and Repair as [as what?]

The most evident consequence of making the invisibilized maintenance and repair work visible through academic assessment is that it becomes possible to establish a connection between a sociotechnical understanding of the city and the socio-ecological implications of the work that this workforce perform. The urban configuration is after all constructed through maintenance and repair practice and the ways that this practice co-exist with the material surroundings of the city. The maintenance and repair workers are in a sense geologic agents, as the bits and pieces of infrastructure that are left in the ground over time alter the geological configuration of the urban subsurface. Infrastructure systems role as material mediators, not only with regards to the material flows of system services but also the material flows of the systems components, is in this way highlighted through the inclusion of maintenance and repair workers.

Furthermore, their inclusion also allows for the establishment of a connection to aspects often left out within infrastructure studies such as disconnections, decay, deceased supply and even death of infrastructure. This allows for the reversal of the extend-and-supply-logic of system flows that is commonly the focus of infrastructure studies (Moss, 2008), to a correlating and interrelated ”disconnect and leave behind”-logic of the material flows that the infrastructure components and parts are part of. This reversed logic is furthermore intimately related to questions on how work practice relate to waste creation, another invisibilized characteristic of infrastructure systems.

The methodological extension to include the maintenance and repair workforce thus resulted in the academic possibilities of a theoretical contribution to the field of infrastructure studies. In sum, three concepts was suggested; infrastructure *coma*, infrastructure *paralysis* and *dormant cells* of infrastructure. These theoretical concepts are developed at full length in the second article but are also found in an abbreviated version centered around three maps showing different disconnection patterns in the following results-section.

8. Results and discussion

This cover essay has given me the opportunity to further explain the research methodology in the two appended articles and elaborate how the combined effort between the involved research fields was achieved and set out to work in a fruitful manner. This was a natural choice of emphasis since I believe that such a discussion would be rewarding to researchers interested in extending the urban metabolism perspective, and offer them not only a conceptual example of how this could be achieved, but also an empirical one. For the urban infrastructure studies community, I wanted to show how a reconnection to the material aspects of infrastructure systems could benefit theoretical development in the field and in a sense take it back to the basics; the systems' nuts and bolts.

In the following, I shall outline the results that I arrived at through the cooperation made possible in using hibernating stocks as a boundary object between the research fields of urban metabolism and infrastructure studies. The answers to the first three research questions are presented on the basis of the maps that were developed in the articles respectively. The answer to the last research question is thereafter found in the concluding chapter.

8.1 Answers the RQ #1

The first research question asked how much the hibernating stocks of infrastructure weigh. The answer totals for each of the included metals are found in the following table, and are delimited for the case study of Norrköping. [insert a lot of stuff about how this relates to urban mining possibilities here, i.e. the potential].

Category	System	Sub-system	Metal	Connected	Disconnected	Share	Metal	Connected	Disconnected	Share
CABLES	AC POWER	Household AC (active)	Cu	2000 tons	250 tons	<5 %	Al	1210 tons	25 tons	10 %
CABLES	AC POWER	Private AC (inactive)	Cu	75 tons	45 tons	40 %	Al	6 tons	2 tons	25 %
CABLES	DC POWER	Household DC (inactive)	Cu	0 tons	230 tons	100 %				
CABLES	DC POWER	Tram DC (active)	Cu	4 tons	35 tons	90 %				
CABLES	TELECOM	Household Telecom (active)	Cu	n/a	n/a	n/a				
PIPES	TOWN GAS	Household (inactive/ used for fiberoptics)	Fe	975 tons	3560 tons	80 %				
PIPES	DISTRICT HEATING	Heating (active)	Fe	10650 tons	895 tons	10 %				

DISCONNECTED TOTALS:	
Cu	560 tons
Al	27 tons
Fe	4455 tons
Σ	5042 tons

Table 2. The amounts of hibernating metals in Norrköping, both as totals and divided into the different infrastructure systems. For the sake of comparison the connected totals equaled 20000 tons, meaning that every 25% of the infrastructure studied is disconnected. The term connected is in the table used interchangeably with ”in-use” that is used throughout the text.

8.2 The Answer to Research Question #2

The second question related to the spatial distribution of these tons, which can be seen in the following three maps, one for each metal. The highest concentrations for copper and aluminium are found in the central parts of the city, while there is a ring-like pattern in the case of iron which is caused by the fiberoptics that has been installed in the empty town gas pipes of central Norrköping. These parts are not regarded as hibernating. [insert a lot of stuff about where urban mining makes more or less sense in spatial terms]

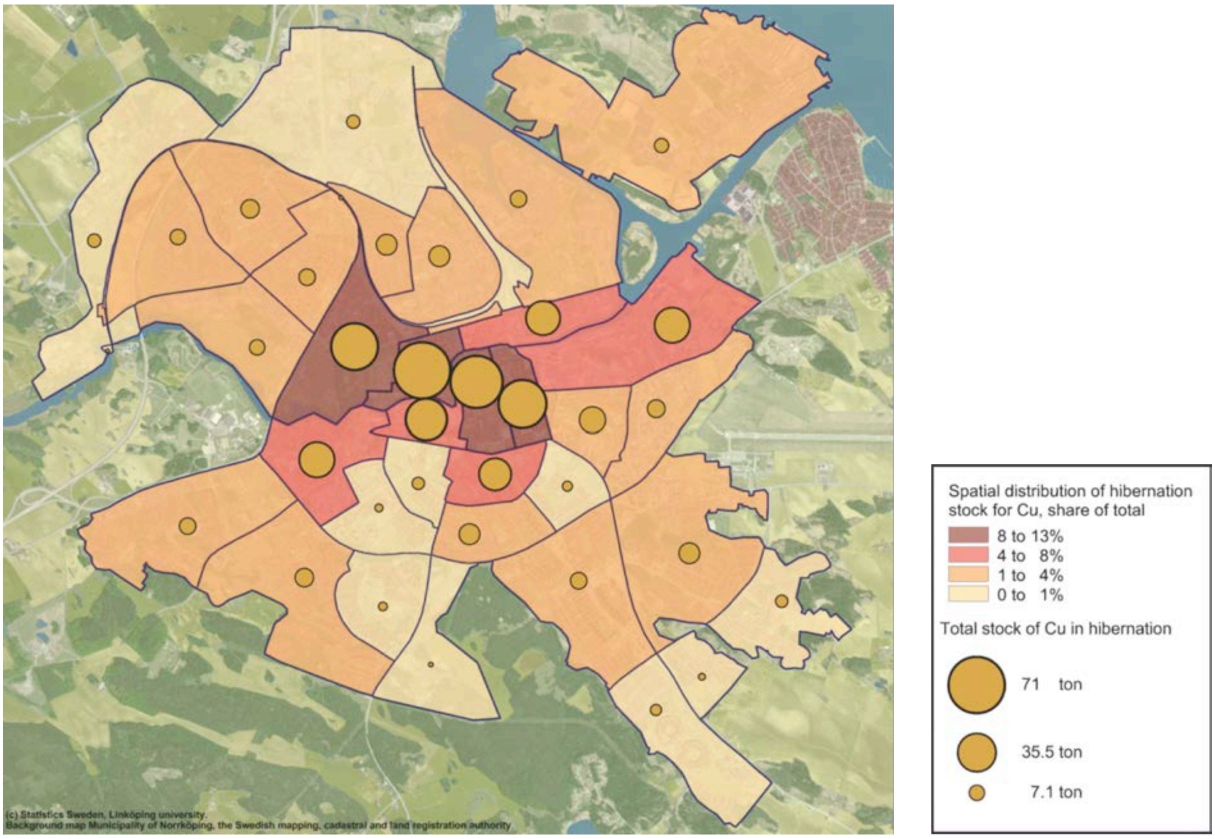

Figure 2. The spatial distribution of the hibernating stock of copper in Norrköping. Infrasystems for AC and DC Power are represented here.

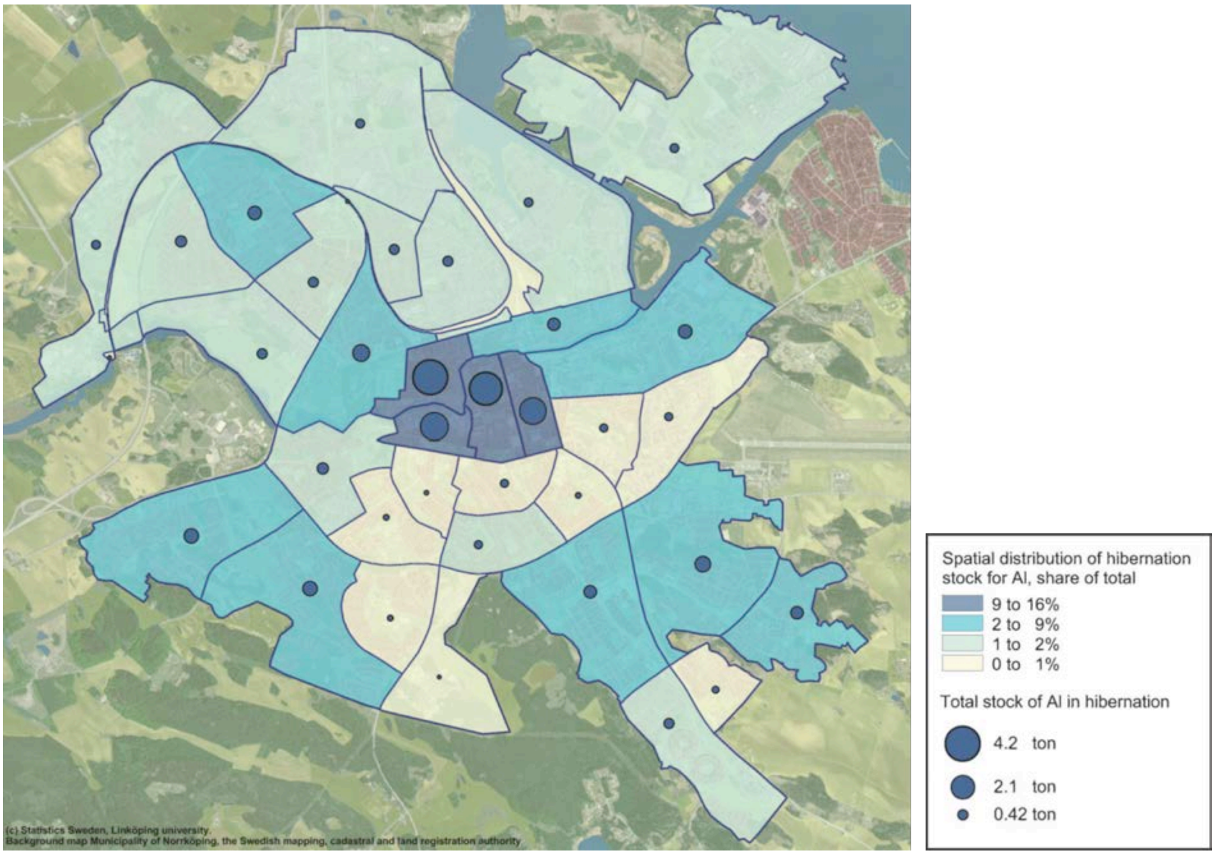

Figure 3. The spatial distribution of the hibernating stock of aluminium in Norrköping. Infrasystems for AC and DC Power are represented here.

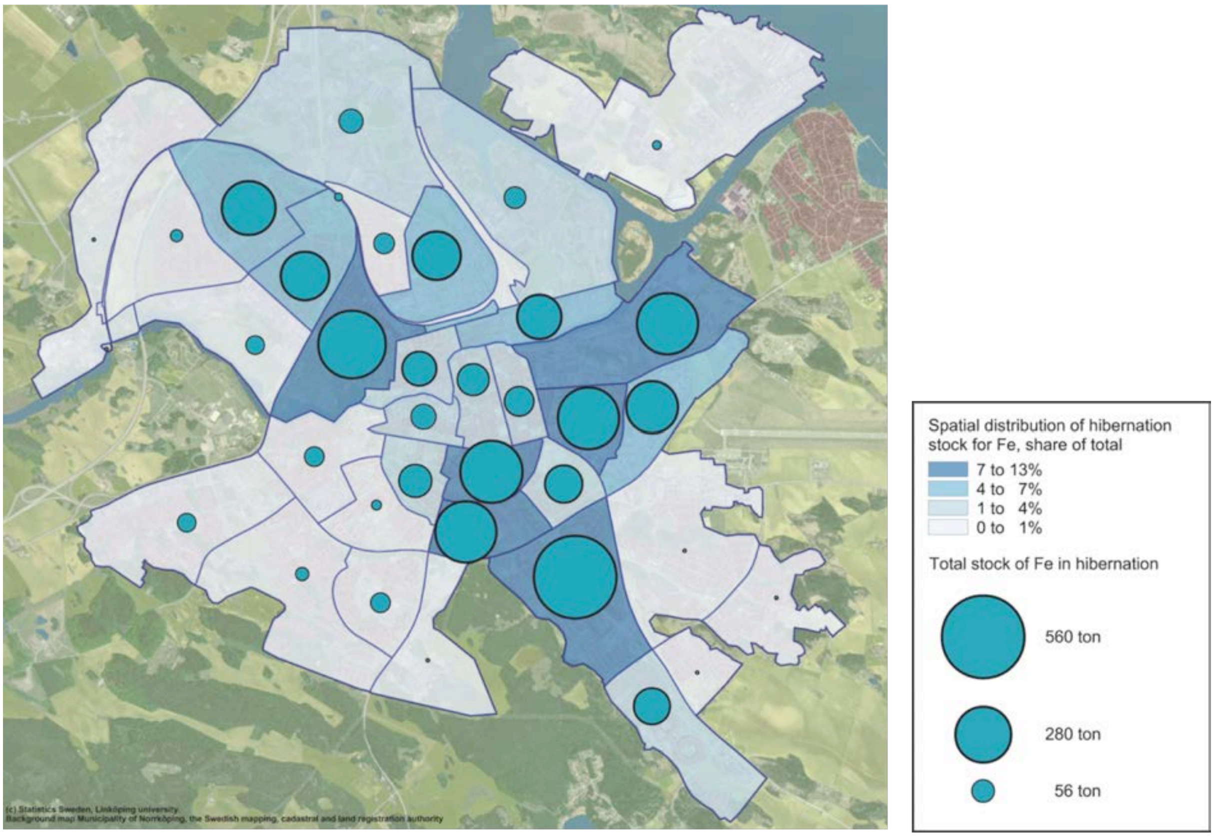

Figure 4. The spatial distribution of the hibernating stock of iron in Norrköping. Infrasystems for towngas and district heating are represented here.

8.3 The Answer to Research Question #3: How does Hibernating Stocks of Urban Infrastructure Come Into Existence?

While the answers to the two first research questions are found in the first article, the third research question is answered in the second.

In the second article, we found that hibernating stocks of urban infrastructure emerge as the result of what we would like to call a ”hibernation logic” inherent to the infrastructure provision in Norrköping (Wallsten et al., 2013). We describe this logic as consisting of two kinds of human actions that follow eachother in intimate succession; the infrastructure components are first *disconnected* and then *left behind* in their subsurface location. This logic give rise to three different spatial patterns according to which hibernating stocks of urban infrastructure come into existence and that differ from eachother in size and concentration. We have assigned them one conceptual name each; ”infrastructure coma” signifying *wholes* of disconnected infrastructure, ”infrastructure paralysis” signifying zones of disconnected infrastructure and ”dormant cells of infrastructure” signifying parts of disconnected infrastructure. Together with their corresponding spatial patterns, these can be seen in the three maps (see figure 5, 6, 7).

The patterns also represent theoretical contributions to previous concepts found in infrastructure studies. These are concepts that also focus on other aspects of infrastructure development than the oft-studied ”extend and supply”-logic, namely: ”infrastructure decline” and ”infrastructure cold spots”. And so while ”infrastructure coma” is an extension to ”infrastructure decline”, ”infrastructure paralysis” and ”dormant cells of infrastructure” are extensions of ”infrastructure cold spots”. A major difference that these extensions signify is that where cold spots signify *zones* of infrastructure in which the system flow is *limited*, my interest is in spatially more refined areas of *non-existent* system flows; namely *parts*, *zones* and *wholes* of what can be referred to as *frozen* or indeed hibernating infrastructure. All of these three patterns have different underlying mechanisms that will be outlined in the following.

8.3.1. Infrastructure Coma

Infrastructure coma is the consequence that follows from the disconnection of an infrastructure system in its entirety. Coma follows a longer process of system decline and is a consequence of that the belief in the system’s future development has been lost for some reason. In Norrköping, infrastructure coma has struck the town gas system that during the course of the twentieth century was supplanted by electricity. The reasons for why town gas was replaced relates in part to the completion of a national swedish transmission grid and the subsequent lower prices on electricity. Electric light furthermore offered a less dangerous product than gas and improved the air quality of many households. After a last attempt to reestablish itself and expand into the heat market (Kaijser, 1986), Norrköping’s town gas supplier suffered from a final crisis in confidence and the system was discontinued in 1988. Upon the discontinuation, the pipes of the town gas system was left lying abandoned, as the costs to dig it all up were inconceivable. The subsurface location was of course a necessary prerequisite to be able do so, as what is not visible does not exist.

8.3.2. Infrastructure Paralysis Dormant Cells of Infrastructure

Invisibility is of course a prerequisite also for zones and parts of disconnected infrastructure to be left behind in their urban location. [insert mer om dessa här, inte minst är kontraktsformerna viktiga för att visa hur de olika mönstren ger upphov till olika förutsättningar för urban mining] MER AGENS PLEASE! /AÅ

~~While it is the maintenance and repair crew that performs the disconnections and leaving behind of infrastructure components, the complete answer to why hibernation come into existence also has many other aspects than only those related to everyday practice.~~

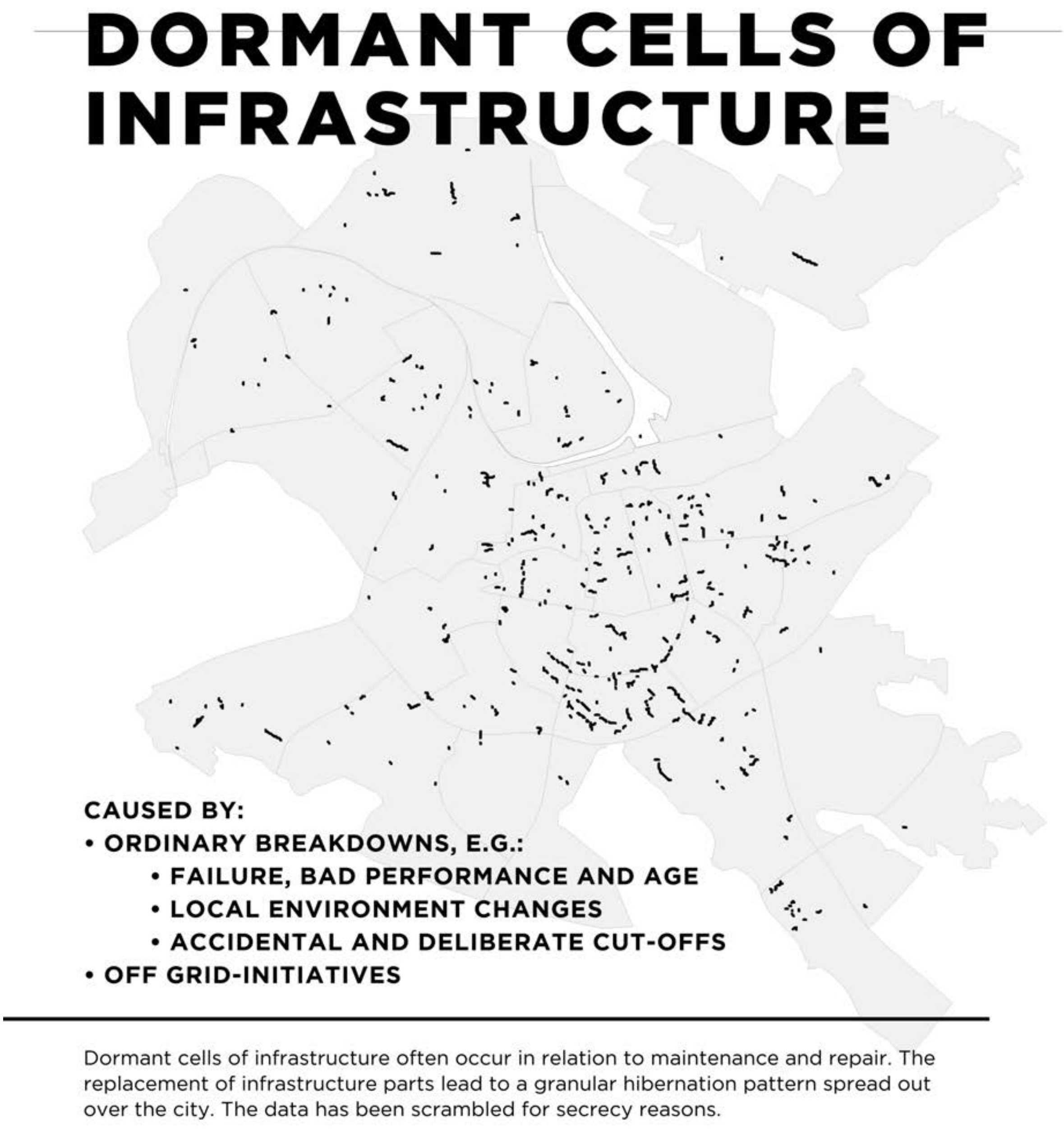

Figure 5. Dormant cells of infrastructure often occur in relation to maintenance and repair. The replacement of infrastructure parts lead to a granular hibernation pattern spread out over the city. The data has been scrambled for secrecy reasons.

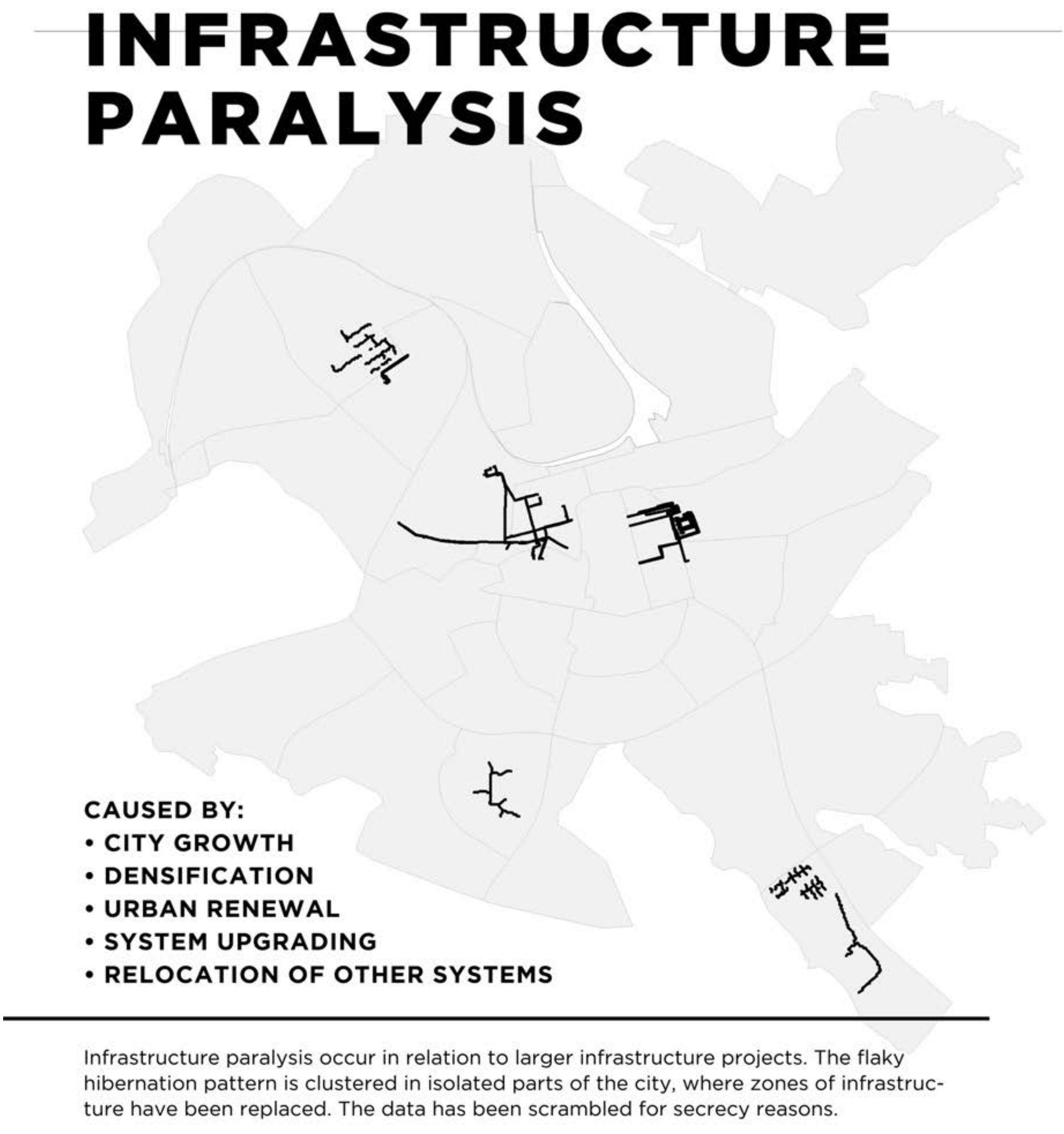

Figure 6. Infrastructure paralysis occurs in relation to larger infrastructure projects. The flaky hibernation pattern is clustered in isolated parts of the city, where zones of infrastructure have been replaced. The data has been scrambled for secrecy reasons.

TEMPORÄR??

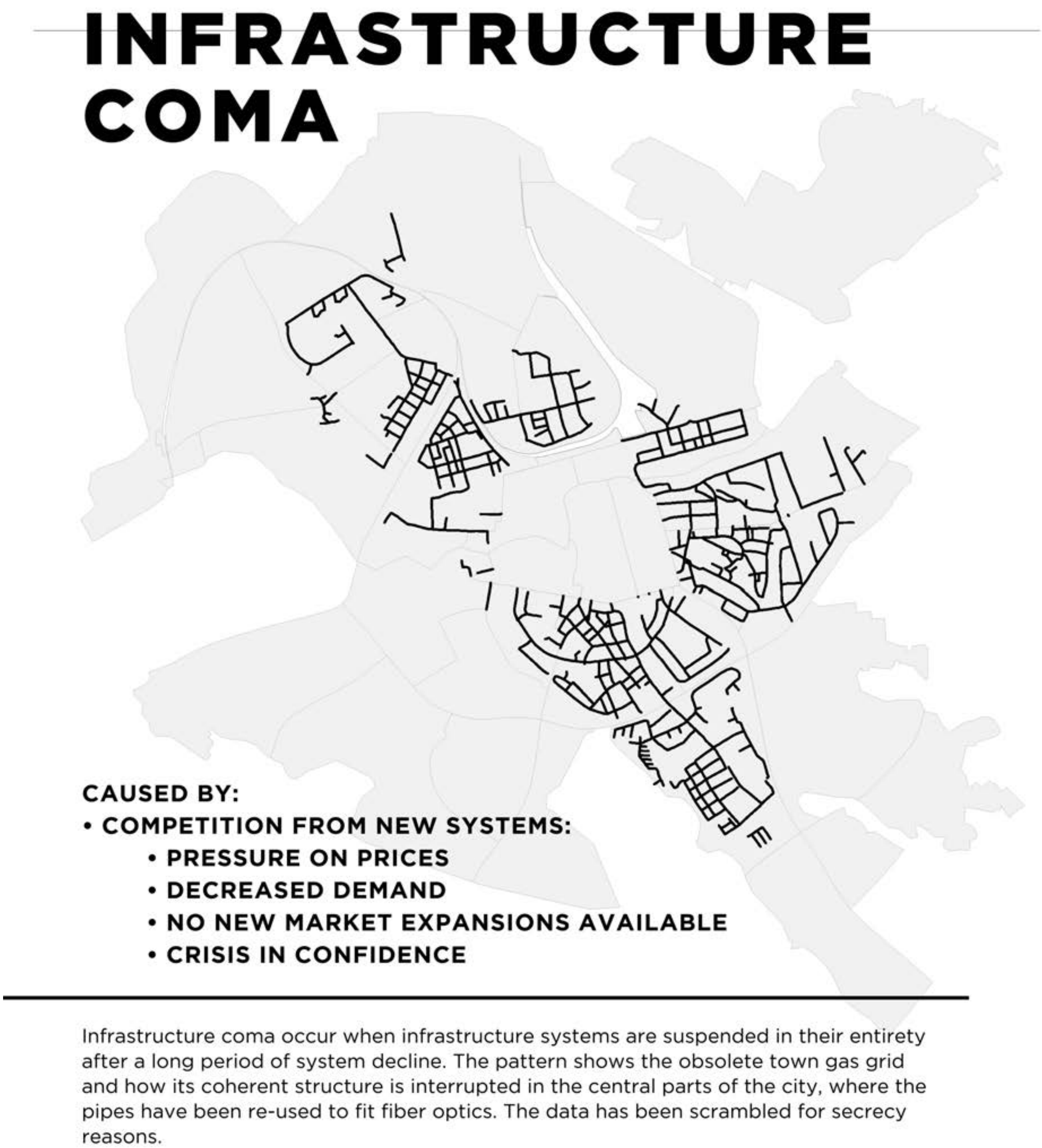

Figure 7. Infrastructure coma occurs when infrastructure systems are suspended in their entirety after a long period of system decline. The citywide pattern shows the obsolete town gas grid and how its coherent structure is interrupted in the central parts of the city, where the pipes have been re-used to fit fiberoptics. The data has been scrambled for secrecy reasons.

9. Concluding Remarks and Future Research

”At a given time in any city, one finds a physical fabric above and below ground being produced, altered, repaired, maintained and demolished by a host of builders, developers, architects, engineers, bulldozers and diggers” - McFarlane and Rutherford (2008) HÄR ÄR AGENSEN! /AÅ

Transformational material processes play an integral part in the everyday life of cities. They are deeply entangled in everything that the urban condition is about; from the urban soundscape to the urban economics. What is important to stress and what this licentiate thesis is all about, is that all such processes result in displaced matter and that this displaced matter over time accumulate into material repositories. In Lydia Kallipoliti’s words (2008): ”Spanning scales, from the scale of obsolete ”objects” to the scale of obsolete ”rooms” and ”buildings,” a mundance reality of *big* defunct objects – displaced building parts – is overwhelming in the contemporary city.” (p.XX)

The subsurface landscape of urban infrastructure networks is full of such defunct objects. This thesis outlines the scale and magnitude of these material stocks, and describes the sociotechnical process of their accumulation. Instead of supporting the widespread assumptions about of infrastructure systems as characterized by perfect order, completeness and internal homogenity, the results add the dimension of material surplus accumulation to the leaky, partial and inevitably messy characteristics of urban infrastructure that Graham and Thrift has only begun to outline (2007). Or in other words, the results add to the observation that infrastructure is ”fixed in modular increments” (Star, XXXX), that the understanding that all such fixes leave traces of material surplus behind.

In doing this, I believe that this licentiate thesis alters the understandings of how infrastructure systems function as the backbones of our built environments. Deeply entangled in the organisational arrangements and practical provision of these systems, are mechanisms that continously accumulate material residues in subsurface sinks that over time become significant enough to constitute a secondary resource base for metals recycling. Infrastructure systems are not only the key mediator of material flows between humans and nature as Monstadt would have it (2009), they are also in and of themselves constituent and part of such flows.

These findings would not have been possible without combining MFA and infrastructure studies into a research approach that was designed to make use of one and the same black box; hibernating stocks of urban infrastructure in Norrköping. This carefully delimited black box functioned as a boundary object between the two research fields. This licentiate thesis also give a practical example of what might be gained if the social study of human actions is connected to material flow analysis; namely an understanding and knowledge creation concerning how materials flow in society might be improved. This, I believe, proves a good example of why, as Anderberg concludes (1997), material flows must be seen ”as related to other processes, elements and structures of society” and ” not be cut off from their social context” (p.197+199).

In circling in on this highly material aspect of urban infrastructure systems, the maintenance and repair workforce become key actors. On the rare occasions when any recycling is actually performed, it is done by these workers and so understanding the prerequisites for their work practice becomes a crucial knowledge base for the further development of urban mining schemes.

[insert here: mer om hur de olika mönstren relaterar till urban mining]

9.1 Future research

Finally then, some words on the possible paths for future research based on these already performed studies.

Aside from the mass and distribution of the material (the concern of my two first research questions), Brunner has highlighted the composition of the material and technologies to exploit and upgrade the materials as crucial to engage in urban mining with any confidence (2007, p.13). Information about the composition of the material is in the case of derelict cables and pipes easily detectable. Degradation is likely a more interesting parameter, which is not addressed here and a possible area of further scrutiny. Facilities to upgrade materials in cables and pipes furthermore exist in numerous places in Sweden. The question is thus not one of developing recycling technologies, it is about including new streams of materials to these already existing facilities. Such involvement can be solved through regulatory, technological as well as organisational means, all of which are to be further explored in the upcoming articles of the final dissertation.

The answer I've given to the third research question in this licentiate thesis is a local and organisational one in so far as it deals with the work practices regulated by the local procurement contracts. [NYHETER! /AÅ] To provide a more regulatory and structural answer to the question, there is a need to widen the scope of actors and include decision makers, legislative bodies as well as other actors outside of the Norrköping context. Further knowledge on the legal framing on the matter might reveal the crucial legislative areas where urban mining measures would make the most sense to implement[31]. This will be the focus of the third and interview-based article in the full-length doctoral dissertation.

The last two articles of my dissertation will in turn discuss possible technological and organisational solutions for increased urban mining of urban infrastructure parts and components.

The fourth article is a case study centered around a recently developed technology that promises the extraction of cable copper cores without digging in the streets. I will follow the first pilot study of this technology in Sweden and assess the organisational framing of the

[31] This study has been argued for from a resource perspective rather than a hazardous toxic one. In hindsight, an assessment of substances such as lead, PCB, asbestos etc., could have yielded important pollution source knowledge and further legislative arguments for not letting infrastructure parts remain under ground.

technology and how its environmental qualities are negotiated in relation to the case study context.

The last study of the dissertation will gather the respondents in all the previous studies in a series of workshops that will explicitly be themed at coming up with solutions for increased urban mining. The research will be interventionist and aim at both concrete suggestions as well as processual knowledge on how environmentally relevant matters can be engaged with in the social sciences.

[infoga en riktig baddare till slutkläm här!]

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11. List of Figures and Tables

11.1 Figures

11.2 Tables