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A new Urban Metabolism approach

Combining satellite data and urban metabolism assessment for promoting sustainable urban development

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ABSTRACT:

This master's thesis provides a new approach to urban metabolism, i.e., energy and material flow assessment. Previous urban metabolism assessment researchers have pointed out a lack in data availability, so this research aims to provide new possibilities related to satellite data utilisation in urban metabolism assessment.

Currently the environment faces serious issues due to the socio-economic changes of growing cities. Cities today use more energy and materials than our planet can re-create to maintain urban living and living standards. To avoid negative impacts on the environment and to minimise impact on the surrounding area such as resource exhaustion and environmental issues cities need to focus on sustainable development. Cities play a key role in decreasing the use of resources, and for this reason urban decision makers should take a more central role in developing the sustainability of urban areas. Urban metabolism assessment focuses on a city's energy and material flows, and monitors simultaneously cities' sustainability. Cities' material and non-material flows occur from different socio-economic and technological processes within the city. The results of the assessment will help increase the sustainability, resource efficiency, and self-sufficiency of cities.

This research scrutinises urban metabolism assessment from different perspectives, such as different research methods and the use of data through a literature review. This research focuses on how urban metabolism assessment has been used to promote sustainable urban development and how urban policies should support new urban metabolism approaches. In addition, during the research process a focus group discussion was organised, which gathered an extensive group of experts to discuss the research theme. The discussion reached guidelines and policies for future research on urban metabolism assessment, such as combining data from different sources and promoting the use of satellite data. Urban policy makers need more science-based data about the urban ecosystem to harmonise sustainable development goals and local-level actions. Obtaining of the required data is currently challenging since the data needs to be collected from various fields. Satellite data, on the other hand, provides a wide range of information on the urban ecosystem, including land use, environment and sustainability. However, the wider use of satellite data in urban research requires promotion of its use and collaboration between researchers and policymakers, in order to provide tools for cities by which to increase their resource efficiency and sustainability. Current urban policies have failed to reduce resource use, whilst urban metabolism assessment appears to be an effective approach for identifying challenges related to urban energy and material flows. On the other hand, research that focuses on urban metabolism assessment is not yet a widely used approach in sustainable urban research.

KEY WORDS: urban metabolism assessment, urban ecosystem, satellite data, remote sensing, Earth observation, sustainable city, sustainable development

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TIIVISTELMÄ:

Tämä pro gradu tarjoaa uuden lähestymistavan kaupunkien aineenvaihdunnan eli energia- ja materiaalivirtojen arviointiin. Aikaisemmat kaupunkien aineenvaihduntaa arvioineet tutkijat ovat nostaneet esille puutteet datan saatavuudessa, mutta tämä tutkimus nostaa esiin uusia satelliittidatan hyödyntämiseen liittyviä mahdollisuuksia kaupunkien aineenvaihdunnan arvioinnissa. Kaupunkien nopea sosiaalinen ja taloudellinen muutos aiheuttaa vakavia ongelmia ympäristölle. Ylläpitääkseen asukkaidensa elämää ja elintasoa kaupungeissa kaupungit nykyisellään kuluttavat energiaa ja materiaaleja enemmän kuin maapallomme kantokyky kestää. Ehkäistäkseen ympäristölle negatiivisten vaikutusten syntymisen ja minimoidakseen ympäröivään alueeseen kohdistuvat vaikutukset, kuten resurssien ehtymisen ja ympäristöongelmat, kaupunkien on keskitytttävä kestävään kehitykseen. Kaupungeilla on tärkeä rooli resurssien käytön vähentämisessä ja tästä syystä kaupunkien päättäjien tulisi ottaa keskeisempi rooli kaupunkialueiden kestävyyden kehittämiseen. Kaupunkien aineenvaihdunnan arviointi keskittyy kaupungin energia- ja materiaalivirtoihin ja mittaa samalla kaupunkien kestävyyttä. Kaupunkien aineelliset ja aineettomat virrat syntyvät erilaisista sosioekonomisista ja teknologisista prosesseista niissä. Arvioinnin lopputulos auttaa lisäämään kaupunkien kestävyyttä, resurssien käytön tehokkuutta ja omavaraisuutta. Tämä tutkimus käy läpi kaupunkien aineenvaihdunnan arviointia eri näkökulmista, esimerkiksi erilaisia tutkimusmenetelmiä ja datan käyttöä kirjallisuuskatsauksen avulla.

Tässä työssä keskitytään siihen, miten kaupunkien aineenvaihdunnan arviointia on käytetty kestävän kaupunkikehityksen edistämiseen, ja miten kunnallispolitiikkojen tulisi tukea uutta kaupunkien aineenvaihdunnan lähestymistapaa. Tutkimusprosessin aikana järjestettiin fokusryhmäkeskustelu, joka kokosi laaja-alaisen asiantuntijaryhmän keskustelemaan yhdessä tutkimusteemaan liittyvistä aiheista. Keskustelu loi suuntaviivoja kaupunkien aineenvaihdunnan arvioinnin tulevaisuuden tutkimukseen ja sitä ohjaavaan politiikkaan, esimerkiksi eri lähteistä saadun datan yhdistämiseen ja satelliittidatan käytön edistämiseen. Päättäjät tarvitsevat enemmän tieteeseen perustuvaa dataa kaupunkien ekosysteemistä kestävän kehityksen tavoitteiden ja paikallisen tason toimien yhteensovittamiseksi. Nykyisellään tarvittavan datan hankkiminen on haastavaa, koska tietoa on haettava eri tutkimusaloilta. Satelliittidata tarjoaa laasti tietoa kaupunkiekosysteemistä, muun muassa maankäytöstä, ympäristöstä ja kestävyydestä. Laajempi satelliittidatan käyttöönotto kaupunkitutkimuksessa vaatii kuitenkin sen käytön edistämistä sekä tutkijoiden ja päättäjien yhteistyötä, jotta kaupungeille voidaan tarjota työkaluja resurssitehokkuuden ja kestävyyden lisäämiseen. Vaikka kaupunkien aineenvaihduntaan keskittyvä tutkimus ei ole vielä kovin käytetty lähestymistapa kaupunkien kestävyyden tutkimuksessa, se näyttää olevan tehokas lähestymistapa energia- ja materiaalivirtoihin liittyvien haasteiden tunnistamisessa. Sen vuoksi se voisi onnistua resurssien käytön vähentämisessä nykyistä kaupunkipolitiikkaa paremmin.

AVAINSANAT: kaupunkien aineenvaihdunnan arviointi, kaupungin ekosysteemi, satelliittidata, kaukokartoitus, Maan havainnointi, kestävä kaupunki, kestävä kehitys

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Abbreviations

CE	Circular economy
EO	Earth observation
EC	European Commission
ESA	European Space Agency
EU	European Union
GHG	Greenhouse gas
GIS	Geographical Information System
ICT	Information and Communication Technology
IE	Industrial Ecology
IoT	Internet of Things
MEP	Member of the European Parliament
MFA	Material Flow Analysis
NASA	National Aeronautics and Space Administration (USA)
RS	Remote sensing
UM	Urban metabolism
UN	United Nations

1 Introduction

Cities are central places of human activities (living, working, and social) and home for the majority of the world's population (Albertí et al. 2017: 1052; Wang et al. 2020: 1). Currently 55% of the world's population is living in urban areas (UN 2018) and 75% of EU-citizens live in urban areas (European Commission 2020a). The urbanisation rate is estimated to rise to 68 % globally (UN 2018) and in Europe to 83.7 % by 2050 (European Commission 2020a).

Nowadays, rapid socio-economic transition is making cities' management difficult, and consequently cities are facing major issues (Zhang 2013: 463; Mostafavi, Farzinmoghadam & Hoque 2014: 702; Seto et al. 2017: 8936). The growing urban population causes a simultaneously use of resources (Albertí et al. 2017: 1052; Moore, Kissinger & Rees 2013:51) and in the demand for materials (e.g., construction materials, floor space, goods, etc.) by citizens per capita, which expands the needed size of stock (Brunner 2007: 12). The current idiosyncrasies of urban culture are high population density, high stock size, high exchange of materials and information, dependency of energy and material sources transferred from hinterlands (Baccini & Brunner 2012: 2). As a city's population increases, it creates a need for more space and the size of city boundaries grow (Kennedy, Cuddily & Engel-Yan 2007: 44; Tan et al. 2019: 2). Urban expansion is linked to sustainability challenges globally (Maranghi et al. 2020: 1).

Urban growth has provided a higher quality of life for a wider range of people, but the urban lifestyle, which includes fast-moving consumer goods and rapid disposal, has been achieved at a cost to nature with the growing use of energy, growing consumption and greater waste generation (Tan et al. 2019: 1–2). The urban development (and planning) trends are currently leading to high consumption, especially of the non-renewable resources (energy), and cause large amounts of waste, emissions, and lead to negative impacts such as the urban heat island effect (Kaur & Garg 2019: 147). Furthermore, cities consumption changes' over time (Westin et al. 2018: 527).

The need for new urban infrastructure for urban citizens will require natural resources and will increase environmental pressure (Athanassiadis, Crawford & Bouillard 2015: 547–548). For example, the usage of fossil fuels has led to an industrialisation that helped to develop new technologies to mobilise people, material and information in urban areas (Mohan, Amulya & Modestra 2020: 1). These current challenges have brought a need for us to 'achieve a more ecological and sustainable society' for which we need an understanding of the complex urban systems processes in a multi-functionary and multidisciplinary way (Palme & Salvati 2019: 2).

We need to understand cities as dynamic and adaptive socio-ecological systems (Bortolotti 2020). Cities are shaped by various social, economic and environmental activities, and are usually conceptualised and modelled as complex, unorganised and sprawling systems. (Movia 2017: 1–2). Urban activities have become a threat to the global environment, and that is why environmentally efficient and sustainable development is needed (Pauleit & Duhme 2000: 1).

Innovative methods for quantifying the material flows entering and leaving the city are needed (Niza, Rosado & Ferrão 2009: 391). Therefore, the present research focuses on finding a new approach for urban metabolism assessment by which to help cities to adapt to current challenges, with the utilisation of satellite data in urban metabolism assessment. Urban decision makers are the key to considering the dependence, exhaustion and exploitation of their cities' resources (Kennedy, Cuddihy & Engel-Yan 2007: 43) and to tackling global climate change (Kennedy et al. 2010: 4828). As the issues of cities are to be solved in each place of origin, urban policies play a key role. In this work, the current urban policies that lead to sustainable urban development are also analysed.

2 Research setting

This chapter presents the research objectives, theoretical framework and materials and methods of this research. This chapter sets the foundation and objectives for this research.

2.1 Research objectives

At the centre of this research is the development of a new urban metabolism (UM) assessment approach that includes the use of satellite data. New and innovative approaches are needed in order to achieve sustainable urban areas, to use energy and resources in a less burdensome way and to create the 'big picture' of urban ecosystems' metabolism. Urban policies are promoting sustainable and efficient use of energy and resources and the cities are key in implementing these policies. That is why this approach is designed to be included in these policies in the future. This work discusses the role of urban policies promoting a new approach to urban metabolism assessment.

This research starts from understanding the urban metabolism assessment theme in a more detailed way and then scrutinizes, via a literature review, how urban metabolism assessment has been used in urban research as a tool supporting development towards sustainable urban areas. Additionally, this work will try to search if and how satellite data could be used in sustainable urban research and development more widely, especially in the context of urban metabolism assessment.

This research aims to answer to the following questions:

1. How has urban metabolism assessment developed and what methods are used?
2. How has urban metabolism assessment been utilised to promote sustainable urban development?
3. How could satellite data improve urban metabolism assessment?
4. How should urban policy promote a new approach to urban metabolism assessment, based on a more efficient use of satellite data?

2.2 Theoretical framework

2.2.1 Urban metabolism and urban ecosystem

Cities are at the heart of economic growth (Tan et al. 2019: 1) and use resources to maintain life in urban areas (Pinho et al. 2010: 143). Cities and their activities connect the urban and natural systems (Mohan, Amulya & Modestra 2020: 3). Cities can be seen as a giant organism, as they consume resources from their surroundings, and such a perspective facilitates an understanding of urban activities and function (Kennedy, Pincetl & Bunje 2011: 1966; Zhang 2013: 463; Elvidge et al. 2011; Pinho et al. 2010: 153; Wang et al. 2020: 1).

The most cited description of urban metabolism is the Kennedy's 'sum of total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste' (Kennedy, Cuddihy & Engel-Yan 2007: 44). In the literature there are various definitions for urban metabolism assessment, since it is seen variously as a tool, as a data collection exercise, as systemic thinking, and as a holistic system (Krabbe 2020; Kennedy & Hoornweg 2012: 780; Pinho et al. 2010: 153; Voskamp et al. 2020: 1).

Urban metabolism (UM) considers a city as a system where flows of energy and material connect with the surrounding environment (González et al. 2013: 109–110; Conke & Ferreira 2015: 146–147; Movia 2017: 2–3). In other words, the field of study requires an understanding of the material, the non-material, the energy and the waste flows across multiple sectors within a city (Beloin-Saint-Pierre et al. 2017: 224; He 2020: 1–2; Huang & Hsu 2003: 61–63; Kennedy & Hoornweg 2012: 780; Pincetl, Bunje & Holmes 2012: 194). Consumption of resources (e.g., raw materials, fuel, water) generates metabolites (e.g., waste, pollutants) (Zhang 2013: 464). Generally, the largest flows of cities include fossil fuels and construction material (Kalmykova, Rosado & Patrício 2015: 73). (See Figure 1).

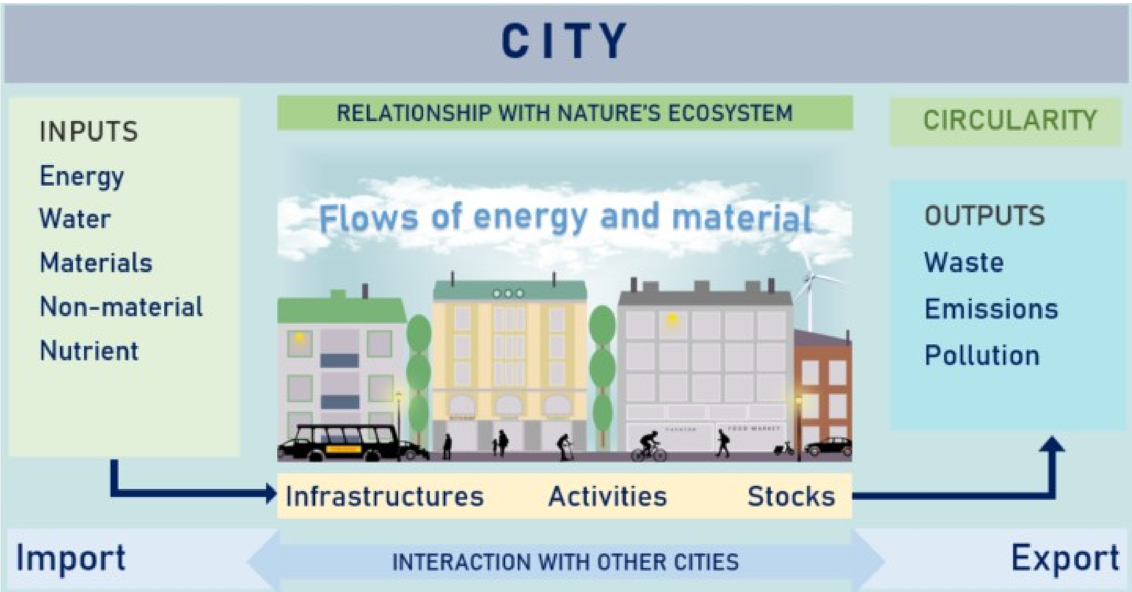

Figure 1. Visualisation of the urban metabolism.

UM is currently a leading method for quantifying energy consumption and material usage in urban environments (Pincetl, Bunje & Holmes 2012: 192). In urban metabolism, the focus is on describing the material and energy flows entering the city, their circulation in the city, and the output flows (different products, wastes and emissions) (Krabbe 2020). Urban metabolism examines the inputs, outputs and storage (income), and pollutants and waste output (outcome) of energy, water, nutrients, materials and their transformation in a city (González et al. 2013: 109–110).

Urban flows are generated or influenced by different activities: economic, political, domestic (e.g., sleeping, eating, care), social, and others. Flows consists of a certain quantity leaving from or arriving at a stock in a certain time. Flows can exist in different forms (e.g., solid, liquid) and can be stored temporarily (by the system or by individuals). (Dijst et al. 2018: 193.) Urban flows vary due to age, stage of development (e.g., available technologies), climate, and cultural factors (Kennedy, Cuddihy & Engel-Yan 2007: 45; Rosado, Kalmykova, Patrício 2016). The stocks include a certain amount of natural or man-made endowment at a certain time. Stock size can vary and can be generated within an urban area, and it can change fast (e.g., information) or slowly (e.g., building stock). Complexity increases when the used flows and stocks are less measurable (Dijst et al. 2018: 200).

Urban metabolism enables quick snapshots of cities and eases the continuous monitoring of urban activities (Kennedy & Hoornweg 2012: 782) by tracking the supply and use of resources in cities (Tan et al. 2019: 2). Tracking can be done in quantitative and qualitative ways (Song et al. 2018: 5). The city's metabolism is dependent on its site-specific history, geography, demography, economy, and climate (Pincetl, Bunie & Holmes 2012: 200).

Davis et al. (2016) sees cities as *urban ecosystems*, more complex than one single organism, an ecosystem that includes multiple organisms (Davis, Polit & Lamour 2016: 310; Pincetl, Bunje & Holmes 2012: 200). These urban ecosystems are kind of mimicking the 'ecosystem metabolism' of nature, via urban flows (Chen & Chen 2012: 4503). Urban ecosystems include landforms that are natural or man-made, connected with each other via urban actions, with separate metabolism processes (Liu et al. 2017: 169). Urban ecosystems are shaped by human-led mechanisms (e.g., urban space, societal priorities, management, urban practices) that have an influence on the urban landscape (Voskamp et al. 2020: 2). The system approach in a city's metabolism assessment requires a multidisciplinary approach, due to the urban resource flows that are driven by policy frameworks and to the human social organisation that guides urban metabolic processes (Pincetl, Bunje & Holmes 2012: 194).

2.2.2 Satellite data and Earth observation

This research will search if and how satellite data could play a role in urban metabolism assessment. One way to approach urban data analysis is with the help of satellite data. Satellite data, and especially Earth observation, provide valuable information about Earth's physical, chemical and biological systems. Satellites monitor and assess the status and changes of nature and of man-made environments (i.e., the urban environment) (Prakash, Ramage & Goodman 2020: 4).

The use of satellite-based observation systems, i.e., Earth Observation (EO), has increased over recent years (Voigt et al. 2016). Earth observation is very important when trying to understand the impacts of human behaviour on the environment, and also facilitates an understanding of the environmental issues and of how to shape more effective policies. The data received from EO instruments support not only scientists and statisticians, but also urban planners and policy-makers (Prakash, Ramage & Goodman 2020: 9).

The usage of satellite data is rising and it has become a major actor in the use of technology, data and services (i.e., mobile phones, navigation, economy, information) (European Commission 2020b). The European satellite programme, called Copernicus, provides real-time satellite images. The data from the satellites will help, e.g., with climate-change forecasting, agricultural management and applications. The European Space Agency (ESA) also has ‘Earth Explorers’ that are separate from Sentinel missions, and those monitor biomass, for example (Ustin & Middleton 2021: 27). The first European satellite, called Sentinel-1A, was launched in 2014, and made it possible to monitor land, water and the atmosphere in the long term (Declan Butler 2014). There are a total of six themes in the Copernicus programme: atmosphere, marine, land, climate change, security, and emergency (Copernicus 2020a). The second generation of Copernicus focuses additionally on *societal issues* (e.g., climate change and urbanisation), so the current capacity is expanded to meet new needs, e.g., to monitor CO2 emissions (Ustin & Middleton 2021: 26).

The American cousin of the European Copernicus programmes is called Landsat, which has been running missions since the 1970s. Landsat is jointly managed by NASA and by the U.S. Geological Survey. The first satellite, Landsat-1, was launched in 1972. There are a total of 8 different satellites, and the newest, the 9th, is to be launched in 2021. (USGS 2021.) For example, Landsat 8 data represents the new generation of Earth Observation satellites that enables different environmental applications to support sustainable city planning. Landsat imagery is free to use for all. Images provided by the Landsat mission help to map and monitor Earth resources. (Sertertekin, Abdikan & Marangoz 2018.)

Nowadays, private companies (e.g. SpaceX, Google, and Apple) also play an increasingly important role in the space sector. The concept of *new space* is related to the commercialisation of space. The most divisive thing between private organisations and public actors is the public organisations' independence in regard to funding and space policies. Private companies use already existing data with their algorithms, all of which is mainly free. Nowadays it is also possible for them to produce their own small satellites with reasonably low cost. (Abi-Fadel & Peeters 2019: 201.) Less expensive remote sensing technology also helps with data deficiency (Dijist et al. 2018). Commercial satellites usually provide high resolution data (< 5 m) and high temporal frequency. Commercial satellites are not commonly free or open, but older data can be found from public access websites. (Ustin & Middleton 2021: 50.)

In Finland, we have satellite-focused organisations such as the start-up ICEYE, which produces microsatellites and satellite data (founded in 2014). This company focuses on issues of using the Earth Observation data. (ICEYE 2020.) The Finnish Meteorological Institute (FMI) is managing the Arctic Space Centre and National Satellite Data Centre (NSDC) that focus on remote sensing and collecting data from polar orbiting systems. The data is open for national and international partners and customers. They also host the Copernicus Sentinel Collaborative Ground Station for the EU's Sentinel satellite data. (The Finnish Meteorological Institute, 2020.) In addition, the University of Vaasa, will have its own small satellite, 'KvarkenSat', as a part of the EU Interreg Botnia-Atlantica project called Kvarken Space Economy (University of Vaasa 2019).

In this field of work, the term 'satellite data' is used to mean the information that is gathered via remote-sensing technology, i.e. Earth observation data. The remote sensing is collecting information from a distance via sensors, e.g., satellites, and providing information about the Earth systems. Remote sensing means 'obtaining the physical properties of an area without being there' on Earth's surface, e.g., with satellite images. (NASA 2020.) Prakash et al. (2020) summarise the benefits of EO well: 'The greatest value of proposition of EO data is its continuous spatial-temporal coverage at a fraction of the cost of traditional methods, while ensuring objectiveness, comparability as well as sustainability of services'.

Remote-sensing technology, for example, helps with determinate Land Use and Land Cover (LULC) via satellite images (Sekertekin, Abdikan & Marangoz 2018: 380). This also helps cities at the local level, when they are able to get high-resolution data at low cost (Prakash, Ramage & Goodman 2020: 4). For example, the Copernicus Land Monitoring Service, called The European Urban Atlas provides, land use maps from urban zones (more than 100,000 inhabitants) and their surroundings (more than 50,000 inhabitants) (European Environment Agency 2021). These have been used in the estimation process of urban areas in Greece, for example (Prastacos, Lagarias & Chrysoulakis 2017).

Satellite data analysis has been used for, *inter alia*, classification of trees, water, or urban areas, by using remote-sensing software (GIS Geography 2020). By using remote sensing, different objects or features can be visualised, captured and analysed via collecting imagery, with the aim of building up land cover to produce land use. Land cover and use information is done via image classification, which makes it a basic source of information in environmental analysis (e.g., carbon modelling, crop yield estimation) (Topaloğlu, Sertel & Musaoğlu 2016 : 1055). There are plenty of different applications to be used for remote sensing (e.g., weather forecasting, and GPS). Remote sensing can be seen as a tool to be used to support the tackling of issues, e.g., those related to climate change. (GIS Geography 2020.) For urban researchers and planners, satellite data provides more insights into urban areas by which to support sustainable urban development, for example, regarding changes in land use and land cover (Boag 2020).

The newest satellite missions provide better information to support urban observation and monitoring (Sekertekin, Abdikan & Marangoz 2018: 380). The Earth Observation sensors have raised the quality (resolution) of satellite images (Taubenböck et al. 2011: 162). The new satellite technologies facilitate an understanding of ecological processes and changes. There is huge potential for increasing understanding and closing the current data gaps in urban metabolism assessment, and in general sustainable urban development with the next-generation satellite technologies. In the upcoming decade we will see different types of data observations available from satellites, which will help in Earth analysis. (Ustin & Middleton 2021: 50.) Reasons such as these are why it is important to look for new approaches to urban metabolism assessment and to put all of this potential into practice.

2.3 Methods and materials

2.3.1 Literature review

The literature review began with a search of what is urban metabolism and how is it defined. After that, the search was focused on the development of urban metabolism assessment via case studies and different assessment methods. The search also focused on what kind of data was used in the urban metabolism assessment, and especially, on what kind of energy and material assessment models were used. As the current study presents a new approach to urban metabolism assessment, it was important to search the information on the usability of satellite data in urban research, and especially in the urban metabolism assessment. The answers were searched from the development of the new space industry and remote-sensing technology. More specifically, valuable information was found from previous studies that combined satellite data and urban metabolism with other research on satellite data and sustainable urban development. The literature review provided an opportunity to gather extensive information and to build a new approach to research that combines urban metabolism and satellite data.

The literature review aims to develop existing theory and build on a new approach. The literature review method also enables the assessment of theory. Using literature review helps to create an overall view of a certain subject area. Literature review also helps to describe the history of the research theory and to identify the problems with it. (Salminen 2011: 3–4.) To develop and clarify the research idea, it is necessary to know what has been written by other researchers (i.e., finding the relation to other researchers' work). The purpose of the literature review is described to critically analyse, summarise, explore and compare previously done research. It also helps with recognition of the trends of the research topic. The literature review should be used to find key concepts, conclusions, theories and arguments about the research topic. Research questions guide and define the literature review process. (Eriksson & Kovalainen 2016: 45–48.)

During the literature review, a wide amount of different research articles focusing on the research questions were analysed. The literature review helped provide an understanding of the urban metabolism 'phenomena', methods used, and applications. It was also used for understanding the history, development and future of urban metabolism assessment. From going through the literature, it has been noted that urban metabolism assessment itself is not the only way, but rather one of the possible perspectives by which to look at cities from a sustainability perspective. That is why information was also gathered about how urban metabolism could encourage sustainable urban development via previous studies. A simple and yet comprehensive way to present all the information was key when starting the process. As the satellite data has not yet been generally used in urban metabolism studies and is still quite underused in urban studies in general, it was interesting to learn about its possibilities and usability.

According to Salminen (2011), literature review types are divided into three basic categories: descriptive, systematic and meta-analysis. In this work, the descriptive literature review was used. Descriptive (or sometimes called traditional) is one of the most used types; it is more of an overview, without strict and accurate rules. With descriptive type, the used literature is wide, thereby enabling a broad description of the research phenomena and categorisation of its characteristics. The process also results in research questions, which usually are quite broad. Descriptive literature review has two orientations: narrative and integrative. The lightest (on the methodological level) is the narrative literature review, which provides an overall view of the topic or a description of its history and development. The integrative approach is closer to a systematic literature review, and is used when the objective to study the phenomena as widely as possible. Integrative orientation helps with critical assessment and synthetisation. (Salminen 2011: 6–8.)

2.3.2 Focus group discussion

When an overall view of the topic had been achieved with the help of the literature view, it was time to organise a focus group discussion. All of the information used is also presented in the literature analysis of this work. At the centre of the organised focus group discussion was the role of satellite data and satellite technologies, and their usability in urban metabolism and urban sustainability research. The information gathered from the literature was combined with the focus group discussion data to make future recommendations for research and policies. The role of the discussion was to support the findings made from the literature. The organised future talk (focus group) discussion gave research- and policy-wise important input on the future of urban sustainability and satellite-data. This was an opportunity to learn and hear the thoughts of a multi-disciplinary panellist group and from the audience participating in the virtual event.

This qualitative research method, the focus group discussion, helped create a new approach to urban metabolism assessment. The focus group discussion is most of all a *social experience* that increases the validity and meaningfulness of findings, as the group can provide a deeper understand of our own views and test our knowledge. Participants usually have similar backgrounds or a specific topic of interest. Usually, the participants check and, if needed, correct each other's comments. The focus group discussion is not for problem-solving nor decision-making; *it is an interview*. Its main difference with one-on-one interviews is that participants can listen to each others' answers, and make additional comments to their own answers. (Patton 2015: 475, 478.)

Focus group discussion refers to people who are 'focused' in their discussion about the selected topic or an issue (Eriksson & Kovalainen 2016: 181). Empirical data is usually collected from people, experts, and from managers' viewpoints and spontaneous interaction in informal settings. The discussion facilitates understanding of why the issue is central and what is salient about it. (Eriksson & Kovalainen 2016: 182–183.) In the focus group discussion, the interviewer is usually referred to as a moderator, since the role is to moderate and guide discussion (Patton 2015: 475).

A group interview is usually used to get diverse perspectives or for creation of consensus. The participants do not have to agree with each other nor reach the consensus. The focus group discussion should be comfortable and sometimes even enjoyable for participation and for sharing of ideas and perceptions. Focus group interviews are done with a small group of people, usually 6 to 10. The interview usually lasts one to two hours, but the use of time should be focused. The moderator's role is to keep participants focused, answers on topic and make sure that one or two participants are not dominating the discussion. The aim is to get a variety of different perspectives and meaningful discussion of the chosen topic by the researcher. For analysis, it helps when, for example, another facilitator takes notes or if the discussion is recorded and transcribed. (Patton 2015: 475–478.)

The future talk event planning started from planning the agenda and structure, so that it fit into the research needs. The next step was to contact different organisations that have experience in urban metabolism assessment, sustainable urban development, and with the utilisation of satellite data in societal development. The five panellists represented the following organisations: the European Commission (Directorate-General for

Research and Innovation – Innovating Cities), the European Parliament, the Ministry of Finance (Finland, Department for Local Government and Regional Administration), the Metabolism of Cities (global network), and the Finnish Institute of Meteorology. These experts were found with the help of colleagues and personal networks. Experts were contacted via email invitation with a request to participate in the panel discussion. All confirmed panellists were interested in discussing the topic and received a question frame beforehand in order to prepare for the discussion.

The event included a welcome speech from the University of Vaasa and then two introductions to the themes of the day, presented by the researcher. I shortly presented for the audience and panellists a new approach to urban metabolism assessment via introducing how satellite data should be used in urban sustainability development, especially in urban metabolism assessment. Then it was time for the facilitated future talk with experts (a 75 minutes talk). Firstly there was one targeted question for each panellist, and simultaneously they were also provided with the opportunity to introduce themselves shortly. After the first round of opening questions, there was a time for three arguments (in which panellists agreed or disagreed) on topics related to the webinars' theme. Each of the panellists was provided with the opportunity to explain why they agree or disagree with the argument.

The webinar ended with open questions for all and was very successful into creating open discussion, in which the role of the moderator was less active, and charge was given consciously for panellists. The aim of the discussion was that the panellists would speak to each other, not to the moderator. The moderator's role was mostly to control that every participant would have equal opportunity to participate in the discussion and to keep the discussion on topic. The discussion got a little side-tracked but provided information that was not familiar beforehand but valuable for the work. Time was also reserved for questions from the audience. The event ended with a summary of the talk, with implications for future research and policy.

Questions for the interview (future talk) were formatted based on the literature and written materials, as modified to fit into the expertise of the panellists. The questions aimed to evoke responses for the set goals of this research, and targeted asking panellists about the usability of satellite-data and Earth Observation in urban metabolism assessment and sustainable urban development. Discussion also included the role of urban- and sustainability-related policies that guide the sustainable urban development. Then there was discussion as to whether there are limitations for the transition of cities towards sustainability. Panellists were also asked about cooperation between different stakeholders and institutions in urban sustainability and the urban metabolism theme.

This future talk concept, was created during the research process. The method was chosen because the interaction between experts from different backgrounds was seen to be interesting and beneficial for this work, providing new information and different perspectives. It combined focus group discussion and current situations where most of the events were turned into online. The future talk concept aims to look into the future, to gather experts from the desired research theme and to provide information on the topic as set for the meeting. This concept was found useful, to invite experts from different fields and a wide-open audience for discussion. It received positive feedback and provided an opportunity for experts to gain more knowledge of presented and discussed themes. At the very least, this opened the path for future cooperation with participants and their organisations.

2.3.3 Materials

Key articles were searched via Scopus and Finna (Tritonia library, University of Vaasa) platforms. To help find key articles, different search commands were used, along with sorting (e.g., most cited and read). To help the search process the Web of Science platform was also used. Searches were placed by using key words, concepts and combinations (e.g., urban metabolism AND urban sustainability, ‘urban metabolism’). Articles were listed in an Excel spreadsheet by name, publication year, method, main input, definition of UM, usage of data, and usage of spatial tools. The same method was then used to discover material about satellite data, by searching ‘satellite-based data AND urban metabolism’, ‘remote-sensing AND urban metabolism’, and ‘satellite data AND urban’. Also, supportive documents and short articles were searched from the webpages of central organisations, such as the European Commission, OECD, ESA, NASA, and GIS Geography. The main ‘operative tool’ was an OneNote sheet to support a systematic reading process and include all notes made.

Secondly, this research material includes the focus group discussion transcription as research material. Only the panel discussion was transcribed and the introduction was left out, so the recording length was 1 hour 15 minutes. The webinar served the role of focus group discussion and was titled ‘Future talk: Urban sustainability and satellite-based observations’. The event was open to the public and it was marketed via social media channels (Twitter, LinkedIn and Facebook) with the help of colleagues from the University of Vaasa. The participants list was collected via a Webropol form. We received 59 registrations for the event (including panellists). All were contacted via email with a link for participating in the Zoom event (including panellists). The event was organised on the third of December 2020 in Zoom and it was held in English. It was recorded to support research analysis. Ultimately, we had 42 participants attending the event.

The focus group interview was recorded and transcribed. The interview group and participants’ basic information (name, time, place, moderator, participants, and other relevant information to the research) was documented. The level of transcription is dependent on the research questions. If the discussion is needed for the collection of opinions and views, word-level transcription is sufficient. In this work, the results are presented via direct quotes. A challenge in the focus group discussion analysis is usually that the discussion is rambling and builds in the setting of participants and their views. The materials received from the focus group were analysed as a whole, and not focused on the individual level. This research method can be used as an independent research method or combined with other research methods (Eriksson & Kovalainen 2016: 182).

The event followed the General Data Protection Regulation (GDPR) principles accordingly and the privacy of the attendees was respected, since personal data (name, email, organisation, interest on topic, and comments) were collected via registration and since the event was recorded. The GDPR law ensures that personal data is collected, stored and managed properly in the EU (European Union 2021). The GDPR requirements apply for European and non-European organisations that handle personal data of EU citizens (European Union 2021). All participants registered via a Webropol form and accepted the terms. When using the collected data, only anonymous statistical data and recording were used. From the recording material, the names of the experts were removed, and their titles and organisation information were kept for data analysis.

3 Literature analysis

This chapter focuses on the analysis of literature that has been used as material in this work. Firstly this chapter focuses on the connection between urban metabolism and urban sustainability. This work then continues explaining how urban metabolism assessment has developed and what kind of research methods have been used. Then the focus is on data used in urban metabolism assessment and the role of satellite data. The final sub-chapter focuses on urban policies that are linked to sustainability, urban metabolism assessment, and satellite data. This chapter focuses on answering the set research questions.

3.1 Urban metabolism's connection to urban sustainability

With this chapter, the focus is on the first research question that focuses on the connection between urban metabolism and sustainable urban development. When cities grow urban planners aim to provide efficient city infrastructure management whilst minimising the impact on the surrounding environment. The urban growth might raise negative consequences such as flood risk or urban heat island effect (i.e., phenomena that result in a city and its surrounding be significantly warmer than the countryside due to urban activities). (Boag 2020.)

In response, cities aim to improve their ecological environments into, for example, an eco-city or a low carbon city. (Zhang 2013: 464). But, 'greening of the cities' must be more than building urban spaces in an environmentally (visually) pleasant way; cities should focus on being ecologically viable (Huang & Hsu 2003: 62). The current sustainability assessment focus needs to shift from energy consumption and waste management strategies to focus on the whole ecosystem. (Kalmykova, Rosado & Partícío 2015: 79–80.) Urban metabolism assessment will help with the ecosystem monitoring in order to create sustainable development.

Most of today's environmental issues are related to sustainability (Liu et al. 2017: 168–169). We are overusing our natural resources, approximately 1.75 times faster than our planet can re-generate, and this has effects on our nature and on our daily lives (e.g., loss of natural capital, climate change) (Global Footprint Network 2019; Mohan, Amulya & Modestra 2020: 2–3). A lion's share of the world's resources is used directly or indirectly in cities, so cities can be seen as nodes of consumption (Moore, Kissinger & Rees 2013: 51). Cities have been described as 'hotspots of resource consumption that mobilise material and energy flows from around the world in order to match its inhabitants' needs' (Athanassiadis, Crawford & Bouillard 2015: 547). Urban areas are responsible for three-quarters of the global consumption and approximately 70 % of global carbon emissions (Mohan, Amulya & Modestra 2020: 2).

It is important to understand the drivers of the energy and material flows in order to address global environmental challenges (Kennedy et al. 2015: 5985). Urban metabolism assessment is used as the basis for sustainable urban design, as its main goal is to define and evaluate the urban systems sustainability (Beloin-Saint-Pierre et al. 2017: 223) via analysing the energy use and processes of urban areas (Chrysoulakis et al. 2013: 100–101). Urban metabolism assessment mostly tracks energy and material flows aiming to reduce environmental impacts in specific areas and to improve urban sustainability (Song et al. 2018: 5).

For example Dijist et al. (2018) highlight how the urban metabolism approach could provide solutions to sustainability-related issues (e.g., the energy supply system, climate change). The goal in urban metabolism studies should be to provide multiple solutions to sustainability-related issues, with social perspectives widely included, such as Newman's 'liveability measures', which were already presented in 1999 (Sahely, Dudding & Kennedy 2003: 472).

The metabolism approach looks at urban sustainability from the ecosystem, or, if preferred, from the organism, perspective where the transformation of natural resources in goods, services and waste happens to maintain living (Conke & Ferreira 2015: 146–147). To maintain a city's operation and development, cities are formed by different energy and material flows that require continuous inputs (e.g., for creating products), which in turn form outputs (emissions and waste) (He 2020: 1–2). These flows are shaped via environmental, social and economic activities (Movia 2017: 2–3), and are essential for the sustainable function of cities concerning resource availability and environmental protection (Brunner 2007: 12).

There are millions of small sources of emissions that are harder to treat, especially in megacities (Brunner 2007: 12). The emissions of service- and consumer-oriented cities are less visible but UM is not efficient from a production point of view, since UM focuses more on the consuming of the products or functions inside and outside urban areas. (Beloin-Saint-Pierre et al. 2017: 233.) As a result, UM assessment provides valuable information about the environmental quality of urban areas (e.g., indications of urban patterns regarding the environment and resources) (González et al. 2013: 109). It could be said that metabolism aims to support people's quality of living in the city (Wei et al. 2015: 63).

To achieve sustainability goals, cities need to focus on their own resource productivity. Being more like a natural ecosystem can be a goal in the development of sustainable cities (Kennedy, Pincetl & Bunje 2011: 1965). UM assessment focuses on the cities' contribution towards sustainable development (production methods, consumption patterns, efficiency, recycling, disposal amounts, level of well-being, and opportunities created) and the infrastructure characteristics of an urban system (Kennedy, Cuddihy & Engel-Yan 2007: 44; Kennedy & Hoornweg 2012: 780–781). Cities' infrastructure (e.g., roads, building types, layouts) can provide information on the environmental quality of urban areas (Beloin-Saint-Pierre et al. 2017: 224). As a result, UM assessment can be used as a tool to identify environmental issues and economic costs related to resource use (input) and for the management of outputs (Niza, Rosado & Ferrão 2009: 387). In addition, UM assessment helps to set long-term visions to decrease consumption (Tan et al. Mayfield 2019: 11).

Self-sufficient – does it make cities more sustainable?

Finding a self-sufficient city is still difficult (Conke & Ferreira 2015: 151). To sustain its metabolism, cities *usually* must import resources beyond their boundaries (Zhang 2013: 464) as they are not capable of producing everything they need (Niza, Rosado & Ferrão 2009: 387). Urban areas are dependent on the resource flows imported (inter-city or international imports or exports) from external environments, hinterlands, directly or indirectly – which makes all cities a marketplace (Tan et al. 2019: 11; Conke & Ferreira 2015: 151; Niza, Rosado & Ferrão 2009: 387). Cities are mostly dependent on global markets (Kennedy, Cuddihy & Engel-Yan 2007: 44). Some cities might not even have enough space for waste disposal, so they need land beyond administrative borders (Conke & Ferreira 2015: 151; Niza, Rosado & Ferrão 2009: 387).

Barles (2009) referred the consuming patterns of cities as a mosaic, as materials come from various parts of the world. This dependence of inputs from other regions increases carbon emissions and a high concentration of the energy footprint in urban areas (Tan et al. 2019: 10–11). Natural ecosystems are saving the mass resources through recycling, and are self-sufficient and subsidised by sustainable inputs. This should be the goal for sustainable city development in the long term. Sustainable development focuses on using energy on the biosphere's capacity, and not exceeding the hinterlands' capacity with disposal of waste, and not increasing the throughput of materials. (Kennedy, Cuddihy & Engel-Yan 2007: 44.)

Wachsmuth (2012) has mentioned that 'problems *of the city* are not necessarily problems *in the city'.* Environmental impacts are less visible when the natural space is used by other regions. (Conke & Ferreira 2015: 151.) Usually, the direct environmental impacts of cities can be seen, for example, from the industry located in the city (unless the good is imported) during the use (Westin et al. 2018: 530). Indirect actions, such as cities being a gateway of goods for the country or other countries, (disaggregating the goods consumed elsewhere or being endogenous), or commuters, can have an effect on material flow estimation (Niza, Rosado & Ferrão 2009: 388).

A total identification of the complex relationships with the origins and destinations of resources, produced goods and waste, is not possible (Conke & Ferreira 2015: 147–151). Nevertheless, UM helps to assess the exchanges 'between cities and the rest of the world' (Geldermans et al. 2017: 32). That brings us to an issue: the quantification of the material flows in a city is limited, since the flows appear in areas with no 'real' borders (Niza, Rosado & Ferrão 2009: 388), so the UM assessment does not provide precise information inside the city's boundaries (Beloin-Saint-Pierre at al. 2017: 233). The complete description of UM is difficult (if not impossible) due to complexity and geographic dispersion (Conke & Ferreira 2015: 151). These issues must be considered and correctly identified, for if not, it may result in overestimation of consumption (Niza, Rosado & Ferrão 2009: 388).

Usually for the UM process, the definition of the city's (urban system) borders is needed (Wang et al. 2020: 2). The spatial scope of the UM studies is usually limited to the city's name and time (i.e. when the activities are considered) but it can also be regional (metropolitan, state, country) or global level (Beloin-Saint-Pierre at al. 2017: 230). Usually in urban metabolism assessment, the boundaries can be described by the level of the urban area (city) or with the combination of city boundaries in an urbanised region (Kennedy & Hoornweg 2012: 780). Administrative borders are the most used (Wang et al. 2020: 2), but the regional perspective should be included: the urban, suburban and rural systems (Wei et al. 2015: 69).

There are different definitions for urban areas with political, demographic or economic reasons, so the same cities or urban areas can have different boundaries with different scopes. There has been some suggestion to use alternative definitions, such as functional areas, density (population or buildings) or built-up areas, to urbanised areas (Taubenböck et al. 2011: 171). A proper definition of the borders is still the starting point for the UM analysis and for the understanding of the issues. (Geldermans et al. 2017: 9.) The known challenge is that using the broadest scope and detailed approach is difficult in the assessment (Beloin-Saint-Pierre et al. 2017: 228).

When discussing urban sustainability, it should be noted that urban metabolism is related to other similar concepts (e.g., circular economy, smart city) that focus on urban areas and sustainability. These concepts of circular economy and smart city are discussed in this work, due to the importance of understanding the overlapping of urban sustainability-related concepts as they operate in the same area of interest, when targeting the urban sustainability with urban development processes and policies. In addition, this overlapping of concepts has led to complexity in urban development in practice. In this work, the aim is to link these concepts to urban metabolism assessment, and by so doing, clear the complexity.

Circular economy

Urban metabolism also focuses on the sources of resources and their circulation in urban ecosystems (Zhang 2013: 464). Urban ecosystems can be linked to circular economies (Beloin-Saint-Pierre et al. 2017: 227). Urban economies are generally unsustainable by being open and linear, due to high rates of flows of energy and materials and waste production, all of which is opposite to nature's circular metabolism (i.e., where waste becomes a resource and is used in continuous cycles) (Chrysoulakis et al. 2013: 101; Davis, Polit & Lamour 2016: 310; Movia 2017: 2–3).

Circular economy (CE) aims to extend the lifespan of products and materials via reuse, repurposing and recycling, by reducing waste generation and by improving the use of secondary raw materials in production (Bortolotti 2020: 10). CE enables the resource and energy flows to be ‘closed’ systems (the opposite of linear economy), helping to tackle environmental challenges (Mohan, Amulya & Modestra 2020: 10). CE aims to resource minimisation and adaptation of cleaner technologies and create growth without pressure on the environment (Santonen et al. 2017: 1–2). CE helps to create optimal flows of production, consumption and use on the temporal and spatial scale to provide favourable conditions (highest economic, ecologic and social value) (Geldermans et al. 2017: 7). CE includes a new kind of business model that uses reducing, reusing and recycling (the 3Rs) (Mohan, Amulya & Modestra 2020: 4).

In a sustainable city, most material and energy flows circulate in a closed circuit, being still usable, i.e., either renewable or recyclable. In addition, a sustainable city has few harmful emissions to the environment; it is waste-free, emission-free and living within the limits of the Earth’s carrying capacity. (Krabbe 2020.) When the linkage between the flows and circularity is found, it helps in assessment of cities’ dynamics, related to mass and energy conservation, scarcity, and carrying capacity (Geldermans et al. 2017: 33).

Unsustainable and unstable metabolic processes impact the local and regional environment, and can cause exhaustion of resources and losses of many potential resources (Conke & Ferreira 2015: 146; Davis et al. 2016: 310–311). It is important to circulate and reuse materials (Mohan, Amulya & Moderstra 2020: 4). As cities start to utilise circular methods, it will help them to reduce their ecological footprint and negative impact on nature (Huang & Hsu 2003: 69). We need to change from the ‘cradle-to-grave’ pattern to one that is ‘cradle-to-cradle’ (Wei et al. 2015: 69). Recycling and reusing (not limited to technical materials) can help cities to decouple with economic growth from escalating resource use (Mohan, Amulya & Modestra 2020: 4).

Smart city

The concept of a smart city was first presented in 1994 and is currently much used – like urban metabolism, it does not have a clear and consistent definition. In the smart cities framework, the general goal focuses on improving cities' sustainability with the help of technologies. The smart cities concept has been described as 'smart cities bring together technology, government and society to enable a smart economy, smart mobility, smart environment, smart people, smart living and smart governance'. The concept of smart cities can be divided into two different avenues of focus, such that the focus is 1) on information and communication technology (ICT) and technology (efficiency, technological advancement), and 2) on people (human capital, knowledge, social innovation). (Ahvenniemi et al. 2017: 234–236.) A smart city has the potential for energy-efficient and sustainable urban development and management, with digital technology (Rigenson, Höjer, Kramers & Viggedal 2018).

According to Ahvenniemi et al. (2017) the European Commission describes smart cities via technologies that help achieve sustainability in cities. The smart city projects usually focus on energy, transport and ICT, and public services, and result in innovative transport, logistics and energy systems. The smart city assessment focuses on measuring cities with ICT and modern technologies, just as in urban metabolism assessment. The smart city assessment uses data to monitor and optimise existing infrastructure, it encourages collaboration between different economic actors and the development of innovative business models. (Ahvenniemi et al. 2017: 235.)

Researchers have mentioned that there is a lack of connection between concepts of sustainable cities and smart cities. The solutions that smart cities offer usually do not include social or environmental sustainability – those rather focus on economic growth and ecological modernisation. Possibly one reason is that ICTs have a large impact on economic activity, but their impact on the environment is not easy to monitor and assess. The smart city model has been criticised for its private and corporate interest to promote smart technologies and corporate economic interests. (Haarstad & Wathne 2019: 919–920).

The smart city concept has been combined with the urban metabolism context with the hybrid approach in an article by D'Amico et al. (2020). Smart urban metabolism is about combining traditional urban metabolism with smart innovations (e.g., real-time monitoring systems, smart tracking and controlling, AI, and big data). Since cities do not act like companies, the urban metabolism assessment could help avoid being too technocentric and could give more of a multidimensional and holistic perspective. (D'Amico et al. 2020: 1–3.)

3.2 Urban metabolism assessment and its development

Secondly, the aim is to find the answer to the first research question about urban metabolism assessment and its development, without forgetting the used methods. This work will not go through all the UM assessment methods, but will present shortly the most used.

Urban metabolism assessment 'focuses on the analysis of trends and transitions in different stages of city development, on developing classification systems and identification of metabolism profiles for urban areas' (Rosado, Kalmykova & Patrício 2016: 206). Usually, the UM analysis includes the quantification of urban flows to a produce picture of urban processes (Wei et al. 2015: 69). The analysis within a city may, for example, reveal diversities within the city (Conke & Ferreira 2015: 151). Urban areas are an interesting field to study and especially in a multi-disciplinary way. To complete assessment of urban areas, different approaches, methods and analysis are needed. Different research fields have focused on and contributed to UM (e.g., urban and regional studies, economics, industry, environmental studies, chemistry, physics, atmospheric studies) (Pincetl, Bunje & Holmes 2012: 200–201).

No later than 1960–1970, urban development and environmental focus were added to what had previously been mostly economic growth-focused land use and societal development. Afterwards, also urban design and planning were included. (Kaur & Garg 2019: 147–148.) It is necessary to look at the city as a whole in order to understand and resolve the complex urban issues (Pinho et al. 2010: 153; Mohan, Amulya & Modestra 2020: 10). It is important to understand the weaknesses of the various systems that are interacting with the larger urban system, to enhance urban sustainability (Sahely, Dudding & Kennedy 2003: 472, 481). UM research can be helpful for cities to solve their ecological and environmental problems, e.g., for saving resources and developing an environment-friendly society (Zhang 2013: 464).

The concepts of urban metabolism assessment and circular economy have their roots in industrial ecology (IE). This 'science of sustainability' came from the need to create knowledge on the mechanisms of energy and material use in industrial systems, in order to be more sustainable and closer to natural ecosystems (Ehrenfeld 2004). IE aims to understand the circulation of materials and energy flows (Saavedra et al. 2018: 1514), and the impact to the environment in the socio-economic system, via analysis (Hoekman & Bellstedt 2020: 1).

Industrial ecology has been described as the 'traditional metabolism', where the focus has been in analysing the existing industrial systems, systems energy and socio-economic transitions (Newell & Cousins 2015: 708). IE aims to be opposite to the insufficient industrial 'end-of-pipe' product manufacturing processes, by guiding the sustainable industrial transformation. The Industrial Metabolism (presented by Robert U. Ayres in 1988) focuses on the understanding and knowledge of natural resource use and their impacts on the environment. (Saavedra et al. 2018: 1514). The development of the urban metabolism assessment is presented in the Figure 2.

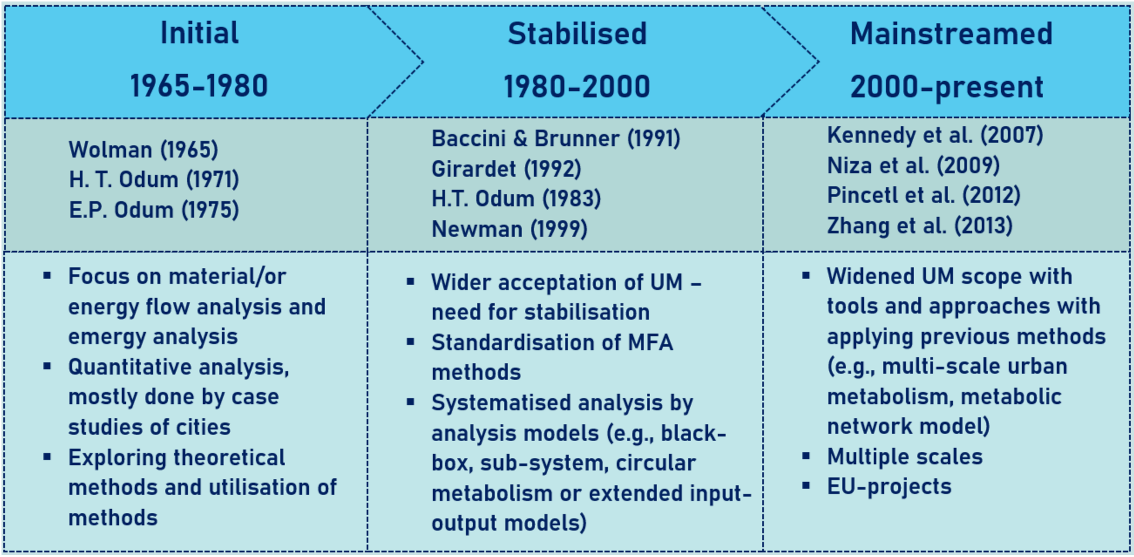

Figure 2. Urban metabolism assessment and its development, divided into three periods: initial, stabilised and mainstreamed. Researchers mentioned are examples of the most known at the time period. Modified by the author, based on Song et al. (2018) article.

The 'second ecology' as described by Newell & Cousins (2015) is Marxist ecology. In 1883, Karl Marx first brought urban metabolism into discussion, by focusing on 'the material and energy exchanges between nature and society' (Zhang 2013: 463; Newell & Cousins 2015). Marxist ecology also includes the urban political ecologists (UPE), who focus on describing 'nature-society relationships' (dynamic networks) via use of urban metabolism assessment. In Marxist ecology studies, the focus has been in in urban space, which is formed by socio-economic practices in nature and which model the metabolic relationships to other spatial areas. This approach also includes the city-countryside approach and focuses on the 'metabolic rift' between the areas. (Newell & Cousins 2015: 710–711.)

Abel Wolman (1965) re-launched the urban metabolism concept and groundwork for sustainable cities (Beloin-Saint-Pierre et al. 2017: 224; Kennedy, Pincetl & Bunje 2011: 1965; Zhang 2013: 463). Wolman, as an engineer (Kleiner 2011), focused on assessing cities' stocks and flows (Wolman 1965; Newell & Cousins 2015: 708). His study brought attention to the consumption of goods (inflow) and the generation of waste (outflow) (i.e., the material flows) (Sahely, Dudding & Kennedy 2003: 470; Kennedy, Pincetl &

Bunje 2011: 1965). Wolman saw metabolic requirements as a basis for sustainable city development, focusing on impacts of material consumption and waste generation of an imaginary city of one million citizens (Wolman 1965: 178–193).

H. T. Odum suggested emergy (energy with an ‘m’) theory for the energy and resource system assessment (Odum 1986, as cited Wang, Chai & Li 2016). According to Sahely et al. (2003), emergy is defined as follow: ‘total amount of energy needed directly or indirectly to make any product or service’. (Sahely, Dudding & Kennedy 2003: 470; Wang, Chai & Li 2016.) Odum (1996) focused his work on quantifying the embodied energy flows, via presenting energy equivalents, primarily concerned with describing metabolism in terms of solar energy equivalents or with e**m**ergy (Kennedy, Pincetl & Bunje 2010: 1965–1967).

Newman (1999) extended the metabolism concept by including liveability to the UM for sustainability assessment. The new extension brought the human ecosystem (including social aspects of sustainability) and the economic approach to UM. His model included indicators such as health, income, education, employment, leisure, housing and community activities. Newman sees that the liveability of human environments cannot be separated from the natural environment, which means that sustainability should focus on increasing human liveability, not just on reducing metabolic flows. (Newman 1999: 219–225.)

Kennedy et al. (2007) extended the metabolism scope to ‘the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste’. Kennedy et al. (2011) divide urban metabolism into two schools, both of which try to quantify the same items with different units: Odum’s e**m**ergy and more broadly used UM focus on the city’s flows of water, materials and nutrients in terms of mass fluxes.

Urban metabolism assessment methods

In the urban metabolism assessment process, different models have been developed to track and evaluate urban flows and environmental effects and relationships with nature (Ravalde & Keirstead 2017: 242; Beloin-Saint-Pierre et al. 2017: 228). In the urban metabolism assessment, input and output are both easy and simple to quantify (e.g., energy, water, traffic, capital, air pollution) or harder to quantify directly (e.g., that which is immaterial such as information, social capital and culture). Some of the UM studies focus on very specific issues (e.g., energy use) or only for some of the flows (e.g., copper, nitrogen), which means they don't follow Kennedy's definition of urban metabolism assessment (Beloin-Saint-Pierre et al. 2017: 224). In most cases, urban metabolism assessment focuses on a static quantification (i.e., metabolic flux calculation), excluding environmental quality effects which are more relevant in policy-making (Wei et al. 2015: 64).

The common way to categorise UM research models is to divide them to three different system-modelling models: black-box, grey-box and network. The complexity increases when using the network model, with the black-box model being less complex, due to the increasing need of data. (Song et al. 2018: 15–17.) If there are challenges for the methodological choices, those mostly come from the difficulty of defining the systems' functions or effect on the environment or from finding enough representative data (Beloin-Saint-Pierre et al. 2017). See Figure 3.

	Black-box	Grey-box	Network
Focus	Inflows (input) and outflows (output), the main processes in urban system.	Inputs-components-outputs. Disaggregates input and output flows for different material components (e.g. buildings, parks, services).	Internal characteristics of UM system. Analyses the component interactions via processes and nodes. Results in mathematical definitions of flows.
Methods	MFA ENA	MFA, LCA, emergy	MFA, ENA, EE-I/O, LCA
Use	Initial research	Large-scale analysis	Not for detailed analysis (e.g., identification of hotspots)
Data	Top-down	Top-down & bottom-up	Requires information of inputs, uses top-down data
+	Easy to analyse, it simplifies the data by combining it. Looks at city as a whole single unit. Enables long time-series.	Gives more detailed information about environmental impacts of UM. Attempts to use indicators.	Spatial elements can be identified and evaluated. Good for use in urban design.
-	Doesn't support regional identification or dynamic/complex patterns or specific activities, actors or spatial information. Lacks of the spatial elements.	Requires adding the environmental effects of products, services and systems (i.e., from cradle-to-grave). Lacks spatial elements (hard to use for urban designer).	Requires a lot of data. Time-consuming. Challenging to implement.

Figure 3. Beloin-Saint-Pierre et al. (2017) divided UM assessment into three different models. Modified by the author, based on Geldermans et al. 2017 & Song et al. 2018.

In the earliest UM assessments, material flow analysis is used for quantifying stocks and flows in the urban system and their outcomes. Later on, it has been used for energy and ecological footprint method or life cycle analysis. (Peponi & Morgado 2020: 12.) There is no consensus about what methods should be used (i.e., no standardised method), so there are a variety of different methods (Beloin-Saint-Pierre et al. 2017: 232–234, 236; Papageorgiou et al. 2020). In the field of industrial ecology, the methods, tools, and conventions have been in constant change, and have no clear structure. According to Hoekmann & Belldsted (2020) 'chosen classification and definitions are by no means universally acknowledged and they carry a degree of subjectivity', meaning there is overlap in terminology. (Hoekman & Bellstedt 2020: 1.)

The relevance of UM research in practice depends on the assessment methods applicability and on the transfer of knowledge between scientists and practitioners (Perrotti 2019: 1458). The accounting method definition includes anything that involves quantification of material stocks or flows on an urban level (Hoekman & Bellstedt 2020: 1–2). UM assessment can be combined with other assessment methodologies, resulting in, for example, environmental standards and sustainability criteria (Sahely, Dudding & Kennedy 2003: 481). In the future, the standardized use of UM will provide more transparent and comprehensive data. (Beloin-Saint-Pierre et al. 2017: 233.)

Material flow accounting (MFA) (developed by Baccini & Brunner, 1991) focuses in a systematic way on assessing the flows (e.g., company, private household, city, region, etc.) and stocks of materials in a system, and the outputs in an urban system (Arciniegas et al. 2019: 33–34; Niza, Rosado & Ferrão 2009: 385; Pincetl, Bunje & Holmes 2012: 196; Wang et al. 2020: 1–2). MFA describes the city's exchange between the natural environment and the socioeconomic system (Wang et al. 2020: 1–2). The method helps to identify and understand the metabolism of urban areas (city and region), link the urban activities (input-output) and relationship between city and both region and surrounding hinterland (Niza, Rosado & Ferrão 2009: 385). MFA focuses on sustainability and direct flows of cities, but also is used for analysing the indirect flows (Barles 2009: 899–901). The method includes four methodological scopes: the temporal, spatial, material and system modelling approach.

MFA is the basis for material flow management and resource use optimisation, a tool for research that supports decision making in environmental policy and management (Barles 2009: 899; Newell & Cousins 2015: 708; Patrício et al. 2015: 837–838; Liu et al. 2017: 169). MFA can help decision makers to improve, prepare and react to present and future material, stock and flow issues. Usually the (current) data of an urban area needed to run MFA analysis is not available or it is unsuitable. Another issue with utilising the MFA is that there are non-existing boundaries for the flows, which make the quantification of products flows complex. (Geldermans et al. 2017: 32–54.)

Most use the time scope of a specific year or a time series, depending on the target of the investigation (Geldermans et al. 2017: 33–34). Usually, the MFA assessment is done by certain years, through economic development time series (tracking the trends of consumption) (Niza, Rosado & Ferrão 2009: 385). Barles suggests that data for MFA analysis should be conducted annually or, at the minimum, every five years; this means upgrades for the government's data production, collection and availability (Barles 2009: 905). MFA can be associated with other factors such as climate and population density (Rosado, Kalmykova, Patricio 2017: 207).

The MFA method is widely used on a national scale (Barles 2009: 899). Economy-wide MFA (Eurostat method, 2001) is used at the national level, developed to enable comparison between different countries in different time scopes (Barles 2009: 899, 911; Patrício et al. 2015: 837). EW-MFA includes materials of the entire economy (Geldermans et al. 2017: 35). The adaptation of the national-scale MFA to an urban scale is difficult, as there is no unified framework for the MFA at the urban or regional level (Wang et al. 2020: 2).

Activity-based Spatial Material Flow Analysis (AS-MFA) connects the spatial, material and social assessment, so it consists of activities related to material flows and stocks in subsystems, and describes the interrelations and involved actors. The main components are economic activities, activity-associated materials, and the involved actors. The social part focuses on the relationship between general environmental issues and socio-cultural features and social sensitivity. This method is used to identify the key actors and activities and their relationship. Focus is on regional actor networks and material flows. (Geldermans et al. 2017: 37.)

Life cycle analysis (LCA) assesses environmental, economic and social equity impacts, and captures hidden energy and material flows of various products associated with manufacturing processes (including inputs and outputs) (Pincetl, Bunje & Holmes 2012: 196; Liu et al. 2017: 169). LCA is a qualitative and analytical assessment tool for the environmental impacts (beginning to end) of urban activities (direct, indirect), i.e., a cradle-to-grave accounting (Pincetl, Bunje & Holmes 2012: 196; Movia 2017: 10; Maranghi et al. 2020). The LCA method views urban activities as supply chains point of view, estimating and defining the products environmental impacts (Movia 2017: 10). Focus is on where the processes are located (e.g., boundaries of a company, city, region, country or global); the boundary definition might not be precise to the administrational boundaries (Geldermans et al. 2017: 34).

The LCA method requires a lot of data and time, for tracking each process step-by-step, which usually is not available (Arciniegas et al. 2019: 34; Pincetl, Bunje & Holmes 2012: 196). It also requires an expert audience when communicating about the results (Arciniegas et al. 2019). The LCA method can be a good tool to analyse the evolution of sustainability and so effectively monitor the impacts for UM, but that requires analysis for different years (Beloin-Saint-Pierre et al. 2017: 233). When using the LCA method, the results can be used to support sustainable decision making (Albertí et al. 2017: 1052). The method identifies wasteful processes and practices (Pincetl, Bunje & Holmes 2012: 196). LCA results are simple to analyse and useful to decision makers for identifying the most sustainable urban planning options. The challenge, however, is that the results are more complex to implement. (Beloin-Saint-Pierre et al. 2017: 228.) The method has been standardised (ISO1044, ISO14040, ISO1067, ISO14072 & ISO14001) (Albertí et al. 2017).

The emergy analysis (EA) method was created by Odum. He focused on solar energy measuring available solar energy being used to make a product or deliver a service directly or indirectly. Measurement is done by converting of the flows to solar emergy joules (seJ). The metric is complex and results in limited application of the method. Also challenging for the method use is the inadequate or disparate data. His method is based on solar energy, measured in solar energy joules (seJ). Emergy analysis is a quantitative analysis focused on mass or energy flows in an urban system. The method emphasises the dependence of almost all energy on the planet on solar power. (Pincetl, Bunje & Holmes 2012: 196.)

Input-output analysis (IOA) assesses direct or indirect consumption that is required in the production of goods and services based in urban areas. The input-output table provides an overview of study areas of economic and material flow balances and activities. Methods can be used to evaluate local and regional energy use and emissions. With IOA it is possible to compare the consumption globally. (Movia 2017: 11–12.)

Ecological footprint assessment (EFA) focuses demand and supply comparison via, estimating the bio capacity required to produce the energy and materials that are consumed by the city, and to assimilate the resultant wastes. The method does not take account of the embodied energy or up-stream material inputs. (Moore, Kissinger & Rees 2013: 52–53.) It tries to understand the hidden impacts of the city. It shows the direct and indirect inputs and outputs induced by domestic consumption of the city in other areas (Wei et al. 2015: 64).

EF can be quantified into different ways by the direct component method or with the adapted compound method. The direct method uses per capita data on ecological footprint quantification (scaled to reflect the city as much as possible) and by using local data (reflecting the population's consumption activities in the study area). Direct methods include input-output analysis (monetary) and require direct estimations of the energy and material throughput. An adapted method uses national level production data (import and export) which is easier to locate (vs. city-specific). The ability of reflection on the local policy and action impacts is limited. (Moore, Kissinger & Rees 2013: 53.) This method is being used to measure and visualise the resources that are needed to sustain urban ecosystems (Liu et al. 2017: 169).

3.3 Data used for urban metabolism studies – the potential of satellite data?

The third question focuses on how satellite data could improve urban metabolism assessment. Firstly, the general requirements of data used in urban metabolism assessment are presented. This work does not talk about the technical frameworks to be set for the use of satellite data, nor those of the required software.

Urban metabolism assessment generally starts by defining the boundaries of urban areas and collecting the data from different sources to assess energy, material, waste and other resource flows in a city (inflows and outflows) on a specific period. All types of data can be linked to UM assessment methods and data can be converted (e.g. from economies to physical) to estimate material flows and consumption (Beloin-Saint-Pierre et al. 2017: 226–228).

Used data in UM processes connects the actors, the activities and the impacts across time and space, and also reveals the processes. The data provides better understanding, design and management of socio-economic flows by providing a comprehensive picture. (Bortolotti 2020: 45.) The type of data depends on the method chosen to model UM and its effects (i.e., the results of the studies) (Beloin-Saint-Pierre 2017: 226–228). The data used for UM studies is rich and likely to be used for other applications (Kennedy, Pincetl & Bunje 2011: 1968).

Data to be used in urban metabolism studies describes the human activity and urban infrastructure (Beloin-Saint-Pierre et al. 2017: 226–227). There is a growing potential in the usage of big data and sensing technologies that have provided a huge amount of data available by which to analyse human activities. (Bortolotti 2020: 161). The digital age and development of the ICTs has an effect on urban development (OECD 2019). Urban digitalisation has an impact on living and consumption (Lyons et al. 2018: 246–247), and it has provided us opportunities to collect data that heretofore have been difficult to get (Dijist et al. 2018). Nowadays, data is more personalised and real-time, which helps to understand the urban flows of energy and material (Dijist et al. 2018).

Basic data includes:

- Inflows, e.g., water, construction materials, fossil fuels, electricity
- Production, e.g., food, wood
- Stocks, e.g., minerals, nutrients
- Outflows, e.g., emissions, waste-water, solid waste

Data to be used can be obtained from statistics (mostly macroscale, e.g., Eurostat), studies, reports, on-field measurements, from industry values or databases specific to a city or to lower levels (e.g., neighbourhoods) (Beloin-Saint-Pierre et al. 2017: 227). Used data is dependent on the financial and human resources (Geldermans et al. 2017: 34). Usually, UM studies use local data, energy and material flows, within the urban area (e.g., city or metropolitan). Urban metabolism studies also include extrapolations of national data (Zengerling 2019: 191). National data is provided, for example, by Eurostat (Bortolotti 2020: 19). Some studies use European averages or data from international organizations (Beloin-Saint-Pierre et al. 2017: 227). Data is commonly collected at the city-wide scale for energy and material consumption, and per the urban sector (Bortolotti 2020: 37).

When used for urban planning or land management, the data is usually generated by cities themselves rather than from the national level. Cities use different types of surveys (e.g., land use, topographical, traffic and air quality) to develop urban demographic and socio-economic databases by which to support urban planning. Cities might also use other departments' data such as meteorological, geographical and geological surveys. (Prakash, Ramage & Goodman 2020: 3.)

The data aggregation (i.e., gathering and presenting) level can be divided into top-down and bottom-up (Beloin-Saint-Pierre 2017: 227). In most of the cases, the data used for UM studies is top-down, usually using data from the country level. Generally, gathered data provides a snapshot of energy or resource use with no specific information about locations, activities or people. This often results from the lack of bottom-up data that includes more detailed data (e.g., from individual properties or the neighbourhood level) from the neighbourhood or city level, which is less used in studies (e.g., presenting sub-systems). (Beloin-Saint-Pierre et al. 2017: 227; Chrysoulakis et al. 2013: 115.) The level of aggregation of data is not usually voluntary, but depends on the data availability and on the researcher's 'domain-of-expertise'. Using the top-down and bottom-up data in a study in a useful manner has turned out to be difficult to fit (Beloin-Saint-Pierre et al. 2017: 227–228).

Data aggregation has issues since data varies between the different levels (city cf. municipal), which makes the comparison difficult. The main difference between national and regional scales is the data availability (Patrício et al. 2015: 842). Data are usually available at the national scale, to be ordered (on a case-by-case basis) to lower scales (Kalmykova, Rosado & Patrício 2015: 72). Notably, there is missing data on exports and imports between cities (Wei et al. 2015: 64). Especially limiting is the availability and accuracy of the data in the city since there are data gaps, omitted and hidden flows, and segregated information for specific cities (Pincetl, Bunje & Holmes 2012: 201).

Prakash, Ramage & Goodman (2020) listed the following three key reasons for access to data in cities.

1. The cost of generating data through traditional methods remains high.
2. The technical capacity in geospatial sciences in many countries is low. There is a shortage of skilled professionals who can find and/or process available data.
3. The inertia against distributing routine workflows and adopting new practices are not imposed through legal requirements at the country level.

Issues arise from the lack of harmonisation and common definitions of city boundaries (Bortolotti 2020: 19). In addition, there is a difference with data reliability between the national and local level, with the local being sometimes being less reliable (Conke & Ferreira 2015: 147). This usually means that cities need to have access to collect their own data needed for the assessment (Moore, Kissinger & Rees 2013: 53).

Several UM researchers have raised the issue of lack of the data supporting UM assessment (Beloin-Saint-Pierre et al. 2007: 234; Wei et al. 2015: 64). To get useful data for UM assessment might require statistical agencies to adjust or develop new surveys, or for cities themselves to collect data and manage it (Kennedy & Hoornweg 2012: 780). Data collection has to be carefully considered, as to what kind of data can be practically collected (Kennedy & Hoornweg 2012: 780). One should especially consider effects on the access to data and how the quality of research might be lowered (Bortolotti 2020: 161). In addition, studies that use approximations due to restrictions in data availability, can lead to different results (Dijist at al. 2018). Satellite data could be seen as a solution for solving these two first challenges raised by Prakash et al. (2020), but the third one should be solved on a political level.

Urban environment observation via satellites

As explained earlier, satellites – especially the newer satellites that monitor air quality and climate – provide data that is helpful for urban sustainability research. When aiming to solve environmental and societal problems, satellite observation helps to define and predict the problems in different spatial scales from local to global, and in different time scales (past to future). Satellite data can be used from various sources (e.g., Landsat and Sentinel added to thermal imagery) and types (e.g., calendar dates or combining spectral data) that helps improve the classification process. The wider collection of different satellite instruments is presented in an article written by Ustin & Middleton (2021). (Ustin & Middleton 2021: 51–56.)

The combination of satellite data with other socio-economic datasets provides an important link in the urban planning process imparting the necessary insights to make effective planning decisions. Researchers have been using satellite data for the classification of buildings (building density, orientation, heterogeneity of pattern, shape and distribution), for example. These classification exercises help to create algorithms that support urban planners in the measurement, mapping, and understanding of changes and in making more efficient urban areas, since cities are ever-changing. Also, satellite data have been used in green area monitoring via recognising vegetation cover and biomass for cities to help improve their green spaces and quality of life. (Boag 2020.)

In regard to urbanised areas, satellite imagery applications relate, for example, to measuring, quantification and identification (Taubenböck et al. 2011: 174). In the urban metabolism process, satellite technology combined with GIS has been used to help estimate, for example, material flows in the urban system (He et al. 2020). According to Elvidge et al. (2011), satellite-based remote sensing has been in use from the mid-1970s for terrestrial ecosystems, e.g., for tracking spatial and temporal variations.

There are supportive tools nowadays for researchers to use when analysing data, which was not the case in the early stages of UM assessment. Various different open-source programmes can be used as supportive for analysis, such as Github for Sentinel and Landsat, Google Earth Engine, ESA’s Science Toolbox Exploration Platform (STEP), and others. (Ustin & Middleton 2021: 11.) For example, usage of Geographic information systems (GIS) as a tool helps to analyse the data from databases with high-resolution. GIS also can be used as a tool for visualisation (e.g., of geographic and spatial data), to highlight the issues, relationships and patterns, and thereby support decision making. GIS software nowadays includes 3D visualisation capabilities. (Djist et al. 2018.) Google Earth or Big are not in and of themselves GIS software but provide a lot of possibilities, since they are open to use and include spatial data around the world (See et al. 2016: 39).

The toolbox, therefore, is similar to non-satellite data. As represented, the tools to be used when applying satellite data (e.g., GIS) in urban research are usually quite familiar to urban researchers. When using satellite data, one needs 'a basic understanding of the physical, chemical, and structural properties underlying the measurements' (Ustin & Middleton 2021: 4).

The biggest opportunity of the utilisation of satellite data lies in satellite openness. For example, Sentinel satellite data is free, open and global – with a short timespan (Transon et al. 2018: 1). Remote-sensing provides long-time (almost 40 years) accumulation of satellite data for large areas (Taubenböck et al. 2011: 162), and has already been referred to as the 'Sentinel Era' of the open big data. This openness will help the issues that previous researchers have raised in urban metabolism – e.g., difficulty with data accessibility and data gaps. To support the openness of satellite data (possibly unconsciously), citizens are producing georeferenced included data *in situ* (on site) for datasets. We, the citizens, are collecting environmental data, whenever we use, for example, social media and geotags. (See et al. 2016: 38.) Remote sensing and GIS give enormous benefits over traditional in situ data collection methods for urban planning (Boag 2020).

Satellites can be linked with other technical systems, such as IoT. We can get data from, for example, smart phones, smart applications and sensors (home, business and public spaces), drones, satellites, product tagging and other utilities. Because of the new kinds of data and sources (also from stakeholders, citizens, and companies), data collection is widely spread and, has an effect on the data and its quality, the type and coherence. (Dijist et al. 2018.) The use of multiple different data sources helps create wider dimensions, including a holistic view of the issues and it provides various different perspectives (Ustin & Middleton 2021: 5).

Although satellite data is quite rich and usable, it is wise for the validation and testing to be done first on a smaller scale to avoid misconnections and errors (GIS Geography 2020). Sometimes there are difficulties in receiving correct data, due, for example, to shadows or angles that result from cloud coverage and Earth geometry (Sekertekin, Abdikan & Marangoz 2018: 380; Taubenböck et al. 2011: 162). Other limitations include, for example, temporal and spatial coverage, storage capacity, sensor utilisation and the acquisition period (Taubenböck et al. 2011: 162).

To create suitable remote-sensing data, it is necessary to consider image resolution, which is being divided into three different types. Spatial resolution focuses on the pixels of an image; the higher the resolution, the more detailed the image. Spectral resolution refers to spectral details (colours). Temporal resolution means the time used to complete a full orbit (of Earth). There are different types of orbits (geostationary, sun synchronous and polar) and also two different types of sensors (active or passive). (GIS Geography 2020.)

User cases of satellite data in urban metabolism studies

Elvidge et al. (2011) have used satellite-based data (the remote sensing of night-time lights) in their urban metabolism estimation process. They used remote sensing for mapping and monitoring of the human enterprise ('form follows function'). They collected data from lights (within a country's boundaries) and paired it with national-level data (population, GDP, energy consumption, fossil fuel CO2 emissions) in a time series to find relationships between nominators (i.e., using it as a proxy of the distribution and intensity). Elvidge et al. (2011) describe proxy as a measure of information that is able to be received, when the exact way in which the information is wanted is not measurable.

Coscieme et al. (2014) used night-time satellite images in energy consumption investigation in urban and suburban areas. They used a time series approach for their research of 'sum of lights' and non-renewable emergy that aims to describe the energy consumption patterns and dynamics. They focus on scale dependency. Night-time lights allow estimation of resource consumption in an urban system, at the territorial scale, in a quantitative way. The instruments used for this kind of estimation processes are Visible Infrared Imaging Radiometer Suite (VIIRS) or Operational Linescan System (OLS).

Shuqi He (2020) used remote-sensing images and field-research data to study urban material-accumulation systems (black-box study). He used sample surveys (260 samples from a 65km2 study area), spatial methods and buffer analysis on an ArcGIS platform and SPSS to check the data. Abertí et al. (2017), Mori & Christodoulou (2012), and Ferraini et al. (2001) have studied satellite-based sustainability. The method uses night-time imagery and ecosystem service evaluation via an empirical environmental sustainability index. They used land-cover dataset and ecosystem service values to measure light energy emitted and ecosystem services.

3.4 Promoting a new urban metabolism approach via policies?

This chapter focuses on the third research question, and, by so doing, on the policies and legislation and governance perspective related to promoting a new urban metabolism approach and sustainable urban development. The focus is especially on urban policies that are focusing on environmental agreements and sustainable development goals that are linked with this new approach to urban metabolism. Policies that are especially targeted for the utilisation and promotion of satellite data will be presented. The policies and legislation are presented to guide and support the practical adaptation of presented methods and their approach.

Urban policies promoting sustainable urban development and urban assessment

There are plenty of international policies focused on responsible and sustainable resource use, e.g., the United Nations (UN) 2030 Agenda for Sustainable Development including Sustainable Development Goals (SDGs), the Paris Agreement (COP21), and the

New Urban Agenda (NUA) (UN 2020; Prakash et al. 2020: 3). The UN Agenda 2030 includes 17 Sustainable Development Goals (SDGs) and aims for a more sustainable and better future for all. SDGs are action plans towards addressing global challenges. There are also urban- and city-related goals that can be linked to the urban metabolism theme can be linked the *Goal 11: Sustainable Cities and Communities,* and the *Goal 12: Responsible Consumption and Production*. (UN 2020.) Goal 11 especially addresses challenges related to urbanisation, and supports green and innovative city development (EC 2020c). These SDGs can be used as indicators to help define the UM and for the assessment process (D'Amico et al. 2020: 3).

There has been, for example, the EU-funded Horizon 2020 project (SMURBS), that has used Earth observation for the SDG indicator tracking and reporting at the city level, using information from built up areas combined with data of population growth. There is also much of other projects that have been using EO applications in international agreements monitoring and reporting processes (e.g., climate change, air quality, soil moisture, housing, transportation). (Prakash et al. 2020: 4.) Examples such as these are valuable to recognise for larger-scale use.

Related to the UN blueprint, the EU has its own 2030 strategy, 'Towards Sustainable Europe by 2030'. The strategy binds EU member states to a sustainable development strategy on their action (EC 2019). The EU has several different targets (2020, 2030 and 2050) for issues related to the climate, energy and environment. Most importantly, the EU aims to be a carbon neutral economy by 2050. Urban sustainability development is part of the Ursula von der Leyen (VDL) Commission's many priorities for 2019–2024 (European Commission 2020g). For example, one of the priorities is the new European Green Deal instrument, which is an action plan towards a sustainable EU economy, including efficient use of resources, restoring biodiversity losses and cutting emissions (EC 2020d, EC 2020e).

The European Commission is currently focusing on promotion of the holistic and cross-sectoral approach, and on funding the knowledge base. There has been a lot of funding for urban partnerships, under 'Urban Agenda for the EU'. The European Union has funded several projects from the Horizon funding programme, related to urban metabolism (SUME, BRIDGE, ECO-URB, Urban_Wins and REPAiR) (Song et al. 2018: 9). The representative from the EC presented during the interview one of the key funding programmes for cities: the Horizon (Horizon 2020, Horizon Europe), and its cities-targeted mission, 'Climate-neutral and smart cities'.

The EU's two directives, *Strategic Environmental Assessment* (2001/42/EC, SEA) and *Environmental Impact Assessment* (97/11/EC, EIA), both focus on evaluation of environmental viability and sustainability. These directives are not required at UM processes, but might be useful by providing information on the environmental quality of urban areas. (González et al. 2013: 109).

On Finland's national level, aims for a sustainable future are high. Finland was the first country to deliver a roadmap for the circular economy in 2016. In 2019, the map was updated to include updated aims and actions towards a circular economy-based society. (Järvinen, Sinervo, Laita & Määttö 2019.) PM Sanna Marin's Government Programme 2019 aims for Finland to be carbon neutral by 2035 and to be the world's first fossil-free society by 2035. The programme includes, for example, actions on climate policy, boosting the circular economy, and reducing carbon foot-printing and environmentally harmful activities with taxation (Ministry of Environment Finland 2020).

Urban metabolism is not such a familiar concept in Finland, although research has been active in the EU area. In Finland, mostly sustainable development actions are related to CE or to resource wisdom, but, for example the City of Helsinki has been involved in the EC Horizon 2020 BRIDGE project, which focused on urban metabolism. Finland's National Urban Strategy for 2020-2030 is just published, co-produced with and linked to the governments (PM Marin's) shared vision. The strategy is for cities, citizens, businesses and local actors to support their partnership in the sustainable future development of cities and operative environments (Ministry of Finance 2020). Finland has a network for sustainable communities, called FISU, which aims to achieve carbon neutrality, zero waste and globally sustainable consumption by 2050. Parties involved in the FISU are municipalities, regions and companies. (FISU 2020.)

Maybe these networks and strategies will in the future also include mention of urban metabolism assessment, since, via adding the concept of UM, we could achieve even better and longer lasting solutions for urban areas. As one example, The Finnish Environment Institute (SYKE) has been using the urban metabolism approach alongside their sustainable cities study. Their study focuses on urban fabrics and urban planning – connected with resource efficiency and sustainability. (Newman et al. 2019.) This urban fabrics theory has been developed during past 20 years and could also be further used in upcoming research projects.

Space-based policies guiding Earth observation and data's utilisation in urban processes

The EU has focused on setting the space policies (European space industry), and as a result there are three space programmes called Copernicus (The European Earth Observation programme), Galileo (The European satellite-based navigation system) and EGNOS (The European Geostationary Navigation Overlay Service) (i.e., the flagship projects) (European Commission 2020f). This also highlights the fact that there is a will to make satellite data accessible for all, to popularise it (for expert or non-expert use) (Oikonomou 2017: 5–10). The EU has its own Space strategy (launched in 2016) to support European space activities and businesses (European Commission 2020f). Also, the VDL Commission's priorities for 2019–2024 are highly linked to the space related-actions, especially in the Copernicus programme (environment, informatics, digitalisation and working).

One of the most important principles of the European space programme is that data is free for anyone to access and use: the ESA Sentinel Data Policy 2013 and the EU Delegated Act on Copernicus Data and Information Policy 2013. Indeed, at the start it was already predicted that the largest user group would be the scientists (Declan Butler, 2014). For example, ESA has data hubs for public, geospatial apps. The European satellite programme Copernicus is managed by the European Commission, and co-designed with the ESA, for the use of EU Member States as a tool for monitoring and developing environmental policies. (Declan Butler, 2014.)

The EU is not the only one with a space strategy, since there are national-level strategies. Finland's Space Strategy (2018) supports market access, international influence and research. There are also legal acts regarding space. On Finland's national level there is Act on Space Activities (63/2018) and Decree of the Ministry of Economic Affairs and Employment on Space Activities (74/2018) that regulate space-related activities. Then there is the United Nations Space Law Treaties and Principles, to which, for example, Finland has committed. These guiding documents between sustainable urban development and space data are still quite separate from each other. The efforts towards wider utilisation of satellite data in urban development have been promoted but should be more visible in these documents.

How to implement policies and agreements with a new urban metabolism approach

Cities are in the central spot for implementing development and environmental agreements, and by so doing having the greatest impact. Therefore, urban design and management policies play an important role (Moore, Kissinger & Rees 2013: 59). Resource consumption trends show that implemented policies have not succeeded in reducing resource and energy throughput (Kalmykova, Rosado & Patrício 2015: 70). We need new approaches, such as the urban metabolism approach presented in this work. In addition, municipalities, and governments have the possibility to encourage and to guide consumption via taxation or refurbishments (Westin et al. 2018: 536).

The policymakers' role is key in sustainable urban development, since they are in the position to promote more collaborative consumption and alternative ways to use resources for achieving more efficient use of energy and resources (Lyons et al. 2018: 251). Cities are 'complex social-ecological-technological systems' and the development and design of urban policies requires a holistic, multi-scale, approach – such as urban metabolism assessment (Peponi & Margado 2020: 13). Urban metabolism assessment has grown significantly, possibly since UM can be informative in resource-efficient urban policy planning (Perrotti 2019: 1459). Urban metabolism can help increase the urban quality by focusing on self-sufficiency, resource efficiency, identification, flexibility and diversity. Urban metabolism is a large system and complex to analyse; results of the analysis can have a significant impact on regional economy, industrial activities and at the global level. (Beloin-Saint-Pierre et al. 2017: 236.) The real benefit (of being more sustainable) for the cities is, that they save money, become more resilient, and make better investments.

The knowledge that is gathered during the urban metabolism process is very valuable to use for political decision makers and local actors. The urban metabolism approach helps to assess and monitor changes in urban sustainability performance, and can be linked to policy (Dijst et al. 2018: 201). For policy design and planning for sustainable urban resource management, an understanding is needed of the factors influencing resource consumption (how much, where and when), and of the background mechanisms (Voskamp et al. 2020: 2).

Ahvenniemi et al. (2017) have pointed out that, in the 21st century, the focus of cities has shifted from sustainability assessment to smart city goals. It could be said that smart cities have similar goals as sustainable cities. Cities are interested in including 'smartness' and modern technologies in their frameworks, although there is a lack of environmental indicators when analysing social and economic actions. The new innovative technologies help to improve material and energy efficiency and cut harmful emissions in cities – with smartness and relative low-cost. As a result, the citizens' liveability increases and the negative impact on the environment decreases. Currently, there is high number of smart city initiatives and research projects funded in the EU area that support the EU's 2030 targets. However, the EU's set frameworks focus not only on smartness, but also on urban sustainability. Such actions help policymakers to push their cities towards the aimed direction. (Ahvenniemi et al. 2017: 234– 235.)

Urban metabolism assessment is needed in order to understand local material consumption and how it can be controlled and reduced (Barles 2009: 899). UM assessment can support local decision-making and help to tackle urban ecosystems' challenges (such as pollution, sewage treatment, resource scarcity, water shortage and heat) (Conke & Ferreira, 2015: 147; Schandal et al. 2020: 1–2). Urban metabolism assessment provides representative and valid data for urban planning (Conke & Ferreira 2015: 146–147). Cities especially lack guidance on reducing their indirect impacts (Westin et al. 2018: 526).

Commonly, urban policymakers use best practices, rather than quantitative data, as a base for policy decisions (Mostafavi, Farzinmoghadam & Hoque 2014: 702). There have been issues with policymakers finding out which urban indicators they should use when evaluating their cities' strengths and weaknesses. To achieve better results, data of the 'who-is-using-what-flows-where-to-do-what' must be added for the analysis, otherwise it's impossible to know and reduce unsustainable flows. (Pincetl, Bunje & Holmes 2012: 199). Best practice is generally based on single case studies and used by scaling up, but the same outcomes should not be taken for granted (Mostafavi, Farzinmoghadam & Hoque 2014: 702–703).

Policymakers should understand their cities' metabolism, since it will help them to understand the insights of their city (Maranghi et al. 2020: 8). Region- or city-specific data and results provide custom-made policy solutions (Westin et al. 2018: 527). Currently, cities and their actors are more aware of the value of high-resolution data and hence provide more information in production and the neighbourhood scale of urban activity (Chester, Pincetl & Allenby 2012: 454). The benefit from urban metabolism assessment builds up to the full understanding of the urban system and so helps policy-makers' priority setting in effective ways (Sahely, Dudding & Kennedy 2003: 481). When bringing actions under observation, one becomes more conscious and makes better choices, and pays more attention to environmental issues. In addition, the urban areas metabolism knowledge helps decision makers to improve policymaking and to reduce unintended consequences. However, knowledge does not necessarily transform into better decisions. (Pincetl, Bunje & Holmes 2012: 200.)

Having a long-term perspective for urban planning helps to develop and put into practice activities, of which single projects are often not capable. Negatively, Beloin-Saint-Pierre et al.'s (2017) review shows that almost half (45 %) of the UM studies include plenty of complex urban data, which might not be easy for policymakers to understand so in the data walk-trough they will need additional experts to help analyse and identify the priorities for sustainable development. Additionally, quantitative data analysis itself is not enough, and the political, institutional, economic, and design contexts need to be set to analysis (Pincetl, Bunje & Holmes 2012; Bortolotti 2020: 162). This requires active cooperation with stakeholders in all levels of administration (local authorities, businesses and citizens) (Prakash, Ramage & Goodman 2020: 11). This also includes various stakeholders and the co-creation, co-design and co-implementation at local and international levels (Santonen, Creazzo, Griffon, Bòdi & Aversano 2017: 37).

A comparison with the metabolic rates of other cities could help city planners, e.g., for double-checking the environmental costs of high metabolic rates (Sahely, Dudding & Kennedy 2003: 481). However, it should be understood that UM can offer different functions and quantitative environmental assessment in different cities, also during a different time scope, so the results are not straightforwardly comparable or easily divided from the system (Beloin-Saint-Pierre et al. 2017: 228).

To support urban metabolism assessment it requires becoming more numerate in resource flows (energy and material flow assessment) (Kennedy, Pincetl & Bunje 2011: 1971). Urban metabolism studies have been criticised about their suitability to policy making, when focused on static accounting (e.g., metabolic fluxes) rather than environmental quality effects examination (e.g. environmental simulation models).

In cities, urban planners and policy-makers aim towards sustainable policies (e.g., resource efficiency, waste minimisation, and greenhouse gas, GHG, reduction) and therefore require data, which is often lacking (Schandl et al. 2020:1). Cities need to have spatially disaggregated data at a sufficient level, in order to build up on actions towards sustainability (Prakash, Ramage & Goodman 2020: 3). However, such issues could be avoided by using satellite data and GIS-based spatial analysis methods. In this research, the idea is to take one-step forward, by combining Earth observation data to complement and enhance traditional data provided for urban areas, thereby responding to the issue of a lack of suitable data for cities' needs (Prakash, Ramage & Goodman 2020: 3–4).

On a temporal level, approximately half of UM studies use a one-year scope, since it requires less data, but might not be most informative, since environmental effects and impacts to urban infrastructure are wider than one year. The used time scope depends highly on the availability of data. Most databases provide statistical data annually. Using a time series (e.g., two specific years or time ranges up to centuries) requires modelling of energy and resource flows with statistics over time. The benefit of a wide time scope is that it provides valuable information for policy makers and users about urban consumption (the history and development of sustainability trends). One-year results are hard to utilise for sustainability goal setting (e.g., simplifications might not be valid), but are good for benchmarking. (Beloin-Saint-Pierre et al. 2017: 229.) With satellite data, this is not usually an issue, since the time scope is already quite wide.

New satellite data is an information source that supports effective and sustainable management, since it helps to measure, monitor and project vast quantities of data with data analysis (Liang, Li & Wang 2012: 2). Remote-sensing data can also help to explore, test and model urban areas and help with the analysis and response of decision makers on urban issues (Patino & Duque 2013: 2). As presented previously in this work, the biggest benefit of satellite policies is that they are built to be freely available for everyone, which eases up usability. Prakash et al. (2020) argue that, in the local government, there is possibly inertia to EO data adoption and use to daily practices, although EO data is open, low-cost and has wide opportunities for urban data.

What is currently missing from urban policies is that there is no mention of the role of satellite data. More and more governments around the world are setting their space strategies, which is a very welcomed direction, since satellite data will enjoy a larger role in future research, and also in regard to urban issues. On the national level and also at the local level there is needed for stronger engagement for embracing geospatial technologies. This means cooperation with EO specialists, collaborative frameworks and investments in needed capacities. In order to receive more resources for wider EO and satellite data use in urban planning, opportunities needs to be better communicated to political leaders. In addition, the EO tools need to be tailored to the needs of local administrations that differ widely from each other; starting from city borders, the standardised version is usually rather difficult to use and might lead to false measures. (Prakash, Ramage & Goodman 2020: 16.)

Maybe Prakash et al. (2020) are on the right track by arguing that currently the issue resides in a lack of trained professionals who have skills to process satellite data, and who work on urban studies. There is a need for increasing the data management and collection (Conke & Ferreira 2015: 147). To scale up the use of EO data, GIS software should be further developed to fully utilise EO data and so provide the ability to analyse local needs. This means our governments should allocate resources for building up technological capacities (computing infrastructure) and human resources needed for this upgrade to happen. To speed the process up, there has already been established an intergovernmental partnership in 2005, the Group on Earth Observations (GEO), which advocates the EO data to address environmental and social issues (which many cities are facing) via the Global Earth Observation System of Systems (GGEOSS) portal. (Prakash, Ramage & Goodman 2020: 11.)

On the other hand, there is a need of policies for an integrated database for pooling the data from various sources, where the data is compiled, managed and synthetised, which would ease up the statistical analysis and cross-checking for the information and improve the data quality and standardisation (Sahely, Dudding & Kennedy 2003). A major challenge is that the data are not regularly collected and are fragmented (Conke & Ferreira 2015: 147). What is needed is a set of standards and unified procedures for international data collection, to bridge the gap between different institutions and their data collection. (Patrício et al. 2015: 845, 850).

4 Future talk – focus group discussion

This chapter analyses the focus group discussion, the future talk that was organised during the research process. This chapter uses literature to support the key findings made from the focus group discussion (Figure 4) analysis. Research-wise, the aim of the event was to create knowledge by which to further develop a new urban metabolism approach, and, by so doing, respond to the research questions of this work. The space was given to present current urban research and to present technologies and policies that promote and support a new urban metabolism approach, which was developed during this work.

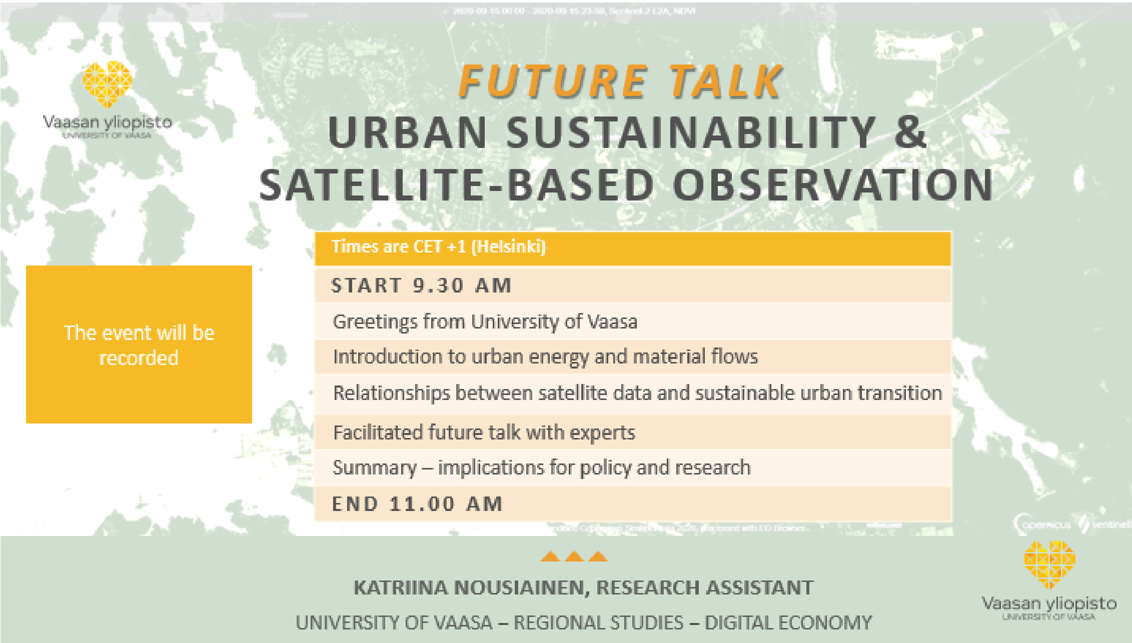

Figure 4. Schedule of the future talk webinar that was organised 3. December 2020.

As the starting point of the future talk, an urban metabolism expert described the relationship between urban metabolism (as an indicator) and sustainable urban development. He stated that nearly every environmental issue could be linked to the use of resources ‘from extraction and production to consumption and transport and disposal’.

> *‘At the core of urban metabolism we have this tracking of materials’*
> *(Urban metabolism expert)*

In the urban metabolism assessment, mass balance is established to build up the holistic picture, via the tracking of things, according to the urban metabolism expert. Cities are shaped by different components (infrastructure, buildings, transport, energy systems, water supply) that define the city operations, resulting in how to live in a city (how people use their money, what companies produce). Urban metabolism assessment does not focus on the individual components; it is about putting the big picture together, such that a city is viewed as a system with its interlinkages. Therefore, that is why there is a need for the system approach rather than focusing on only one kind of flows.

It was nicely pointed out by the urban metabolism expert during the future talk that 'I think that it's useful in achieving urban sustainability up to an extent, and I think there is more to it, and we shouldn't rely only on tools like this'. The satellite expert continued by saying that he thinks it is not the case of one methodology, but the scientific measurement process helps us along the way, and she sees urban metabolism assessment as a good starting point. As our cities are complex by nature, there are no simple solutions available. This fact does not mean that we should not use, for example, urban metabolism assessment to help us get closer to our common goals and targets via testing and trying different actions.

> *'You'd like to know and you need to know, what happens inside the city, who is using resources and what are they doing with it. And if you can't say that, then it's similar to what we have now going with countries – China is terrible because it's causing so much pollution. But in the end if other countries consume that – we should unpack a bit more. Same applies to cities, so you need to know, what has been produced with the resources and with your impact to nature. And what do people consume, as residents. And, what do they get for that. Do they have a city that is affordable?'*
> *(Urban metabolism expert)*

As the city specialist mentioned, 'I see sustainable development as such a broad topic that I do not think that this will solve the thing for cities. – What I do think that the urban metabolism concept can do for cities: it can focus action on some of the very impactful areas, like energy and transport. – But urban metabolism cannot get to all of the, say, sustainability areas, such as social'. The urban metabolism expert also pointed that UM should not be the only tool to rely on, but can contribute to urban sustainability challenges with the holistic approach. The Member of the European Parliament (MEP) underlined that 'most important solutions concerning sustainability are actually made in urban areas – it [urban metabolism] can't solve all the sustainability points, but it can go a long way'. You could also include urban sociology, social sustainability, intellectual properties, and a deeper focus on environmental sustainability in urban metabolism studies.

The satellite expert recommended splitting the complex issue into smaller pieces to find the required solutions 'per user issue' in future research. According to the urban metabolism expert, looking at things as separate entities is helpful since the things are so different from each other, and should be governed differently. The city specialist disagreed and would not recommend dividing the issues, but agreed that the most impactful sectors (e.g., energy and traffic) should *obviously* be the starting point: 'If we were able to tackle the energy and the transport issue, we would be over half-way there. And, also through those basic production issues. We would then be kind of able to nudge the consumers into the sort of more suitable and sustainable behaviour at the same time'.

> *'One of the key issues is that we are very good in generalist societies to focus on problems that are clear to us and they are within our control. And sometimes it's easy to focus on those, and they may not be the ones that matter the most. And in the case of our environmental impacts, lots of what we cause we don't see. It doesn't happen near us – I think yeah there are things like circular economy that great concept to get people excited. But we must be aware that it's not about to, you know, to glorify waste management focus, it's really about more, it's more life cycle thinking' (Urban metabolism expert).*

Urban sustainability itself is a broad thing to research and urban metabolism assessment is just one approach. These urban and environmental issues are not to be solve in one research, neither in one research project, neither with one sector nor within one discipline.

The urban metabolism assessment with more efficient utilisation of satellite data

There is potential in the usage of satellite data to support urban metabolism assessment. Satellite imagery provides a lot of opportunities, yet some of the urban issues are easier to link to UM assessment, whilst others are more difficult. Urban metabolism assessment requires quite precisely scaled data, which is not available in every case; also there are data restrictions since private data cannot be fully embraced. The urban metabolism expert has not been using satellite data for the urban metabolism studies.

> *'– a lot of these actions, I do see already that it gets really much mainstreamed to work from satellite-based information.'*
> *(Satellite expert)*

During the interview, the urban metabolism expert highlighted the fact that satellites are not directly measuring the quantities of mass, which is the key element in urban metabolism assessment. It was pointed out that, in regard to satellite data that represents consumption flows is currently difficult to find valid data. Currently, the usability of satellite data fits mostly for the MFA methods. The outputs of the urban metabolism process are quite simple to get from satellite data, such as emissions to water or air, but we rather need the whole picture. Individual things cannot be drawn from a picture of whether a city is sustainable or not. The utilisation of satellite data or the urban metabolism assessment by itself, individually, does not take us far, but together as a new approach it can be used quite efficiently.
Since satellite data is not a new thing, there is already time-scalable data available from the different locations of Earth, the historical data. There are plenty of open databases and platforms that may be used freely. There is also data provided by private companies (e.g., Planet, Capella Space, ICEYE) that is behind a paywall.

It is possible to get forecasts from the satellite data, especially for seasonal forecasting. Both history and the future provide guidelines on where to base actions. Satellites can provide information on a millimetre scale of, for example, ground movement. The expert added that there are already satellites monitoring the whole world at a resolution of 10 meter, so there is information available on the neighbourhood scale or even inside of that scale. It is possible to collect data on human-based things, such as houses and materials. As the satellite expert mentioned, satellites globally track different things, such as emissions and our systems, whatever we want to be tracked. The tracking process is clear, it starts with a target and then you measure your process and get clear (scientific) results in a logical way. That requires system knowledge, but also mainstreaming of the satellite data.

The urban metabolism expert said that we are facing 'luxury problems' in our research. We have already a good base where to start building on our research. That is not the same case, for example, in Latin America and Africa, as the positions faced are not similar in different places. In Finland, we have a very high level of research and activities regarding space, and already a good level of national statistics and governmental cooperation between cities. When, for example, ESA or NASA builds up new satellites, it's not only for observing their own 'operating areas' but everywhere in the world. There are global opportunities with satellite data; it's not locked up to be used only inside the European Union.

The satellite expert explained during the discussion how already existing data can be used for research into various other environments than urban areas. The example is not related to urban metabolism assessment but is rather valuable user information. So, currently in the Finnish Meteorological Institute (FMI), for example, they produce heat maps, which present city heating, to support the energy industry operation. They use SAR (Synthetic Aperture Radar) satellite data, which can provide information, e.g., of building sites. Satellites can also provide information about the vegetation, soil moisture, crops (agriculture), forestry (tree spices) and green spaces.

In the future, we will be getting more and more data to be used. Yes, there are still problems to solve, since the data might not be useful as 'raw' and will need modelling. The city specialist pointed out the matter of scale and access to data. The city specialist also mentioned that, in Finland, we are slightly behind in data utilisation and savings, compared to what is needed, e.g., the housing data is not readily available and usable. The satellite expert also added that the data should be moved to the same places to make the analysis due to the different datasets. We should openly see the potential and look deeply at what is already offered; *the bicycle does not have to be re-designed*. We need to get the data together.

What are the barriers of a new urban metabolism approach at the political level?

As we talked about the policy targets regarding sustainability, climate change and biodiversity, the MEP argued that these targets should be science based so you can base the actions and results in better planning and services. The need for upgrading the knowledge and knowledge-based solutions. Actually, to solve the knowledge gap, there is a need for strong ambition, commitment, leadership and cooperation at the political level, at least on the European scale.

According to the MEP, verification of political commitments is at the level of Member States and national governments, or perhaps even forwarded. She continued to state that this might lead, *or already has led*, to situations where the information is not as accurate as it should be, and even might include false information (e.g., how energy-efficient buildings are, the quantity of forests, CO2 emissions). The economy also is an important factor, as public procurement is about 20 % of GDP. Currently, it is difficult to recognise the amount of consumption followed by public procurement, which could be managed, for example, with internal local regulations and top-down implementation (Westin et al. 2018: 536). To support solving this issue, business ecosystems of the area should also be included (including universities). She ended by stating that we need to focus on the reliable information as the root-level solution, 'not only for the words but metering'.

'– And to have those scientific targets correct – you need observation and you need to actually monitor – more effectively what is the state of the sinks, and the state of the storage, and state and what sources they emit. And we do know already that basically EU would need to be climate-neutral by 2030 or 2035, and so we need to get rid of this kind of political angling, what is the reduction percentage. And like in economics, the figure is the figure, and if you are in debt up to a certain point then you are indebted and you face the bankruptcy. It's a bit the same thing.' (The MEP)

Cooperation between different actors to put things together was identified as the key to solve these presented issues in the future talk. The cooperation is needed at different levels, locally with academia, businesses and authorities, at the EU-level, and globally. The initiatives of the EU (e.g., Innovating Cities) and the programmes such as Copernicus are seen as key in increasing cooperation, and in funding the actions. There are already actions, targets and networks (e.g., Covenant of Mayor), but there has not (yet) been enough to push that issue fast enough to solve the issue. The EU also supports cities to cooperate (twinning of cities), not only inside the EU but on the international level as well, with, for example, a city in Brazil. The EU has really focused on helping cities with this by creating one-stop-shop for cities (i.e., an open page), where cities can find the information needed for their actions.

'Our main principle is cities as actors of open innovation. Open data, available data to everyone, at least the ones in EU, are coming from EU investments, support public-private partnerships, this is what we are doing, in and including the member states, so bringing inside the member states governance and inclusive and participatory governance.'
(Representative from European Commission)

The MEP wanted to remind us that passive information does not move us forward, and cities really are at the central point to do experiments and actions, and challenge and reorganise our actions, in order to achieve sustainability. We have knowledge that needs to be shared and combined with each other, between different sectors, in order to be closer to solving the complex issues that reside in our cities.

The satellite expert continued from there by saying that we should promote further the open and free data policy also for other sectors than satellite and space data. Possibly the most current issue is, as pointed out by the satellite specialist, ‘how do we get people to be able to use it’. This this does not mean that you should download all of the data on your computer. This data obtained from Earth is very data rich and heavy, especially when the accuracy and resolution have been raised. For the smaller areas of data management on your own computer, it is still manageable. The idea according to the satellite expert is to operate with larger areas: ‘the opportunity is there when you want to do for a small area, just go to the cloud and do the same for the whole globe’. We need to start learning how to use the (satellite) data more efficiently in urban environments. Panellist who joined the future talk, representing different organisations, encouraged usage of satellite data in future urban research.

5 Conclusion

This research present a new approach to urban metabolism assessment. A new approach for urban metabolism assessment utilises satellite data. Creation of this approach required a comprehensive literature analysis and focus group discussion. The research problem was that the satellite data is not utilised in urban metabolism assessment very widely, although there is a good potential for its use. The recognised problem was that urban metabolism assessment is not a well-used approach as part of sustainable urban development or related urban policies.

Key results of this research are divided into three different themes: 1) urban ecosystem assessment, 2) data, and 3) policy. The urban metabolism assessment was found to be a useful approach to urban ecosystem monitoring and for building a 'big picture' as part of sustainable urban development. As the previous UM researchers have identified a lack of data, this research showed that the utilisation of satellite data in urban metabolism assessment is useful. The urban metabolism assessment, in particular through satellite data, helps urban policymakers to understand the history and current state of their local urban ecosystem in terms of energy and resource use, and thus adapt their actions to the development of more efficient and sustainable cities. See Figure 5.

I	II	III
Urban metabolism is currently a leading method for quantifying the energy consumption and material usage in urban ecosystem Urban metabolism assessment helps in identification of urban sustainability challenges However, it does not solve urban problems per se and it is not comprehensive – practical use of UM requires collaboration between different stakeholders and multi-disciplinary approach	Urban metabolism assessment requires a lot of data to build an overall picture of urban ecosystem The commercialisation and development of satellite technology help urban assessment since the data is mostly free, open, and has wide spatial and temporal scope. Satellite data has great opportunities and benefits, although it requires investments in human knowledge and data handling capacities	The knowledge gained in urban metabolism assessment helps policymakers understand the local urban ecosystem and their use of resources Urban metabolism is a good approach to be integrated with urban sustainability projects as well as in setting goals The new approach to urban metabolism assessment has major opportunities for cities therefore its use should be promoted via urban policies

Figure 5. This figure represents the three key results of the research

Neither of the research topics – urban metabolism assessment or satellite data – are in themselves new. Urban metabolism assessment is not widely used in Finland, perhaps because it is sounds more complex compared to its partner concepts of circular economy and smart city. Urban metabolism assessment should go hand-in-hand with other urban sustainable development approaches and strategies, to complement them. Satellite data is currently underused in urban research. The potential of satellite data lies in its availability and low cost, which greatly help the effectiveness of urban metabolism assessment with its wide temporal and spatial scope. In the future, the newer satellites will provide even more precise information of the societal issues of urban ecosystems. The urban researchers should engage with the Earth observation community, for example, to further develop geospatial technologies (e.g., GIS) and to promote the utilisation of satellite data in urban research. Any future research should use this developed new approach in practice in case studies of certain areas of a city or city-region. This approach needs piloting and testing in order to be widely used in future urban sustainability projects. This approach is recommended to be used for a longer time scale than one year, in order to provide valuable and long-term information for cities.

At the EU and Member State level, this new approach should be promoted, for example by supporting the use of satellite data in urban research, and by supporting human resources and technical capacity building. Increasing the use of new types of data in urban research also requires support for the development of harmonised datasets. We need to get data together. For future research projects, collaboration between public and private actors at different levels (from local to global) is important, not just in terms of data. In particular, the public sector needs support for data analysis and data management. Researchers should focus their future research on how the results of urban metabolism assessment become simpler and easier to understand and analyse with policymakers and other urban stakeholders (without external experts), which will help on the usability of research results in practice. At the local level, urban researchers and developers should test this new approach so that it can be further developed to meet the needs of urban data.

In further urban metabolism assessment research, socioeconomic urban growth should also be assessed from the social sustainability and urban sociology perspectives, to make the urban ecosystem analysis more complete. In addition, future research should include the potential of new technologies such as artificial intelligence (AI) and the internet of things (IoT), both of which provide new kinds of data that will, for example, help to monitor human behaviour. Along with these presented ideas, data ethics, ownership and privacy considered when using data and should be included in research process.

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