PROSPECTING THE URBAN MINES OF AMSTERDAM

Refining the PUMA method based on findings from practice


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01 INTRODUCTION

An increase in global population in the GNPs of developed countries and in metal production has lead to a rapid accumulation of metals in the anthroposphere (i.e. the built environment) this century (Sörme, 2000). Due to high metal prices and carbon reduction targets, there is an interest in recycling and reusing these metals when they become available as construction and demolition waste (Koutamanis, 2016). Urban areas with high metal concentrations and high building and demolition activity are especially interesting in sourcing metals for reuse.

Urban mining, a term that has become popularized in recent decades, can be defined as the practice of recovering materials for reuse from post-consumer sources like products, buildings, infrastructure, and landfills. By the application of urban mining, metal stocks can potentially be usefully returned to to their respective material cycles, hereby contributing to one of the key characteristics of a circular economy, in which all materials are cycled indefinitely (Gladek et al., 2015). To contribute to the development and implementation of urban mining, a consortium consisting of Leiden University, TU Delft, Waag Society, and Metabolic is developing a methodology for estimating the metal content of buildings in Amsterdam: Prospecting the Urban Mines of Amsterdam (PUMA). The ultimate goal is to visualize these urban metal concentrations in a geological map of Amsterdam.

Amsterdam is considered representative of typical urban environments with high population density. The framework that is being developed as part of the PUMA project can therefore be considered a pilot that can later be applied to other cities. PUMA uses a bottom-up estimation method in which an indication of the total metal stock in each building is made by combining data on the presence and amount of constructions that contain known concentrations of metal (Koutamanis, 2016). The PUMA framework, as proposed by Koutamanis et al. 2016, considers the stocks of steel, copper, aluminum, and zinc in apartments within residential buildings. These kinds of bottom-up frameworks rest on critical assumptions regarding actual metal concentrations, the availability of certain kinds of data, and the validity of the indicators that have been designed (Koutamanis, 2016). Metabolic's contribution to the PUMA project consists of two parts:

- Testing the PUMA framework's assumptions through site-visits and physical inspection of buildings
- Providing recommendations for refining the current framework and proposed methods of estimating metal concentration

In this document, we briefly describe the PUMA framework before elaborating on the results of Metabolic's contribution to the study.

1.1 PUMA FRAMEWORK

The PUMA framework considers individual housing units that together or apart constitute a residential building. These housing units contain certain amounts of metals (steel, copper, aluminum and zinc) that are estimated through a bottom-up approach. A standard housing unit, which represents a single address, is used as a baseline unit, with a certain presumed amount of metal content by category. This baseline metal content assumption is amended to reflect the height and surface area categories to which the building belongs. Using the address of the housing units, the height of the building is determined through the interactive maps and geodata of the city of Amsterdam (www.maps.amsterdam.nl), while the surface of the housing units that constitute the building is provided by the "Basisregistraties Adressen en Gebouwen" (https://bagviewer.kadaster.nl). The final classification defines the total score that is used for estimating the amount of each metal in the housing unit. Figure 1 depicts how the metal classifications are based on the standard housing unit and height and surface characteristics.

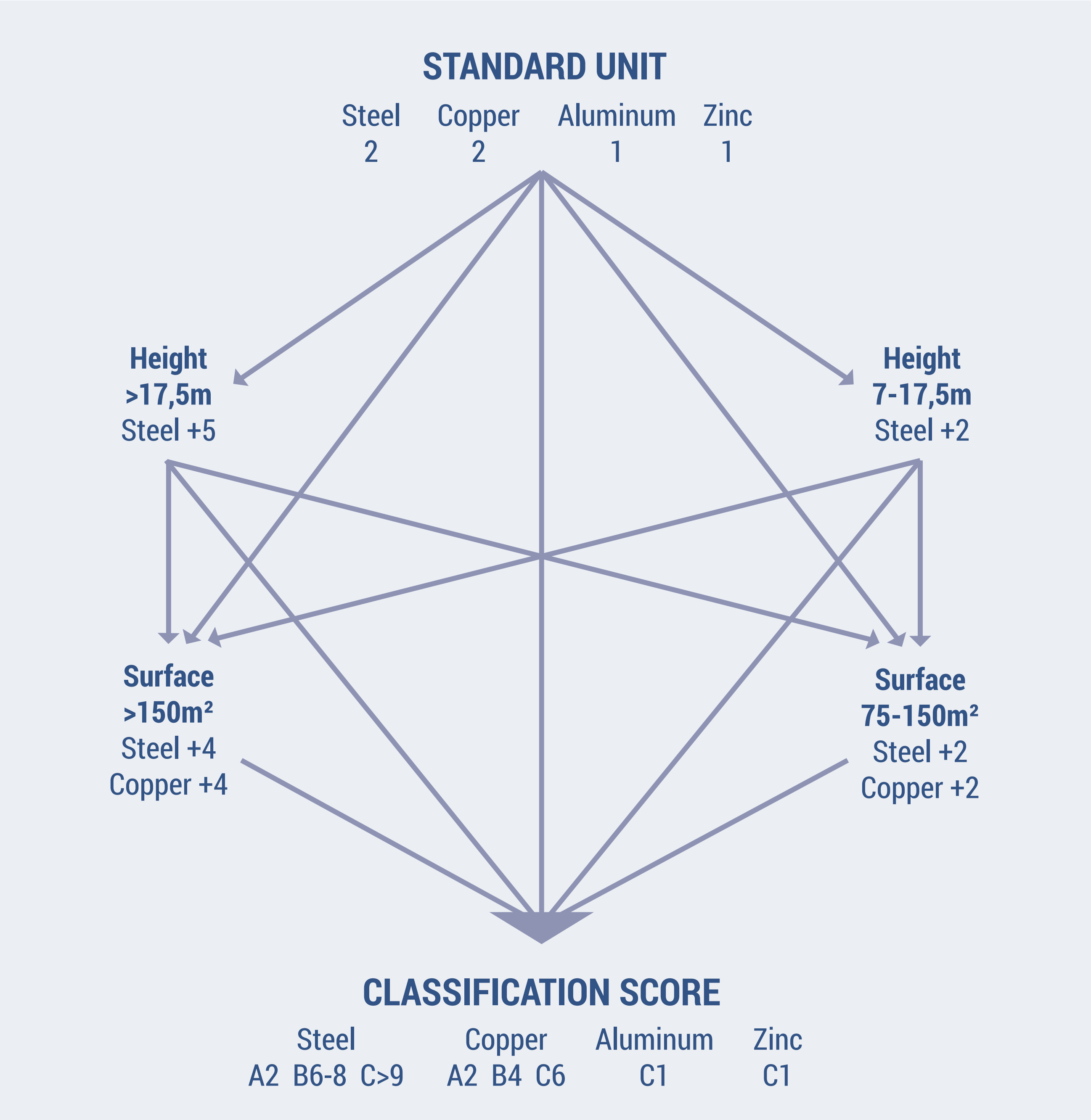


Figure 1: *Flow-chart for categorizing housing units into metal content classifications*

The metal content classifications are subsequently connected to a metal estimation range, which provides a minimum and maximum weight of each metal present in the housing unit. The classifications of the housing units result in nine possible combinations with accompanying metal content ranges as depicted in table 1 as A to I (Koutamanis, 2016).

	SIZE		COPPER			STEEL			ALUMINUM		ZINC	
	Surface (m²)	Height (m)	Score	Min (kg)	Max (kg)	Score	Min (kg)	Max (kg)	Min (kg)	Max (kg)	Min (kg)	Max (kg)
A	55-75	<7	2	5	35	2	500	900	4	9	5	8
B	75-150	<7	4	15	55	4	-	-	4	9	5	8
C	55-75	7-17,5	2	5	35	4	-	-	4	9	5	8
D	75-150	7-17,5	4	15	55	6	600	1000	4	9	5	8
E	>150	<7	6	35	80	6	600	1000	4	9	5	8
F	55-75	>17,5	2	5	35	7	600	1000	4	9	5	8
G	>150	7-17,5	6	35	80	8	600	1000	4	9	5	8
H	75-150	>17,5	4	15	55	9	800	1200	4	9	5	8
I	>150	>17,5	6	35	80	11	800	1200	4	9	5	8

***Table 1:** Metal estimation ranges of different housing unit categories*

There are several assumptions behind this metal content estimation of the different housing unit categories, of which the most important ones are:

- No classification for 4 points in steel, so housing unit types B (75-150m2 and <7m) and C (55-75m2 en 7-17,5m) have no steel estimation
- Surface
  - <55m2: no significant presence, or not different facilities than 55-75m2
  - 55-75m2: 1 kitchen, 1 bathroom, 1 separate toilet
  - 75-150m2: additional amount of copper in wiring, tubing and tabs and double amount as compared to 55-75m2. Steel amounts of 100 to 200 kg higher than in 55-75m2, present in floor, door and window frames and radiators
  - >150m2: second bathroom and/or toilet, amount of copper in wiring, tubing and tabs and triple amount as compared to 55-75m2. Steel amount 100 to 200 kg higher than in 55-75m2, present in floor, door and window frames and radiators
- Height
  - Steel elevators present at >17,5m
  - Extra height supported by steel reinforced concrete

1.2 OPPORTUNITIES FOR REFINING THE PUMA FRAMEWORK

The opportunities to refine the PUMA framework mostly stem from refining, or adding to, its underlying assumptions. Assumptions on the presence of constructions, facilities, or systems, or assumptions about the metal concentrations of these elements could turn out not to be supported in reality. Urban mining literature revealed several of these elements and assumptions which might turn out to be different, and which were thus worth checking. Ground-truthing these assumptions is therefore an important part of the evaluation process for refining the framework. Metabolic tested several of the framework's assumptions by performing site-visits to a number of housing units in Amsterdam, and comparing the situation on the ground to the assumptions in the PUMA model. The methodologies used during these site visits are explained in the following chapter. The main question we aimed to answer through this research is:

What important assumptions in the PUMA framework are in need of revision based on observations from practice?

Additional sub-questions we sought to answer through the site visits include:

- Does the quantity of steel and copper resulting from larger constructions, more facilities, and additional systems vary proportionally with the proposed surface area categories in the methodology?
- Does the quantity of steel resulting from larger constructions, more facilities, and additional systems vary proportionally with the proposed height categories in the methodology?
- Is the amount of zinc and aluminum not proportional to the surface and height?
- Are there significant amounts of metal, such as aluminum, zinc and lead (Fixmyroof, 2016), present in the facade or roofs?
- Did past renovations impact the metal content?
- What materials are used for window and door frames?
- Are load-bearing structures made out of other materials than steel reinforced concrete?
- Are other heating systems than central heating and radiators used in practice?
- Are other metals than steel, copper, aluminum, and zinc present in significant concentrations?
    - For instance, lead could be a relevant metal. According to Sörme, residential buildings in Stockholm, Sweden contain an average of 12,4 kg lead per person (Sörme, 2000). It can mostly be found in lead plates in chimneys, roofing (Fixmyroof, 2016), housing of old phone and power cables, and pipe connections (Elshkaki, 2004). Considering a market price of €2,06/kg (Mining Markets, 2016), the value of this metal stock would amount to €25,58/person. For comparison, other metal concentrations in the Sörme study were present at the following values per capita: copper €253,40/person, zinc €40,45/person, nickel €4,64/person, cadmium €0,08/person and chrome €3,06/person (Sörme, 2000; Mining Markets, 2016).
- Does the building typology impact the metal content?
    - Within the same height and surface categories, different typologies of interest might be present such as: semi-detached, detached, apartment flat, container housing, bungalow, or houseboats (which are a relatively common typology in the Netherlands).

02 METHOD

To answer these questions, a method consisting of the four steps as presented in the sections of this chapter:

2.1 sampling test cases
2.2 metal content estimation according to the PUMA framework
2.3 site-visit, and
2.4 analysis and comparison of results.

This resulted in a report on the sensitivity of the current PUMA framework and recommendations on the refinement of this framework. The four steps of the method are briefly explained in this chapter.

2.1 SAMPLING

The sample consists of six housing units in Amsterdam that represent different categories in building year, building height and surface of the units. The building year is relevant because it affects the chance of renovations, used materials, and systems. The height and surface determine the metal content estimation of the units according to the PUMA framework, which is required for testing the assumptions. Potential samples were collected by approaching inhabitants of Amsterdam within our own network of colleagues and friends, which ensured relatively easy access to private apartments. The inhabitants willing to participate supplied their address by which the building year and surface of their housing unit was determined via the "Basisregistraties Adressen en Gebouwen" (https://bagviewer.kadaster.nl) and the height of their building relative to the ground level was determined via the interactive maps and geodata of the city of Amsterdam (www.maps.amsterdam.nl).

The sample was selected from these inhabitants to ensure representation within the following parameters:

- Height: <7m, 7-17,5m and >17,5m
- Surface: 55-75m2, 75-150m2 and >150m2
- Building year: <1950, 1950-1980 en 1980<

2.2 PUMA ESTIMATION

To estimate the metal content in the sampled housing units, the PUMA database on addresses and buildings was accessed. This provided the metal estimation range for both the individual housing units and for the total building. For the housing units and buildings that were not included in the databases, the PUMA estimation method as elaborated in chapter 1.1 was performed by using the height and surface data as obtained during the sampling step.

2.3 SITE-VISITS

During the site-visit, a checklist was completed that contains all the elements to answer the sub-questions as formulated in chapter 1.2. This checklist can be seen in Appendix I: Site-visit checklist. The checklist was completed by visual checks on the specified elements and by asking the inhabitants of the housing unit. These answers were noted down on paper and subsequently transcribed as short descriptive stories, as well as in a checklist in table form. Additionally, photos were taken of notable elements to complement this documentation.

2.4 ASSUMPTION ANALYSIS

The obtained data of the checklist was analyzed by comparing the observed elements with the elements as assumed by the PUMA framework. This was done in a table format indicating the correctness of the assumption, which provided an image of the alignment of the assumed and observed case compared to all cases. Comparison of the observed elements of the different cases between themselves was additionally facilitated by this format. A short evaluation of each case was then provided, followed by an overall evaluation.

03 RESULTS

This sections of this chapter follow the same structure as the method chapter by respectively presenting:

3.1 the obtained sampling frame
3.2 the metal content estimation according to the PUMA method
3.3 the observations of the site-visits
3.4 the analysis of the assumptions of the PUMA framework against the observations

3.1 SAMPLING

A total of fifteen inhabitants of Amsterdam participated in the research after a selection of the sample as shown in Table 2 was obtained.

ADDRESS	BUILDING YEAR	BUILDING HEIGHT (M)	APARTMENT SURFACE (M²)
Spinnekop 18	1968	31,1	90
Pruimenstraat 6a	2006	13,0	80
Voelbalstraat 87	2016	7,8	23
Nicolaas Witsenkede 12a	1005	15,6	152
Suinameplein 35	1960	20,2	3420
Ruysdaelkade 57 HS	1875	8.0	32

Table 2: *Sample housing units for site-visits*

3.2 PUMA ESTIMATION

		STEEL		COPPER		ALUMINIUM		ZINC	
		Min (kg)	Max (kg)	Min (kg)	Max (kg)	Min (kg)	Max (kg)	Min (kg)	Max (kg)
Spinnekop 18	Apartment	800	1200	15	55	4	9	5	8
	Building	64000	96000	1200	4400	320	720	400	640
	Per m²	8,89	13,33	0,17	0,61	0,04	0,10	0,06	0,09
Pruimenstra 6a	Apartment	600	1000	15	55	4	9	5	8
	Building	17400	29000	435	1595	116	261	145	232
	Per m²	7,50	12,50	0,19	0,11	0,05	0,11	0,06	0,10
Voetbalstra 87	Apartment	500	900	5	9	4	9	5	8
	Building	39000	70200	390	702	312	702	390	624
	Per m²	21,74	39,13	0,22	0,39	0,17	0,39	0,22	0,35
Nicolaas Wilsenkade 12a	Apartment	800	1200	35	9	4	9	5	8
	Building	2400	3600	85	27	12	27	15	24
	Per m²	5,26	7,89	0,23	0,06	0,03	0,06	0,03	0,05
Surinameplein 35	Apartment	800	1200	35	9	4	9	5	8
	Building	800	1200	35	9	4	9	5	8
	Per m²	0,23	0,35	0,01	0,00	0.00	0.00	0.00	0.00
Ruysdaelkade 57 HS	Apartment	500	900	5	35	4	9	5	8
	Building	7600	13600	85	545	60	135	75	120
	Per m²	15,63	28,13	0,16	1,09	0,13	0,28	0,16	0,25

Table 3: *Metal estimation housing units and buildings*

3.3 SITE-VISITS

SPINNEKOP 18

Spinnekop 18 is a gallery-flat built in 1968. It measures 31.1 meters with ten floors. The residential flat counts eighty apartments, although one of these contained a physiotherapy practice. The facade contained metal in the galvanized steel and aluminum gallery railings, as well as galvanized steel rain tubing and aluminum plates on the doors and mailboxes. The bearing structure is likely to be steel-reinforced concrete and the apartments can be reached via two elevators or two stairways with steel handrail supports. The roof was not accessible, but metal chimneys and solar panel support was visible.

The 90m2 apartment contained a kitchen, separate toilet, and a bathroom without toilet. The sink and tap in the kitchen were made of stainless steel, while the toilet and bathroom sink contained no metal. The central heating of the building was connected to seven steel radiators in the apartment. The copper water and gas piping was connected to the boiler, the casing of this boiler was however missing due to recent repairs. The door and window frames were made of wood and there were no visible signs of renovations in the apartment.

PRUIMENSTRAAT 6A

This flat was built in 2006 and contains 29 apartments, which are spread over two buildings that have a shared front door and can be reached via stairs, an elevator, and walkways. There is a Chinese restaurant on the ground floor of the building and a large parking garage and ventilated storage sheds in the basement. Other building features included shading panels in front of some windows and corrugated sheets--both aluminium. Every apartment had a balcony with galvanized steel beams and the gutters, drains, and railings of the walkways and stairs were made of the same material. Lead sheets were found at the base of the building for waterproofing.

The 80m2 apartment has a kitchen, bathroom with toilet, and a separate toilet. Notably, next to the central heating with five radiators, the apartment has floor heating as well in the hallway and bathroom, totalling to approximately 17m2. The apartment additionally contained a ventilation system with aluminium and steel ducts. The fuse box furthermore contained a spare copper pipe and the internal door frames were made out of steel.

VOETBALSTRAAT 87

This flat in Westlandgracht consists of stacked shipping containers that have been transformed into small studios. The flat provides housing for young refugees and students, both of which inhabit half of the studios to promote integration. Prior to the project's realization in 2016, the containers were used for residential purposes in Houthavens, which provides a practical example of metal recycling in residential buildings of Amsterdam. The steel containers, which make up the whole load-bearing structure, can weigh between 2200 and 4150 kg each (Vantage Freight, 2013; Balk Trade B.V., 2016). The actual contribution of the containers to the steel content will be lower due to the windows, doors, and their plastic frames. The building furthermore has corrugated metal plates as roofing, galvanized steel rain tubes, and corridors between the buildings.

Galvanized steel stairs lead to a central hallway with steel doorframes through which the 78 studios can be reached. Four central heating facilities with steel piping supply the radiators in the building, of which each studio has one. The studios have a single room with a kitchen block with a steel countertop and sink, no gas connection, and a bathroom containing a boiler and toilet. There were no visible signs of renovations since the building's construction.

NICOLAAS WITSENKADE 12A

This canalhouse contains three apartments spread over six stories, including the basement. The building could not be dated in the BAG register, but the neighboring houses date back to the end of the nineteenth century according to the register. The load-bearing structure consists of stone and concrete bricks, and thus is unlikely to be reinforced with steel. The frames of the doors and windows are made of wood. Cast iron was found in the fences of the stairs, the four balconies, and basement windows. A steel staircase to reach the first floor's entrance was visible as well, which continues inside up to the sixth floor.

The apartment has one kitchen and two bathrooms with separate toilets, one of which has a tap and sink. An extra tap was found in the hallway and a steel tap, sink, and countertop was present in one of the rooms. The central heating is connected to eight radiators that varied significantly in size, and an extra disconnected radiator was found in the fusebox. All door and window frames were wood. The copper piping of the boiler was significantly corroded, which raised questions on its reusability. Although there were no visible signs of renovations, a large renovation is planned in January 2017 that will remove walls and integrate two of the apartments within the building into one larger apartment.

SURINAMEPLEIN 35

This five story building in Hoofddorppleinbuurt is a former nursing home and is now a cultural incubator, providing housing to 62 people, eight rehearsal rooms and 11 ateliers and offices. Although the building's official function is still healthcare, its current use is mixed residential and commercial. Notable is that it is attached to the office space in Surinameplein 33, which is in fact not an official address and is part of Surinameplein 35 according to the cadastre. The eight balconies have steel railings and the window and door frames leading to them are made of steel. The facade contains galvanized steel drainpipes up to the first floor, from which point onwards they continue as plastic. The entrance to the building has a staircase, and two old elevators and stairs with steel railings lead up to the apartments.

Although the building contains a single apartment of 3420m2 according to the cadastre, and thus in the PUMA framework as well, the floor was defined here as a functional unit for apartment during the site-visit. The findings were multiplied by five to obtain the building and apartment results to compare with the PUMA assumptions. Each floor serves as a separate large apartment, providing housing to 14 people who share one kitchen, four showers and four toilets, and every bedroom has its own tab and sink. The apartments have central heating with 25 radiators per floor. The door frames contain some steel, of which there are 28 per floor with an additional three fireproof doors. There were clear signs of renovations; five walls were removed and the kitchen infrastructure was moved to another room.

RUYSDAELKADE 57 HS

This house from 1875 in Oude Pijp is made of stone bricks for its load-bearing structure. Although the partitioning of the facade and doors suggest the presence of four apartments, the building is actually bigger and contains fifteen apartments and one gallery on the ground floor. The facade furthermore contains cast iron ornaments and galvanized steel rain pipes.

The apartment was on the ground floor and had a separate door, so no stairs leading to the other apartments were visible. There was one kitchen with a gas connection, a stainless steel sink, and a countertop, as well as one bathroom with a toilet but no sink. A separate toilet was not present. The door and window frames were made of wood. There was central heating in the apartment with four radiators. It was indicated that this heating system was recently changed, implying a renovation that might have affected the metal content.

3.4 ASSUMPTION ANALYSIS

The assumptions on the presence, amount, and concentration of elements as defined in chapter 1.2 were compared with the data of the site-visits, which resulted in an indication of the correctness of the different assumptions for the cases as shown in Table 4.

In this table, **green** indicates the confirmation of an assumption, **red** indicates the rejection of an assumption, and **grey** indicates that the assumption could not be confirmed or rejected based on the data from the site-visits. A brief discussion on the correctness of these assumptions is provided following the table.

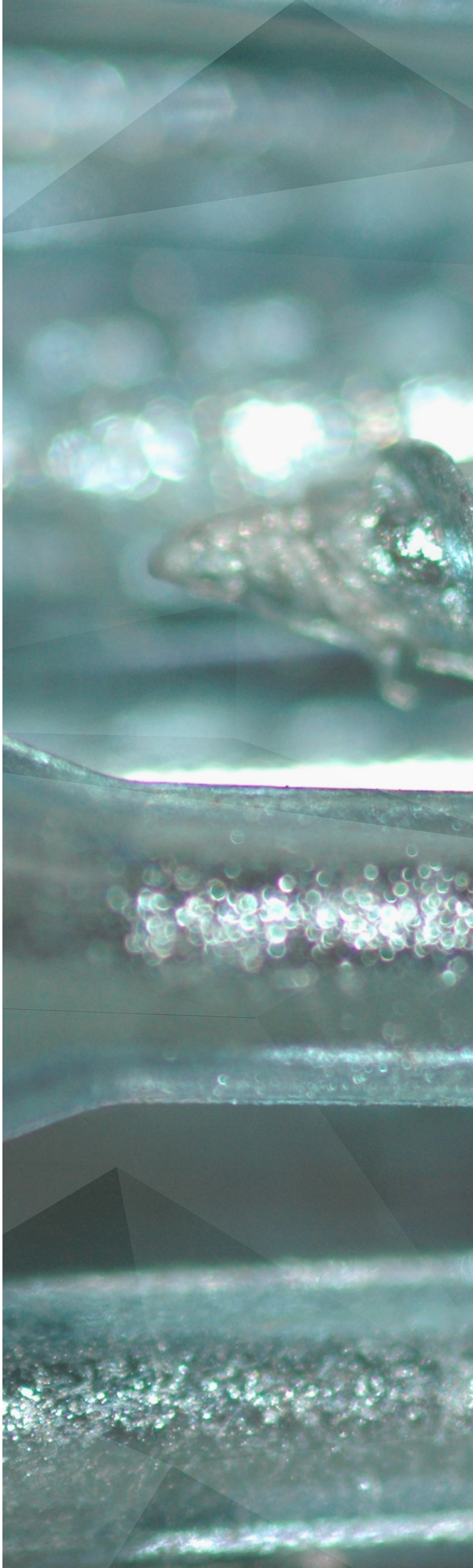
ASSUMPTION	SPINNEKOP 18	PRUIMEN-STRAAT 6A	VOET-BALSTRAAT 87	NICOLAAS WITSENKADE 12A	SURINAME-PLEIN 35	RYUS-DAELKADE 57 HS
Function	green	green	green	green	red	green
Renovations	grey	grey	green	red	red	red
Reinforces concrete	green	green	red	red	green	red
Zinc, aluminium or lead presence	red	red	grey	grey	grey	grey
Facilities and services						
Elevator presence	green	red	green	green	green	green
Heating system	green	red	red	green	red	green
Steel door frames	red	green	green	red	green	red
Copper gas pipes	green	green	red	green	green	green
Kitchen amount	green	green	green	green	red	green
Toilet amount	green	red	red	green	red	red
Bathroom amount	green	green	green	green	red	green
Metal estimation range						
Steel fit	grey	grey	red	red	red	red

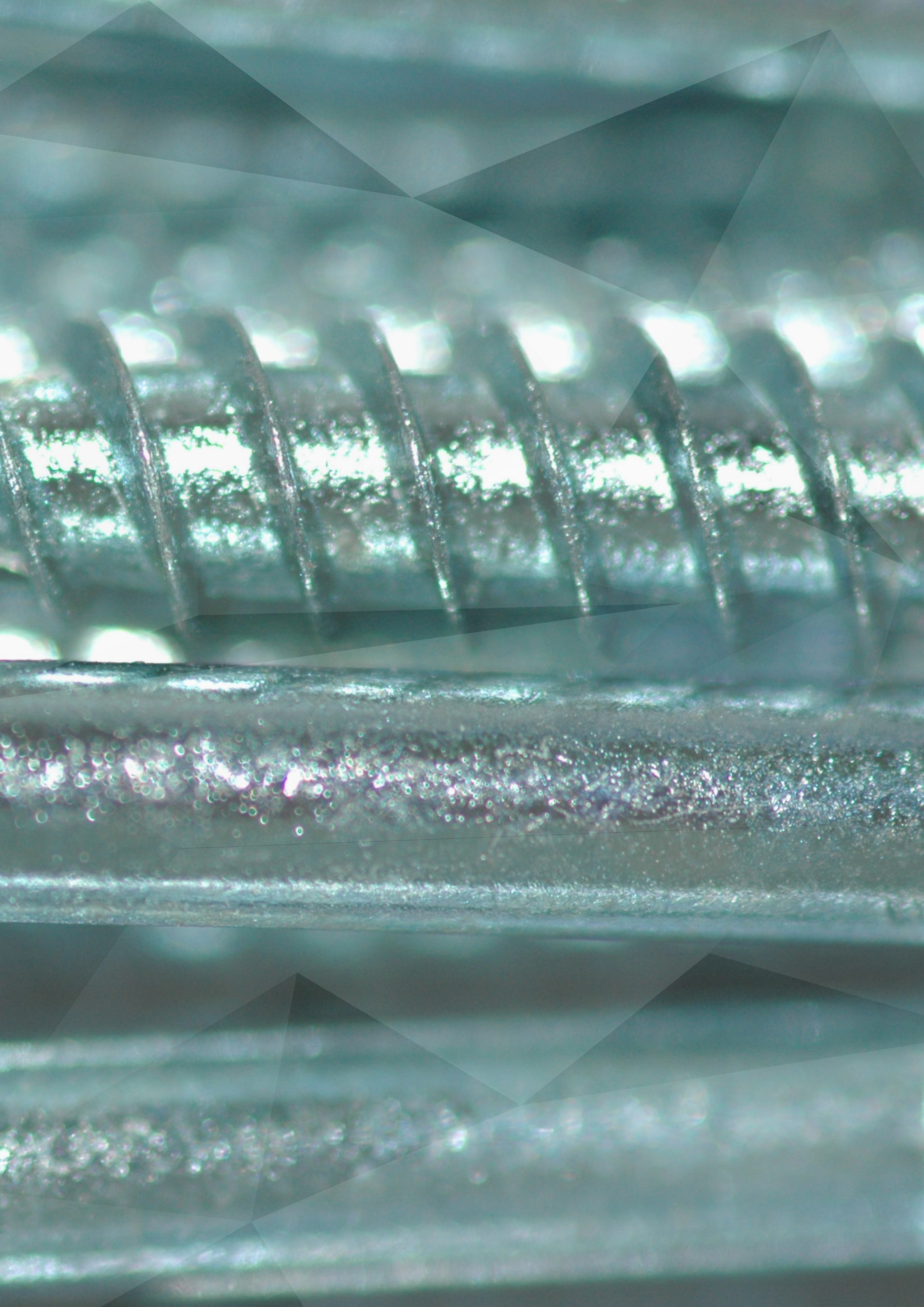
Table 4: *Assumption correctness in sampled cases*

Within the assumptions on building and structures, the residential function applied to all cases except for Surinameplein. Buildings with a temporary or altered function are possibly not classified as residential, and thus not included in the PUMA estimation. Renovations that impacted the metal content were found in three cases. Both removal and addition of metal elements was present, so the impact and direction of change could not be indicated. The assumed presence of steel in reinforced concrete was not found to be true for three of the cases; buildings dating from the nineteenth century were found to be supported by bricks that did not add to the steel content, while temporary housing projects based on shipping containers significantly increases the steel content relative to the assumed reinforced concrete. Lead and additional aluminum was found on the facade in two cases, while a more complete picture of the additional zinc, lead and aluminum content was limited by the roofs not being accessible.

The facilities and services matched the assumptions quite well on the amount of kitchens and bathrooms for the floor surface categories. However, it was found that apartments in the smaller than 75m2 category have a toilet in the bathroom rather than being separate, which is likely to lower the copper and steel content due to less plumbing. Surinameplein did not properly fit in the surface categories and the amount of facilities thus did not match the assumptions. The presence of elevators in buildings higher than 17,5m was confirmed, except for Pruimenstraat that had an elevator while the building was lower than 17,5m. Assumptions of the heating system did not match the findings at Voetbalstraat due to a central heating system per 20 apartments with a single radiator per apartment. Nor did the assumptions match the realities at at Pruimenstraat due to the presence of floor heating in addition to the central heating system. Interior doorframes contained metal in the newer building, except for Surinameplein, while the doorframes in older buildings were made of wood. Finally, Voetbalstraat, being the newest building in the sample, had no gas supply in the kitchen. This lowers the copper content through fewer gas pipes. New neighborhoods in the Netherlands are increasingly constructed as gas-free, a development that might in time influence the copper concentration in residential buildings.

Analyzing the match of the estimated metal range with the findings of the site-visits is challenging given that no complete demolition of structures, disassembly of systems, and weighing of obtained metal components was performed during the site-visits. Therefore, no confirmation of the metal range could be provided, but rather only findings that rejected the estimated metal range with certainty were indicated. First, the steel range was not met in older buildings without reinforced concrete and was exceeded in buildings consisting of steel shipping containers. Second, the copper range was not met in buildings without gas connection and was exceeded in apartments with floor heating. Third, the aluminum range was exceeded in buildings with aluminum facade features. And finally, all metal ranges were exceeded in apartments with a significantly larger surface than 150m.





04 CONCLUSION & RECOMMENDATIONS

Based on the findings of this research, an answer was provided to the research question:

What important assumptions in the PUMA framework are in need of revision based on observations from practice?

Overall, most assumption were found to remain valid, although the validity of some assumptions could not be indicated, specifically due to the lack of access to roof spaces. However, five assumptions were found to be in need of revision, these are briefly listed in this chapter together with associated revision recommendations.

1. **Buildings before 1900 were found to not include steel in the load-bearing structure**

Construction year data from the BAG register is available, which could provide an indication of the metal content of the load bearing structure. Inclusion of the construction year in the dataset, combined with a with a lower steel score for buildings built before 1900, should be considered.

2. **Apartments smaller than 75m2 were found not to have a separate toilet and bathroom, instead the toilet was present in the bathroom**

The assumed amenities of the 55 - 75m2 standard apartment could be changed to one kitchen and a bathroom with toilet. The impact on the metal content should be researched and adapted when change is found to be significant.

3. **Recently completed buildings were found not to be included in the database**

It should be ensured that the database is kept up to date in order to account for these recently completed building.

4. Some buildings with a non-residential function were found to (temporarily) accommodate a residential function

To account for all residential buildings, a clear distinction needs to be made between the residential function and use of the building. Although the currently used BAG function distinction might very well be adequate, research on the relevance of including buildings used for residential purposes, but with other functions according to the BAG register is recommended. This research should account for the metal concentration in these buildings versus the amount of these buildings in Amsterdam.

5. Some buildings were found to use electric cooking appliances rather than gas

The absence of gas connections in the kitchen is likely to lower the copper content of the building. Because policy objectives increasingly aim to disconnect from the gas infrastructure (ECN, 2016), it is recommended to research its impact on the amount of copper in buildings to be able to accurately estimate the copper content in the future.

Altogether, the application of the PUMA framework to Amsterdam proved that the PUMA framework can be a solid initial methodology to estimate urban metal stocks in the built environment in cities across the Netherland. Although a few minor refinements and additions to the methodology and its underlying assumptions were proposed in this chapter, no tremendous validity displacements have been found. PUMA thus provides a promising means to geographically indicate metal stocks in the built environment, and the value of further scaling to also include commercial buildings and infrastructures to academics, policy makers and (future) practitioners of urban mining is apparent. Once these stocks are mapped, questions regarding the timeframe of stocks becoming available and methods to actually obtain these stocks on a high quality level start to become relevant. Further research on these questions, together with the exploration of new policy frameworks to govern potential urban mining processes, is thus very important to stimulate the practice of urban mining now and in the future. The resulting increased application and effectiveness of urban mining could theoretically make a valuable contribution to the ambition of establishing a circular economy in the Netherlands in 2050, as expressed by the Dutch government (Ministry of Infrastructure and Environment et al., 2016).

APPENDIX I:
CHECKLIST SITE-VISIT

INTRODUCTION

- Urban mining, PUMA consortium, metals in residential buildings
- Methodology metal estimation
- Visual check, some questions and photos with permission
- Total duration 20-30min
- Deliverable of research

CHECKLIST

1. **Visual check building facade**
   - Building type
   - Metal components (drainpipe, (balcony) railing, fire escape stairs, and others)
   - Retrofits visible
   - Amount of housing units in building
   - Other building functions than residential present
2. **Visual check entrance**
   - Elevators
   - Load-bearing structure (stone bricks, reinforced concrete, wood, steel)
   - Stairs and railings
3. **Visual check inside**
   - Facilities: amounts and material
     - Kitchen (sink, countertop, gas and water piping)
     - Bathroom (piping, sink, tabs)
     - Toilet (sink, tabs)
   - Retrofits
     - Heating and warm water system (location, source and delivery medium)
     - Door and window frames (amount and material)
4. **Roof and balconies (if accessible)**
   - Roof cladding
   - Chimneys
5. **Other metals in building systems and structures**

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